Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

Groundwater Monitoring

-

Technical report on groundwater monitoring as discussed at the workshop of 25th June 2004

14 December 2004[1]

[1] This document has been developed on the basis of the Guidance Document No. 7 on the Monitoring under the Water Framework Directive and contributions from the participants of the Groundwater Monitoring workshop of 25th June 2004.

1 Foreword

The EU Member States, Norway and the European Commission 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 (hereafter referred to as Common Implementation Strategy (CIS) for the Water Framework Directive (WFD)). The main aim of this strategy is to allow a coherent and harmonious implementation of this Directive. Focus is on methodological questions related to a common understanding of the technical and scientific implications of the Water Framework Directive.

In this framework, a working group on Groundwater Body Characterisation and Monitoring has been established, with the aim - during the period 2003–2004 - to exchange information/experience on groundwater issues covered by the WFD (e.g. characterisation, risk assessment, monitoring, chemical status and trends) in the form of workshops and technical reports gathering the participant's experience. The workshop of 25th June 2004 on Groundwater Monitoring is the third one of the series of this CIS working group activity. The technical report summarises important aspects of groundwater monitoring as they are already discussed in the relevant CIS guidance documents, and includes research and technological development and examples of practices presented at the national and regional levels by the participants.

Table of contents

2 Introduction

2.1 Background – The Common Implementation Strategy of the WFD

The Water Framework Directive (2000/60/EC)[2] is a comprehensive piece of legislation that sets out, *inter alia*, clear quality objectives for all waters in Europe. The Directive provides for a sustainable and integrated management of river basins including binding objectives, clear deadlines, comprehensive programme of measures based on scientific, technical and economic analysis including public information and consultation. Soon after the WFD adoption, it has become clear that the successful implementation of the Directive will be, at the least, equally as challenging and ambitious for all countries, institutions and stakeholders involved. Therefore, a strategic document establishing a Common Implementation Strategy (CIS) for the Water Framework Directive (WFD) was developed and finally agreed under the Swedish Presidency in the meeting held in Sweden on 2–4 May 2001. Despite the fact that it was recognised that implementing the WFD is the full responsibility of the individual Member State, there was a broad consensus amongst the Water Directors of the Member States, Norway and the Commission that the European joint partnership is necessary in order to:

- ✓ develop a common understanding and approaches;
- ✓ elaborate informal technical guidance including best practice examples;
- ✓ share experiences and resources;
- ✓ avoid duplication of efforts;
- ✓ limit the risk of bad application.

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. Following the decision of the Water Directors, a comprehensive and ambitious work programme was started of which the first phase, including ten Working Groups and three Expert Advisory Fora, was completed at the end of 2003[3] and led to the availability of thirteen Guidance Documents which are publicly available[4]. The second phase of the Common Implementation Strategy (CIS) now involves four working groups, namely on Ecological Status (WG 2A), Integrated River Basin Management (WG 2B), Groundwater (WG 2C) and Reporting (WG 2D). The present workshop has been held under the auspices of the WG 2C of which the mandate is described in a separate document[5].

2.2 The Commission proposal on new Groundwater Directive

In parallel of the drafting activities of CIS Guidance documents, an Expert Advisory Forum (EAF) on Groundwater has contributed to the development of the draft proposal of Groundwater Directive,

---

[2] 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)

[3] Final CIS document available under:
http://europa.eu.int/comm/environment/water/water-framework/implementation.html

[4] Common Implementation Strategy for the Water Framework Directive, European Communities, ISBN 92-894-2040-5, 2003

[5] Mandate of the CIS Working Group 2C on "Groundwater"

which has been adopted by the Commission in its final form on 19th September 2003[6]. In the period between the adoption of the proposal and the adoption of the future groundwater directive by the European Parliament and the Council, it has been decided to organise regular workshops to exchange information and experiences among the newly formed Working Group 2C on "Groundwater". In this framework, a workshop on groundwater monitoring has been held in Brussels on 25th June 2004, gathering more than 80 participants from both the WG 2C and the WG 2B.

2.3 Aim of the workshop

The aim of the workshop was to share national and regional experiences on groundwater monitoring, taking into account the CIS guidance. The present workshop report summarises key elements, best practice and tools for the design of groundwater monitoring programmes as they are summarised in the Monitoring Guidance Document[7] and the main findings regarding monitoring of the Technical Report[8] on groundwater statistics. This workshop report is completed by some general features of groundwater monitoring also with regard to point sources of pollution, reports on the research and technological developments in support of groundwater monitoring and reports on monitoring approaches in the light of the WFD, either at the national and/or regional level (Germany, France, Austria, the United Kingdom, the Nordic Countries, Lithuania, Malta, Spain, Italy, Romania, Denmark and the Netherlands).

2.4 Key principles of monitoring

The monitoring guidance paper developed by WG 2.7 states key principles for the development and design of monitoring networks and their operation. The guidance offers an overview of best practice in monitoring and provides a tool box. The main key principles are:

- The amount of groundwater monitoring that is required will be proportional to the difficulty in judging:
  - the status of a body or group of bodies;
  - the presence of adverse pollution trends; and
  - the implications of errors in such judgments.
- The design and operation of groundwater monitoring programmes should be informed by:
  - the **objectives** applying to the body;
  - the **characteristics** of the groundwater body, or group of bodies;
  - the existing **level of understanding** (i.e. the confidence in the conceptual model/understanding) of the particular groundwater system;
  - the type, extent and range of the **pressures** on the body, or group of bodies;
  - the **confidence in the assessment of risk** from pressures on the body, or group of bodies; and
  - the level of confidence required in the assessment of risk.

GW-Bodies may be grouped (on a scientific basis) provided that reliable assessment of each body of the status and the trends is obtained. Designing and operating integrated groundwater and surface water monitoring networks will produce cost-effective monitoring information for assessing the achievement of the objectives.

---

[6] COM(2003)550

[7] Guidance Document No. 7. Monitoring under the Water Framework Directive. ISBN 92-894-5127-0

[8] Technical Report No. 1. The EU Water Framework Directive: statistical aspects of the identification of groundwater pollution trends, and aggregation of monitoring results. ISBN: 92-894-5639-6

WG 2.8[8] developed appropriate algorithms for data aggregation, trend and trend reversal assessment which had to be pragmatic solutions, statistically correct and only one method applicable to different groundwater body sizes, different hydrogeological conditions, different site densities, all parameter types and diffuse and point source pollution. The findings regarding the monitoring network, the monitoring frequency and the quality assurance were:

- **Distribution of monitoring sites** as well as the **selected number and types of sites** was highlighted as important with regard to the applicability of the proposed statistical methods and the comparability of the assessment.
- Minimum requirements (distribution and number of sites) depend on the algorithms applied.
- **Importance of continuity** with regard to selected sampling sites - changes should not affect the outcome of the assessment.
- Sampling frequency should be in accordance with the **natural conditions** of the GW-body
- In the time series some observations may be missing, but the **missing of two or more subsequent values should be avoided** for trend assessment - risk of bias due to extrapolation
- **Take care of the sampling time or period** to avoid bias by seasonal effects which reduces the power of the trend analyses and to avoid induced trend phenomena
- In case of yearly measurements it should be guaranteed that the **measurements are taken in one and the same quarter** or within a certain time period of the year
- Need of sufficient information on LOD (limit of detection) and LOQ (limit of quantification)

The sampling procedure itself and chemical analysis should ensure continuity in results and comparability. (Relevant norms/standards should be applied).

3 Common understanding

3.1 Requirements of the Water Framework Directive

The Water Framework Directive requires the establishment of monitoring programmes covering groundwater quantitative status, chemical status and the assessment of significant, long-term pollutant trends resulting from human activity by 22 December 2006 at the latest. In terms of groundwater chemical status, surveillance and operational monitoring are required. The programmes must provide the information necessary to validate the Annex II risk assessment procedure and to assess the achievement of the Directive's objectives for groundwater. The programmes must also provide for any additional monitoring requirements relevant to Protected Areas.

The relevant objectives are:

- To prevent deterioration in the status of all bodies of groundwater [Article 4.1(b)(i)];
- To prevent or limit the input of pollutants into groundwater [Article 4.1(b)(i)];
- To protect, enhance and restore all bodies of groundwater and ensure a balance between abstraction and recharge with the aim of achieving good groundwater status [Article 4.1(b)(ii)];
- To reverse any significant and sustained upward trend in the concentration of any pollutant in groundwater in order to progressively reduce pollution of groundwater [Article 4.1(b)(iii)];
- To achieve compliance with any standards and objectives for Protected Areas [Article 4.1(c)]. Relevant Protected Areas include areas designated for the abstraction of water intended for human consumption under Article 7 (Drinking Water Protected Areas), Nitrate Vulnerable Zones established under Directive 91/676/EEC, and areas designated for the protection of habitats and species in which the status of water is an important factor in their protection;

Annex V.2 indicates that monitoring information from groundwater is required for:

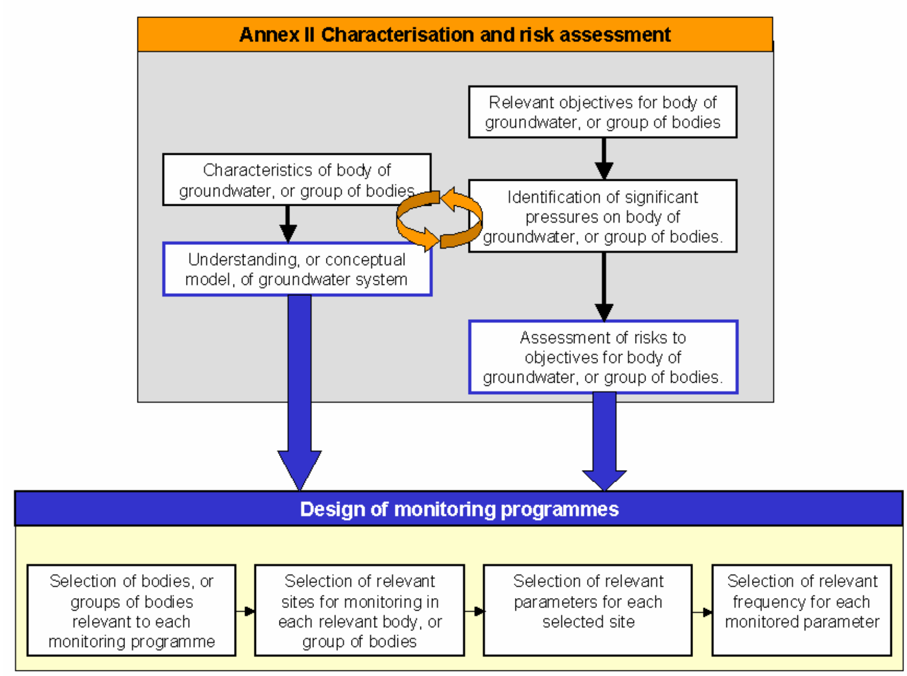
- Supplementing and validating the impact assessment procedure;
- Providing a reliable assessment of quantitative status of all groundwater bodies or groups of bodies including an assessment of the available groundwater resource; *(Member States must provide maps illustrating the* quantitative *status of all groundwater bodies or groups of bodies using the colour-coding scheme set out in the Directive).*
- Estimating the direction and rate of flow in groundwater bodies that cross Member States boundaries;
- Use in the assessment of long term trends both as a result of changes in natural conditions and through anthropogenic activity;
- Establishing the chemical status of all groundwater bodies or groups of bodies determined to be at risk. *(Note: Member States must provide maps illustrating the chemical status of all groundwater bodies or groups of bodies using the colour-coding scheme set out in the Directive.);*
- Establishing the presence of significant and sustained upward trends in the concentrations of pollutants. *(Note: Member States must indicate on the maps of chemical status using a black-dot, those groundwater bodies in which there is a significant upward trend)*; and
- Assessing the reversal of such trends in the concentration of pollutants in groundwater *(Note: Member States must indicate on the maps of chemical status using a blue-dot, those groundwater bodies in which a significant upward trend has been reversed).*

The monitoring programmes must provide the information necessary to assess whether the Directive's 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 to the design of effective monitoring programmes (see chapter 4.2).

To ensure the targeted and cost-effective development of the groundwater monitoring programmes, this information and understanding should serve as the basis for identifying (see Figure 1):

- The bodies, or groups of bodies relevant to each monitoring programme;
- The appropriate monitoring sites in those bodies, or groups of bodies;
- The appropriate parameters for monitoring at each site; and
- The monitoring frequencies for those parameters at each site.

Figure 1: The basic information necessary for the design of groundwater monitoring programmes



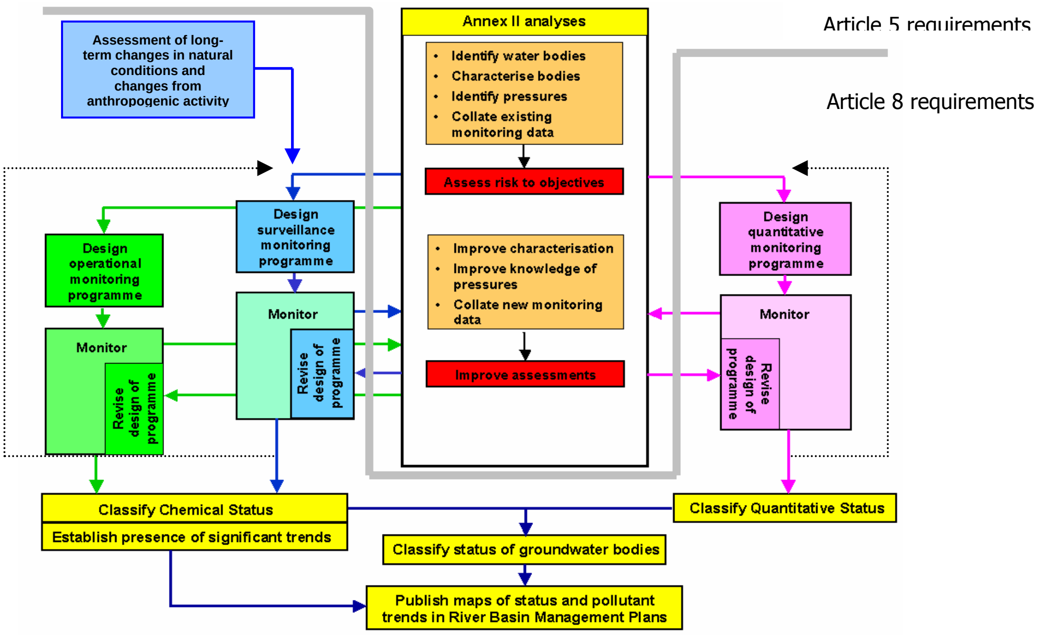
The Directive introduces a flexible hierarchical system for monitoring the very many different types of water bodies across Europe reflecting the fact that natural physical and geological conditions and anthropogenic pressures vary greatly across Europe. Because of this a monitoring system designed for one part of Europe may not be entirely applicable in another. The Monitoring Guidance[9] proposes an overall pragmatic approach. Because of the diversity of circumstances within the European Union, Member States may apply this guidance in a flexible way in answer to problems that will vary from one river basin to the next. This proposed guidance will therefore need to be tailored to specific circumstances. However, these adaptations should be justified and should be reported in a transparent way

3.1.1 Relationship to Annex II characterisation and risk assessment

Monitoring is a cross-cutting activity within the Directive and as such there are important interrelationships with other Articles and Annexes of the Directive. A key Article in relation to monitoring and the design of appropriate programmes for groundwater is Article 5. Figure 2 summarise the relationship between Articles 5 and 8. Article 5 requires river basin districts to be characterised and the environmental impact of human activities to be reviewed in accordance with Annex II. The first assessments must be completed by 22 December 2004. Risk assessments will be on-going as they will be required for subsequent River Basin Management Plans. The first assessments must be completed 2 years before monitoring programmes have to be operational. Thus the Annex II risk assessments play a key role in the initial design and subsequent revision of the monitoring programmes required by the Directive.

[9] Guidance document No. 7. Monitoring under the Water Framework Directive. ISBN 92-894-5127-0

Figure 2: Schematic diagram illustrating the relationship between Article 5 and Article 8 in the design of groundwater monitoring programmes



The monitoring programmes should be designed on the basis of the results of the Annex II characterisation and risk assessment procedure. Guidance on characterisation and risk assessment for bodies and groups of bodies of groundwater can be found in the IMPRESS Guidance[10] and in the Technical Report on Groundwater risk assessment held[11] in January 2004. The results of the assessments should provide the necessary information on, and understanding of, the groundwater system and the potential effects of human activities on it with which to design the monitoring programmes. This conceptual model/understanding for each body of groundwater, or group of bodies, should be (a) relevant to assessing how the identified pressures could affect the objectives for the body, or group of bodies, and (b) proportionate in terms of its detail and complexity to the likely risks to the objectives for that body, or group of bodies.

In particular, monitoring programme design will require:

- Estimated boundaries of all bodies of groundwater;
- Information on the natural characteristics, and a conceptual understanding, of all bodies or groups of bodies of groundwater;
- Information on how bodies may be grouped because of similar hydrogeological characteristics and therefore similar responses to the identified pressures;
- Identification of those bodies, or groups of bodies, of groundwater at risk of failing to achieve Directive's objectives, including the reasons why those are considered to be at risk;
- Information on (a) the level of confidence in the risk assessments (e.g. in the conceptual understanding of the groundwater system, the identification of pressures, etc), and (b) what monitoring data would be required to validate the risk assessments.

However, identifying water bodies that will provide for an accurate description of the status of groundwater will require information from the Article 5 analyses and reviews, and the Article 8 monitoring programmes. The monitoring information may be used to iteratively improve the conceptual model/understanding so that it provides for appropriately reliable assessments.

The initial results of the Annex II assessments must be reported at the end of 2004. However, the assessments may need further development to help design the monitoring programmes for

---

[10] Guidance Document No. 3. Analysis of Pressures and Impacts. ISBN 92-894-5123-8

[11] Technical Report on groundwater risk assessment issues as discussed at the workshop of 28th January 2004.

implementation at the end of 2006. The monitoring data provided by the monitoring programmes will then be available to validate and refine the assessments and the conceptual models/understandings on which they were based.

3.1.2 Risk, precision and confidence

Risk[12] is used in Annex II (2.1) (in terms of risk of failing to meet the environmental objectives under Article 4), and risk, confidence[13] and also precision[14] are words used in Annex V (2.4) (design of monitoring programmes). Their interpretation will affect the scale and extent of the monitoring required assessing status at any particular time and changes in status with time. What is considered to be "acceptable", "adequate" and "sufficient" levels of precision and confidence, and a "significant" risk, will determine aspects such as the:

- number of stations that will be required to assess the status of each water body; and,
- frequency at which parameters have to be monitored.

Choosing levels of precision and confidence would set limits on how much uncertainty (arising from natural and anthropogenic variability) can be tolerated in the results of monitoring programmes. In terms of monitoring for the Directive, it will be necessary to estimate the status of water bodies and in particular to identify those which are not of good status or are deteriorating in status. Thus status will have to be estimated from the sampled data. This estimate will almost always differ from the true value (i.e. the status which would be calculated if all water bodies were monitored and sampled continuously for all components that define quality).

The level of acceptable risk will affect the amount of monitoring required to estimate a water body's status. In general terms, the lower the risk of misclassification desired, the more monitoring (and hence costs) required to assess the status of a water body. It is likely that there will have to be a balance between the costs of monitoring against the risk of a water body being misclassified. Misclassification implies that measures to improve status could be inefficiently and inappropriately targeted. It should also be borne in mind that in general the cost of measures for improvement in water status would be orders of magnitude greater than the costs of monitoring. The extra costs of monitoring to reduce the risk of misclassification might therefore be justified in terms of ensuring that decisions to spend larger sums of money required for improvements are based on reliable information on status. Further, from an economics point of view, stronger criteria should be applied to avoid a situation where water bodies fulfilling the objective are misjudged and new measures applied. Also it should be noted that for all groundwater monitoring sufficient monitoring should be done to validate risk assessments and test assumptions made.

The Directive has not specified the levels of precision and confidence required from monitoring programmes and status assessments. This perhaps recognises that achievement of too rigorous precision and confidence requirements would entail a much-increased level of monitoring for some, if not all, Member States.

On the other hand the actual precision and confidence levels achieved should enable meaningful assessments of status in time and space to be made. Member States will have to quote these levels in RBMPs and will thus be open to scrutiny and comment by others. This should serve to highlight any obvious deficiencies or inadequacies in the future.

---

[12] At the simplest level, a risk can be thought of as the chance of an event happening. It has two aspects: the chance, and the event that might happen. These are conventionally called the probability and the consequence.

[13] The long-run probability (expressed as a percentage) that the true value of a statistical parameter (e.g. the population mean) does in fact lie within calculated and quoted limits placed around the answer actually obtained from the monitoring programme (e.g. the sample mean).

[14] The discrepancy between the answer (e.g. a mean) given by the monitoring and sampling programme and the true value.

The starting point for many Member States will probably be an assessment of existing stations and samples to see what level of precision and confidence can be achieved by those resources. It is likely that this will have to be an iterative process with modification and revision of monitoring programmes to achieve levels of precision and confidence that allow meaningful assessments and classification.

It is also likely that Member States will use expert judgement to some extent in assessing the risk of misclassification. For example in the case of a misclassifying bodies "at risk" the persons responsible for making the decision to implement expensive measures will clearly secure their decisions by further assessments before implementing the measures. In the case of misclassifying bodies as "not being at risk" there will be much local experience and expert judgement (by water managers or public persons) to doubt the monitoring results and assessment and look for further clarification.

3.1.3 Groundwater monitoring programmes

The Directive sets out its requirements for the different groundwater monitoring programmes in Annex V (2.2 and 2.4). The monitoring programmes must include a monitoring of groundwater quantitative status, a monitoring of groundwater chemical status which is distinguished in surveillance and operational monitoring and a monitoring of protected areas.

Groundwater level monitoring

The 'groundwater level monitoring' network shall:

- provide a reliable assessment of the quantitative status of all groundwater bodies or groups of bodies including an assessment of the available groundwater resource;
- supplement and validate the Annex II characterisation and risk assessment procedure with respect to risks of failing to achieve good groundwater quantitative status in all bodies or groups of bodies of groundwater;

The network shall include sufficient representative monitoring points and sufficient frequency of monitoring to:

- take into account short and long-term variations in recharge when estimating the groundwater level and assessing the quantitative status of each groundwater body;
- assess the impact of abstractions and discharges on the groundwater level for groundwater bodies identified as being at risk of failing to achieve environmental objectives under Article 4;
- estimate the direction and rate of groundwater flow across the Member State boundary for groundwater bodies within which groundwater flows across a Member State boundary.

Surveillance monitoring

Surveillance monitoring should be undertaken in each plan period and to the extent necessary to:

- supplement and validate the Annex II characterisation and risk assessment procedure for each body or group of bodies of groundwater with respect to risks of failing to achieve good groundwater chemical status;
- establish the status of all groundwater bodies, or groups of bodies, determined as not being at risk on the basis of the risk assessments; and
- provide information for use in the assessment of long term trends in natural conditions and in pollutant concentrations resulting from human activity.

The programmes should be operational from the beginning of the plan period where necessary to provide information for the design of the operational monitoring programmes, and may operate for the duration of the planning period if required. The programmes should be designed to help ensure that all significant risks to the achievement of the Directive's objectives have been identified. Where confidence in the Annex II risk assessments is inadequate, parameters indicative of pressures from human activities, which may be affecting bodies of groundwater but which have not been identified as causing a risk to the objectives, should be included in the surveillance monitoring programmes in order to supplement and validate the risk assessments.

No minimum duration for the surveillance programme is specified. For the first river basin planning period, Member States that already have extensive groundwater monitoring networks may only need a short period of surveillance monitoring to help design their operational monitoring programmes. However, Member States whose existing networks are more limited may require more information from surveillance programmes before the design of their operational programmes can be completed.

Surveillance monitoring is only specified in the Directive for bodies at risk or which cross a boundary between Member States. However, to adequately supplement and validate the Annex II risk assessment procedure, validation monitoring will also be needed for bodies, or groups of bodies, not identified as being at risk. The amount and frequency of monitoring undertaken for these bodies, or groups of bodies, must be sufficient to enable Member States to be adequately confident that the bodies are at 'good' status and that there are no significant and sustained upward trends.

Operational monitoring

Operational monitoring has to be carried out for the periods between surveillance monitoring. In contrast to surveillance monitoring, operational monitoring is highly focused on assessing the specific, identified risks to the achievement of the Directive's objectives.

An 'operational monitoring' network shall:

- establish the status of all groundwater bodies, or groups of bodies, determined as being at risk; and
- establish the presence of significant and sustained upward trends in the concentration of any pollutant.

Monitoring requirements dependent on applied algorithms for status and trend assessment

The requirements on monitoring can not only be derived from the WFD directly but depend on the algorithms which are applied by Member States to implement the Directive and comply with its objectives. The WFD does not exactly prescribe the assessment methods to be used. WG 2.8[15] developed appropriate algorithms for data aggregation, trend and trend reversal assessment which had to be pragmatic solutions, statistically correct and only one method applicable to different groundwater body sizes, different hydrogeological conditions, different site densities, all parameter types and diffuse and point source pollution.

In fact it is the individual duty of the Member States to decide on the algorithms applied in order to perform the required assessments. The correct implementation of appropriate methods imply that certain method specific requirements on the monitoring have to be met which is then reflected by the precision and the confidence of the assessment results.

The main findings regarding the monitoring network, the monitoring frequency and the quality assurance of the algorithms proposed by WG 2.8 were summarised in chapter 3.1.3.

Protected areas

These types are to be supplemented by monitoring programmes required for Protected Areas registered under Article 6. Annex V only describes requirements for Drinking Water Protected Areas in surface water and for Protected Areas for habitats and species. Member States may wish to

---

[15] Technical Report No. 1. The EU Water Framework Directive: statistical aspects of the identification of groundwater pollution trends, and aggregation of monitoring results. ISBN: 92-894-5639-6

integrate monitoring programmes established for other Protected Areas within the programmes established under the Directive. This is likely to improve the cost-effectiveness of the various programmes.

3.1.4 Reporting

Member States have to submit summary reports of the monitoring programmes designed under Article 8 within three months of their completion in 2006 (i.e. by March 2007). The results of monitoring must be used to estimate the chemical and quantitative status of bodies of groundwater which has to be reported in the management plans. The draft River Basin Management Plans must be published by 22 December 2008 and the finalised River Basin Management Plans by 22 December 2009. The following must be reported in the River Basin Management Plans:

- Maps of the monitoring networks;
- Maps of water status;
- An indication on the maps of the bodies of groundwater which are subject to a significant upward trend in concentration of pollutants and an indication of the bodies of groundwater in which such trends have been reversed; and,
- Estimates of the confidence and precision attained by the monitoring systems.

The results of monitoring should also assist in designing programmes of measures, testing the effectiveness of these measures and informing the setting of objectives. Later on monitoring results should be used in the reviews of the Annex II risk assessment procedure, the first of which must be complete by 22 December 2013.

The confidence in the status classifications included in the first plan might be lower than in subsequent plans as the assessment is rather based on surveillance monitoring than on operational monitoring. Member States must report the confidence and precision achieved in the results of monitoring in each plan.

The detailed purposes of, and requirements for, each of the groundwater monitoring programmes are discussed in chapter 4. Chapter 5 contains a toolbox of good practice examples illustrating how the guidelines could be implemented.

4 Specific Guidance on the design of groundwater monitoring programmes

This chapter of the report provides specific advice on the design of groundwater monitoring programmes given in the Monitoring Guidance[16] and furthermore takes into regard the main findings of the Technical Report on groundwater statistics. It also describes the general principles applicable to all of the groundwater monitoring programmes, as well as the specific requirements for each of the groundwater monitoring programmes.

The guidance uses the term conceptual model as shorthand for the understanding, or working description, of the real hydrogeological system that is needed to design effective groundwater monitoring programmes. The term should NOT be taken to imply that a mathematical model is required for all bodies of groundwater. On the contrary, complex mathematical models are only likely to be required to properly design and justify very expensive restoration measures for bodies that are failing to achieve the Directive's objectives.

4.1 Identify the purposes for which monitoring information is required

The design of monitoring programmes involves deciding what to monitor, where and when. The answers to these questions depend first and foremost on the purpose which monitoring will serve. The first step before designing a network is therefore to clearly identify the purpose, or purposes, for which the monitoring information is needed.

The monitoring required by the Directive is intended to provide information to help assess the achievement of the Directive's environmental objectives. Monitoring programmes should therefore be designed to provide the information needed to establish whether the particular environmental conditions specified by these objectives are being achieved. Among other things, this will involve monitoring to test the understanding of the groundwater system on which assessments are based and the effectiveness of any measures applied.

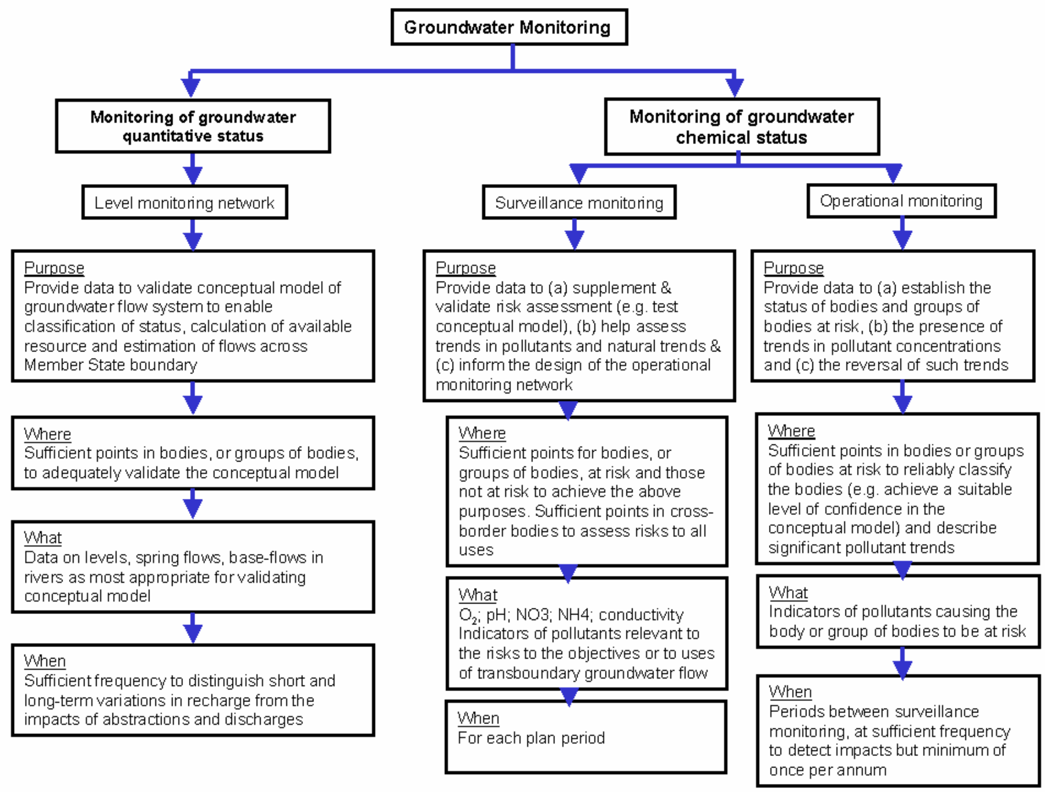
The relevant environmental objectives for groundwater are listed in Chapter 3.1 of the common understanding.

Annex V of the Directive describes the purposes of the different groundwater monitoring programmes. It also specifies certain criteria for determining what, where and when to monitor in respect of these purposes. Figure 3 summarises these requirements.

Monitoring of spring flows (e.g. flow rate, chemical composition;) and/or river base-flows will often be an important and sometimes the principal means of obtaining reliable information for use in assessing quantitative and chemical status.

[16] Guidance document No. 7. Monitoring under the Water Framework Directive. ISBN 92-894-5127-0

Figure 3: Summary of the purposes of, and requirements for, the groundwater monitoring programmes specified in Annex V of the Directive



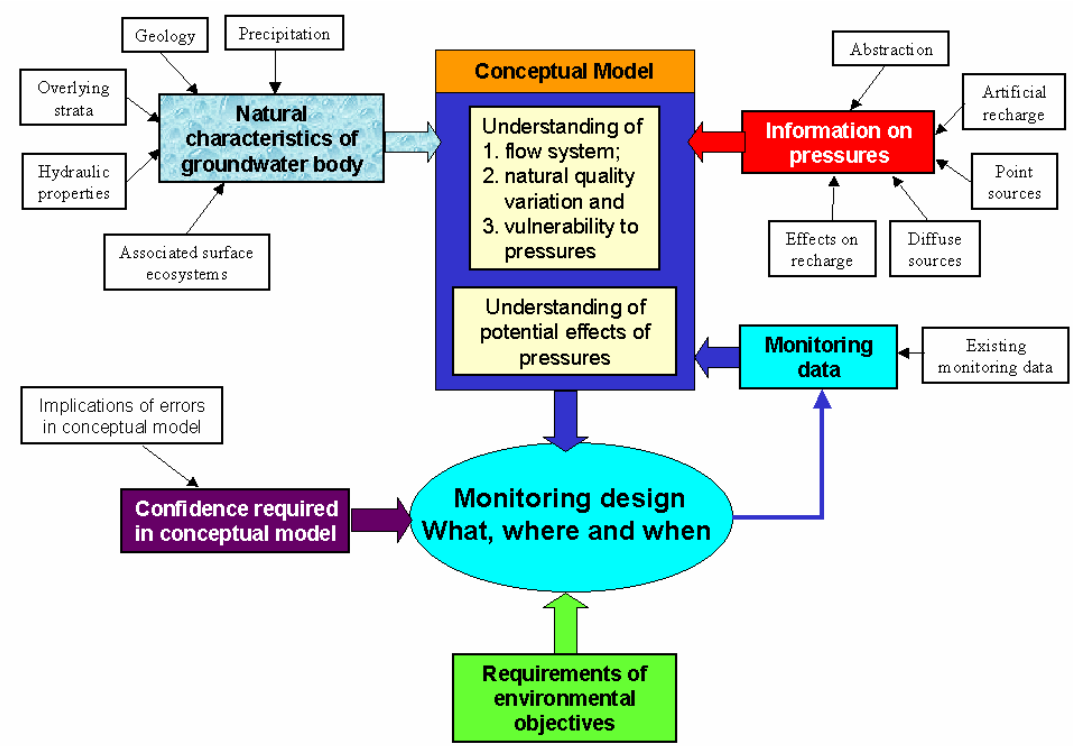
4.2 Monitoring should be designed on the basis of an understanding of the groundwater system

The Annex II risk assessment procedure is intended to help target and prioritise monitoring effort to where there are likely to be environmental problems. The monitoring programmes should be designed to provide the information needed to validate the risk assessment procedure and establish the magnitude, and spatial and temporal distribution, of any impacts. Risks assessments for groundwater should be based on a conceptual model/understanding of the groundwater system and how pressures interact with that system. A conceptual model/understanding is not only necessary to design monitoring programmes it is also needed to interpret the data provided by those programmes, and hence assess the achievement of the Directive's objectives.

The testing of conceptual models/understandings is important to ensure they provide for acceptable levels of confidence in the assessments they enable. The Directive requires the confidence in the results of monitoring to be reported in the River Basin Management Plans. Guidance on testing conceptual models/understandings using water balances is provided in chapter 5. It is important to note that although the guidance recommends testing models numerically this does not mean that the models themselves have to be mathematical. On the contrary, complex mathematical models are only likely to be required to properly design and justify very expensive restoration measures for bodies that are failing to achieve the Directive's objectives.

The level of detail in any conceptual model/understanding needs to be proportional to the difficulty in judging the effects of pressures on the objectives for groundwater. The first model will be a simple, generalised sketch of the groundwater system. Where necessary, the spatial specificity of this first conceptual model/understanding can be gradually improved (Figure 4). Monitoring data is required to test or validate the conceptual model/understanding. Such testing will require some monitoring data for all bodies, or groups of bodies, identified as being at risk as well as a selection of those identified as not being at risk of failing to meet their objectives.

Figure 4: Monitoring programmes should be designed on the basis of a conceptual model/understanding of the groundwater system



The amount of monitoring information needed to validate the Annex II risk assessments will depend in part on the level of confidence in, and complexity of, the conceptual model/understanding. The greater the difficulty in judging the risks to the objectives, the more monitoring information is likely to be required. The highest amount of monitoring will be necessary where the implications of misjudging the risks to the objectives would be very serious (e.g. lead to substantial costs being unnecessarily imposed on water users or fail to identify risks of significant damage that could be averted).

During the course of each planning cycle, and between one planning cycle and the next, new monitoring data will contribute to improved understanding of groundwater systems and their vulnerability to pressures. This will increase confidence in the conceptual model/understanding and the risk assessments it enables. The amount of monitoring that is required will be proportional to the difficulty in judging (a) the status of a body, or group of bodies, of groundwater and (b) the presence of adverse trends, and (c) to the implications of errors in such judgements.

Designing the monitoring programmes on the basis of conceptual models/understandings ensures that the programmes will be appropriate to the hydrogeological characteristics of the body, or group of bodies, of groundwater and, where relevant, to the behaviour of pollutants in the groundwater system.

It could be summarized that the design and the operation of monitoring programmes should be based on:

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

Groundwater systems are 3-dimensional. In some circumstances, where a body is at risk of failing to achieve its objectives and potentially costly restoration and improvement measures may be needed, monitoring information from different layers in a body of groundwater may be required to enable appropriate measures to be designed and targeted. The need for this sort of monitoring should be indicated by the risk assessments required under Annex II. However, most pressures are likely to have significant effects in the upper layers of aquifers.

4.3 Ensure the cost-effective development of groundwater monitoring networks

Reliable monitoring data are essential for the cost-effective achievement of objectives for groundwater. However, installing groundwater monitoring networks is expensive. The use of conceptual models/understanding contribute to a selection of monitoring points providing relevant and reliable data and it will also enable Member States with limited existing networks to iteratively build up their networks to the extent needed to test or develop their conceptual models/understandings.

The Directive permits bodies of groundwater to be grouped for monitoring purposes contributing cost-effective design of monitoring networks. However, such grouping must be undertaken on a scientific basis so that monitoring information obtained for the group provides for a suitably reliable assessment that is valid for each body in the group. This means that either:

- The conceptual models/understandings for the bodies in the group should be similar such that the testing of the models and the predictions made on the basis of those models, for a selection of the bodies in the group will also provide sufficient confidence in the models and predictions for the other bodies in the group; or
- Monitoring information from a selection of the most sensitive bodies in a group demonstrates that those sensitive bodies, and hence the group as a whole, are not failing to achieve 'good' status because of the effects of a pressure, or pressures, to which all the bodies in the group are subject (e.g. diffuse pollution). Monitoring information may be needed initially from a range of bodies in the group to determine which are the most sensitive bodies.

The adequate testing of a conceptual model/understanding may require new, targeted monitoring data. However, particularly where pressures are low, adequate validation of a model may be achieved using existing data or data from a surface water monitoring programme.

Monitoring data from surface water bodies may be important in assessing the condition of bodies of groundwater. Surface waters with a large base flow can be used to indicate the quality of groundwater. The effects of human alterations to groundwater quality and levels on the status of large base flow surface waters are also likely to be larger than the effects of the same alterations on the status of low base flow surface waters.

Designing and operating integrated groundwater and surface water monitoring networks will produce cost-effective monitoring information for assessing the achievement of the objectives for both surface and groundwater bodies.

4.4 Quality assurance of monitoring design and data analysis

The confidence in any assessment of groundwater will depend on the confidence in the conceptual model/understanding of how pressures are interacting with the groundwater system. The confidence in any model needs to be evaluated by testing its predictions with monitoring data. However, errors in the monitoring data could lead to errors in the evaluation of the reliability of the conceptual model/understanding. It is important that the probability and magnitude of errors in the monitoring data are estimated so that the confidence in the conceptual model/understanding can be properly understood. For the surveillance and operational monitoring programmes, estimates of the level of confidence and precision in the results of monitoring must be given in the river basin management plans[17].

[17] Annex V 2.4.1

An appropriate quality assurance procedure should reduce errors in monitoring data. Such a procedure should review the location and design of monitoring points to ensure that the data they provide are relevant to the aspects of the conceptual model/understanding being tested. Errors can also occur in sampling and in the analysis of water samples. Quality assurance procedures may take the form of standardisation of sampling and analytical methods (e.g. ISO standards); replicate analyses; ionic balance checks on samples; and laboratory accreditation schemes. Details can be found in chapter 5.

4.5 Monitoring of quantitative status

4.5.1 Purpose of monitoring

The Directive's requirements for good groundwater quantitative status are three-fold:

1. There is a requirement to ensure that the available groundwater resource[18] for the body as a whole is not exceeded by the long-term annual average rate of abstraction[19].
2. Abstractions and other anthropogenic alterations to groundwater levels should not adversely affect associated surface water bodies and terrestrial ecosystems that depend directly for their water needs on the body of groundwater.
3. Anthropogenic alterations to flow direction must not have caused, or be likely to cause, saltwater or other intrusion.

In assessing quantitative status, the water needs of associated surface water bodies and directly dependent terrestrial ecosystems must be taken into account. For the latter, good groundwater status requires that human alterations to groundwater flows and levels have not caused, and, taking account of time lags, will not cause, significant damage. Existing data held by Member States about the ecological, cultural and socio-economic significance of dependent terrestrial systems should be used as the basis for estimating the significance of damage.

4.5.2 Water Level Monitoring Network Design

The water level monitoring network should be designed so that it supports and aids the development and testing of the conceptual model/understanding. The development of the network will be an iterative process, evolving over time where necessary. The amount of monitoring required also depends on the extent of existing information on water levels and the groundwater flow system. Where this is adequate and reliable, it may not be necessary to extend monitoring programmes.

4.5.3 What to monitor

The most appropriate parameters to monitor quantitative status will depend on the conceptual model/understanding of the groundwater system. For example, spring flows or even base-flows in rivers may be more appropriate than the use of boreholes in low permeability fractured media or where the risks of failing to achieve good quantitative status are low and information from the surface water monitoring network can adequately validate this assessment.

4.5.4 Where to monitor

The choice of where to monitor will depend on what is needed to test the conceptual model/understanding and the predictions it provides. In principle, the more spatially variable the groundwater flow system or the pressures on it, the greater the density of monitoring points that will be required to provide the data needed to make suitably confident assessments of the status of a groundwater body, or group of bodies.

[18] Article 2.27

[19] Annex V 2.1.2

4.5.5 When to monitor

The most appropriate monitoring frequency will depend on the conceptual model/understanding of the groundwater system and the nature of the pressures on the system. The frequency chosen should allow short-term and long-term level variations within the groundwater body to be detected. For example, for formations in which the natural temporal variability of groundwater level is high or in which the response to pressures is rapid, more frequent monitoring will be required than will be the case for bodies of groundwater that are relatively unresponsive to short-term variations in precipitation or pressures. Where monitoring is designed to pick up seasonal or annual variations, the timing of monitoring should be standardised from year to year.

4.6 Monitoring of chemical status and pollutant trends

4.6.1 Purpose of monitoring

Groundwater quality monitoring carried out in accordance with the WFD should be designed to answer specific questions and support the achievement of the environmental objectives. The principal purposes of groundwater quality monitoring are to (a) provide information for use in classifying the chemical status of groundwater bodies or groups of bodies; (b) establish the presence of any significant upward trend in pollutant concentrations in groundwater bodies and the reversal of such trends.

The requirements of good groundwater chemical status are threefold:

1. The concentrations of pollutants should not exhibit the effects of saline or other intrusions as measured by changes in conductivity;
2. The concentration of pollutants should not exceed the quality standards applicable under other relevant Community legislation in accordance with Article 17. The daughter directive will clarify this criterion; and
3. 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.

All three criteria must be met for a body to achieve 'good' groundwater chemical status. The classification of groundwater chemical status is only concerned with the concentrations of substances introduced into groundwater as a result of human activities.

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 the Annex II 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.

4.6.2 Surveillance monitoring

The confidence in the Annex II risk assessments will be variable depending on the confidence in the conceptual model/understanding of the groundwater system. Surveillance monitoring is intended to provide information to:

- supplement and validate the assessments of risks of failing to achieve
  - (1) good groundwater status [Article 4.1(b)(i) and Article 4.1(b)(ii)];
  - (2) any relevant Protected Area objectives [Article 4.1(c)]; or
  - (3) the trend reversal objective [Article 4.1(b)(iii)]; and

- contribute to the assessment of significant long-term trends resulting from changes in natural conditions and anthropogenic activity.

Surveillance monitoring is only specified in the Directive for bodies at risk or which cross a boundary between Member States. However, to adequately supplement and validate the Annex II risk assessment procedure, validation monitoring will also be needed for bodies, or groups of bodies, not identified as being at risk. The amount and frequency of monitoring undertaken for these bodies, or groups of bodies, must be sufficient to enable Member States to be adequately confident that the bodies are at 'good' status and that there are no significant and sustained upward trends. Colour-coded maps of the status of all bodies must be published in the river basin management plans.

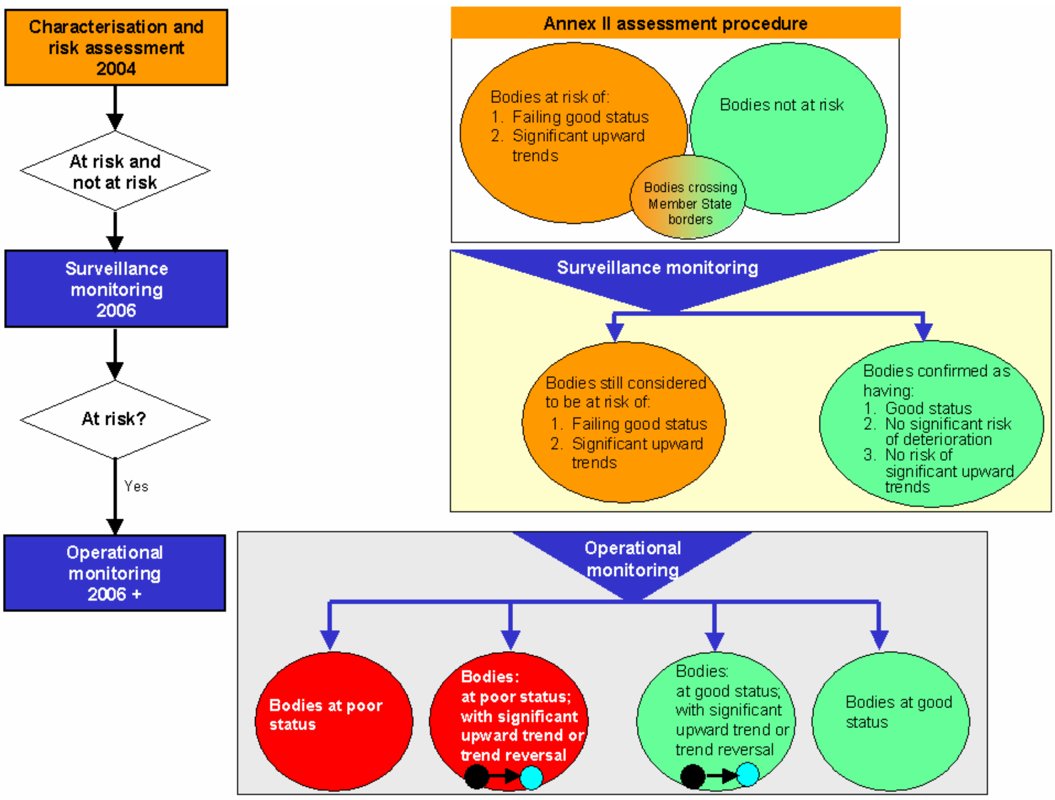
Validation will involve testing the conceptual models/understanding to the extent necessary to confidently differentiate bodies at risk from those not at risk and thus classify as 'good' status those bodies considered not to be at risk. Surveillance monitoring may also provide sufficient information to reliably classify, as 'poor' status, some bodies thought to be at risk.

4.6.3 Operational monitoring

Operational monitoring must provide the monitoring data needed to achieve an appropriate level of confidence to classify bodies at risk as either poor or 'good' status or to establish the presence of significant upward trends in pollutants (see Figure 5).

The surveillance monitoring programmes must be designed on the basis of the results of Annex II characterisation and risk assessment procedure. Operational monitoring programmes must be designed on the basis of the characterisation and risk assessment as refined by the data from the surveillance monitoring programmes. To supplement and validate the Annex II risk assessments, surveillance monitoring will be necessary in bodies, or groups of bodies, identified as being at risk and a selection of those identified as not being at risk. Operational monitoring is focused exclusively on bodies, or groups of bodies, at risk. Note the information provided by operational monitoring may establish that some bodies, or groups of bodies, considered likely to fail to achieve environmental objectives on the basis of the Annex II risk assessment and the surveillance monitoring programme are at 'good' status.

Figure 5: The outputs of risk assessment, surveillance and operational monitoring.

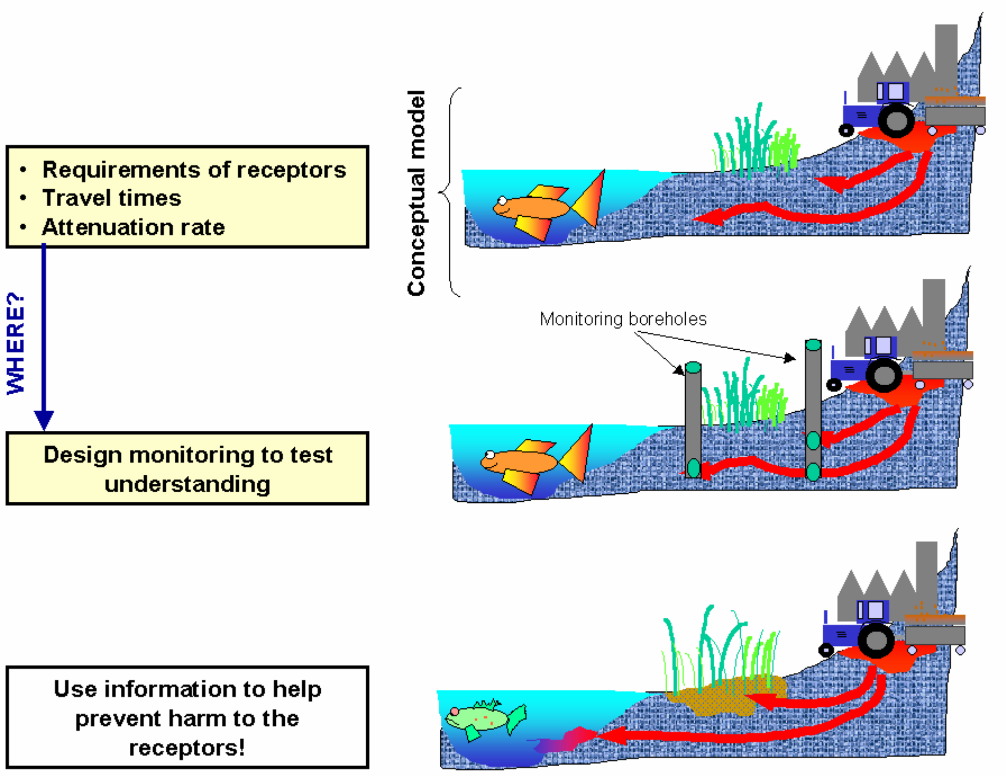


4.6.4 Where to monitor

Information on pressures, the conceptual model/understanding of the groundwater system, the fate and behaviour of pollutants in it and the consequent risks to the objectives should be used to determine the most appropriate locations for monitoring points. For example, where a surface water body or a directly dependent terrestrial ecosystem is at risk from a significant point source, the monitoring locations to test the prediction provided by the conceptual model/understanding would be different from those needed to test a conceptual model/understanding suggesting a risk to the objectives from diffuse pollution distributed uniformly across a groundwater body.

Where the conceptual models/understandings of a group of groundwater bodies and the pressures on each of the bodies in the group is similar, the validation of the model may be achieved using monitoring information from a selection of water bodies rather than using monitoring data for each body. In some cases, existing monitoring data or monitoring data collected by the surface water monitoring programmes may be sufficient to adequately test a conceptual model/understanding.

Figure 6: The selection of monitoring locations will depend on the development of a conceptual model/understanding of how the objectives for the body of groundwater may be at risk.



4.6.5 What to monitor

Where surveillance monitoring is required, the Directive requires that a core set of parameters be monitored. These parameters are oxygen content, pH value, conductivity, nitrate and ammonium. Other monitored parameters for both surveillance and operational monitoring must be selected on the basis of (a) the purpose of the monitoring programme, (b) the identified pressures and (c) the risk assessments made using a suitable conceptual model/understanding of the groundwater system and the fate and behaviour of pollutants in it. For example, the principal purpose of surveillance monitoring is to supplement and validate the Annex II risk assessments. To do this, the predictions of risk made during the Annex II assessments must be tested. Such testing should involve consideration of:

a) the predicted effects of pressures identified during the Annex II risk assessment procedure; and

b) whether there are any significant effects due to pressures not identified during the Annex II assessment procedure.

In the case of point (b) above, the guidance recommends that Member States select monitoring parameters that, if present, would indicate effects associated with different types of human activity. Some examples of indicators relevant to different activities that may be present in the recharge area of bodies, or groups of bodies, of groundwater are suggested in Table 2.

Table 3 provides examples of pollutants typically associated with different human activities, and which may therefore be appropriate to consider in monitoring programmes depending on the conceptual model/understanding and the likely risks to the objectives. For example, suites of parameters commonly associated with certain types of pressures have been identified (e.g. gas works: PAH, Phenol, hydrocarbons, etc). Parameters indicative of the pollutants that are liable to be present can be used to ensure cost-effective monitoring. The toolbox outlines some of the indicators used by Member States.

Other chemical parameters may need to be sampled for quality assurance purposes. For example, measuring the concentrations of major ions in a water sample so that an ion balance can be used as a check that the water analysis results are representative of the sampled groundwater should be considered as a routine quality assurance procedure.

4.6.6 When to monitor

The conceptual model/understanding of the groundwater system and the understanding of the fate and behaviour of pollutants within it, and the aspect of the model being tested should also determine the appropriate frequency of monitoring. Table 5 and Table 6 provide examples of frequencies that Member States have found appropriate in a number of hydrogeological circumstances and in relation to different pollutant behaviours.

4.7 Monitoring of Protected Areas

The Water Framework Directive establishes a planning framework to, among other things, support the achievement of the standards and objectives for Protected Areas established under Community legislation. In the context of groundwater, these areas may include Natura 2000 sites established under the Habitats Directive (92/43/EEC) or the Birds Directive (79/409/EEC), Nitrate Vulnerable Zones established under the Nitrates Directive (91/676/EEC) and Drinking Water Protected Areas established under Article 7 of the Water Framework Directive.

To ensure monitoring programmes are as efficient and as effective as possible, it would be appropriate to ensure that the quantitative status and the chemical status 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

The achievement of the Drinking Water Protected Area objective requires that the quality of the abstracted groundwater prior to treatment does not change as a result of human activities in a way that would require an increased level of purification treatment to meet the standards required at the point of consumption under Directive 80/778/EEC, as amended by Directive 98/83/EC. Assessing compliance with, and providing the necessary information to achieve, this objective requires:

- Establishing the chemical composition of the abstracted water prior to any purification treatment. This analysis should take account of any parameters that could affect the level of treatment required to produce drinking water. Member States are required under Annex II 2.3(c) to collect and maintain information on the chemical composition of water abstracted from (i) any points providing an average of 10 m^3 or more per day, whether or not that water is intended for human consumption, and (ii) points serving 50 or more persons;
- During each planning period, collecting information, where relevant, on the composition of water abstracted in a way that is proportionate to the risks to the quality of that water identified in the Annex II risk assessment procedure. This should enable the detection of any deterioration in the

abstracted water's quality that could affect the level of purification treatment required to produce drinking water – and hence indicate a failure to achieve the Protected Area objective;

- Establishing a conceptual model/understanding of the groundwater system from which the abstracted water is drawn. The model should be proportionate to the likely risks to the objective and should enable measures to be designed, where necessary, to protect the recharge area from any inputs of pollutants that would result in a failure to achieve the Protected Area objective (see Chapter 5).

4.8 Monitoring requirements dependent on applied algorithms for status and trend assessment

The requirements on monitoring can not only be derived from the WFD directly but depend on the algorithms which are applied by Member States to implement the Directive and comply with its objectives. The WFD does not exactly prescribe the assessment methods to be used. WG 2.8[20] developed appropriate algorithms for data aggregation, trend and trend reversal assessment which had to be pragmatic solutions, statistically correct and only one method applicable to different groundwater body sizes, different hydrogeological conditions, different site densities, all parameter types and diffuse and point source pollution.

The main findings regarding the monitoring network, the monitoring frequency and the quality assurance of the algorithms proposed by WG 2.8 were:

- **Distribution of monitoring sites** as well as the **selected number and types of sites** was highlighted as important with regard to the applicability of the proposed statistical methods and the comparability of the assessment.
- Minimum requirements (distribution and number of sites) depend on the algorithms applied.
- **Importance of continuity** with regard to selected sampling sites - changes should not affect the outcome of the assessment.
- Sampling frequency should be in accordance with the **natural conditions** of the GW-body
- In the time series some observations may be missing, but the **missing of two or more sub-sequent values should be avoided** for trend assessment - risk of bias due to extrapolation
- **Take care of the sampling time or period** to avoid bias by seasonal effects which reduces the power of the trend analyses and to avoid induced trend phenomena
- In case of yearly measurements it should be guaranteed that the **measurements are taken in one and the same quarter** or within a certain time period of the year
- Need of sufficient information on LOD (limit of detection) and LOQ (limit of quantification)

The sampling procedure itself and chemical analysis should ensure continuity in results and comparability. (Relevant norms/standards should be applied).

In fact it is the individual duty of the Member States to decide on the algorithms applied in order to perform the required assessments. The correct implementation of appropriate methods imply that certain method specific requirements on the monitoring have to be met which is then reflected by the precision and the confidence of the assessment results.

4.9 Reporting requirements, Schedule of monitoring

A summary report of the network must be submitted to the Commission by 22 March 2007 (Article 15), and a map showing the network must be included in the river basin management plan.

---

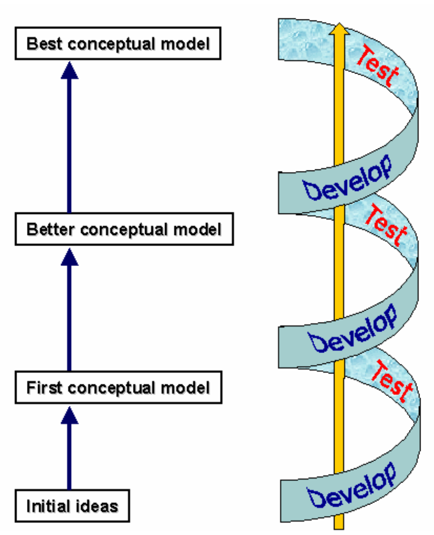
[20] Technical Report No. 1. The EU Water Framework Directive: statistical aspects of the identification of groundwater pollution trends, and aggregation of monitoring results. ISBN: 92-894-5639-6

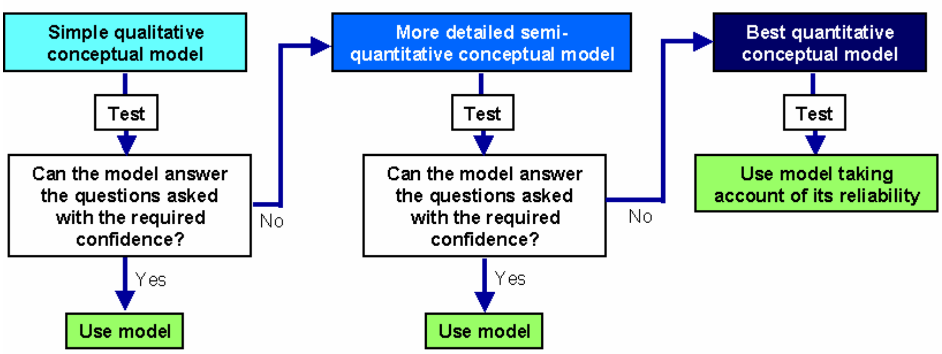
5 Best practices and tools to assist

5.1 Conceptual modelling/understanding - Examples

A conceptual model/understanding is a simplified representation, or working description, of how the real hydrogeological system is believed to behave.

- It is a set of working hypotheses and assumptions
- It concentrates on features of the system that are relevant in relation to the predictions or assessments required
- It is based on evidence
- It is an approximation of reality
- It should be written down so that it can be tested using existing and/or new data.
- The level of refinement needed in a model is proportionate to (i) the difficulty in making the assessments or predictions required, and (ii) the potential consequences of errors in those assessments.





The testing of conceptual models/understandings is important to ensure they provide for acceptable levels of confidence in the assessments they enable.

The level of complexity involved in any model will depend on the difficulty in judging the status of the body of groundwater and the implications of that status assessment. For example, where a body of groundwater is subject to no or only minor pressures, a very basic conceptual model/understanding will be adequate. However, to justify, and properly target, very costly restoration or enhancement measures for bodies failing to achieve 'good' status, relatively complex models are likely to be required. Different sorts of data, and different levels of confidence and precision in data, will be relevant to the development and subsequent testing of conceptual models/understandings in these different circumstances (Figure 7). This chapter describes the development and testing of basic conceptual models/ understandings, and provides examples of under what circumstances and in what ways such models may need to be improved (Figure 9 to Figure 12).

Figure 7: Schematic illustration of a simple conceptual model/understanding of a body of groundwater in which the only significant groundwater discharge is to a river [i.e. the groundwater body has been delineated in such a way that any flows across its boundaries are negligible[21]].

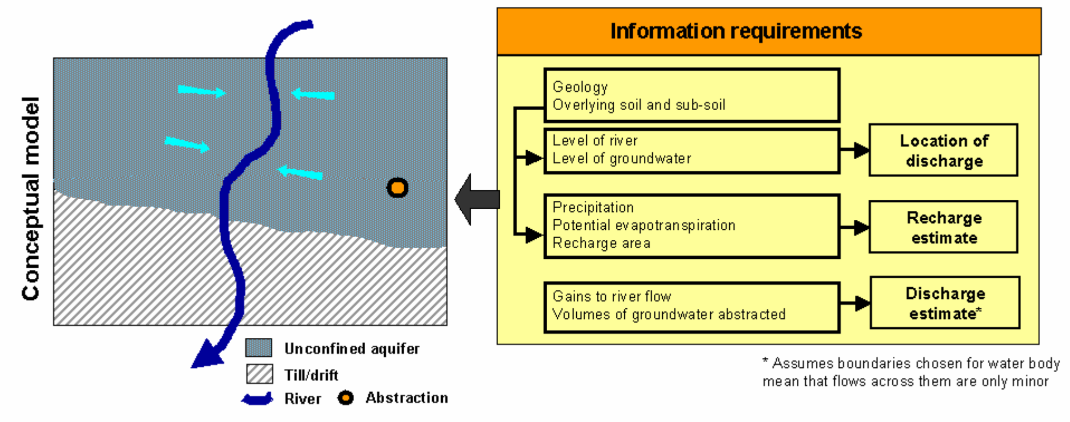
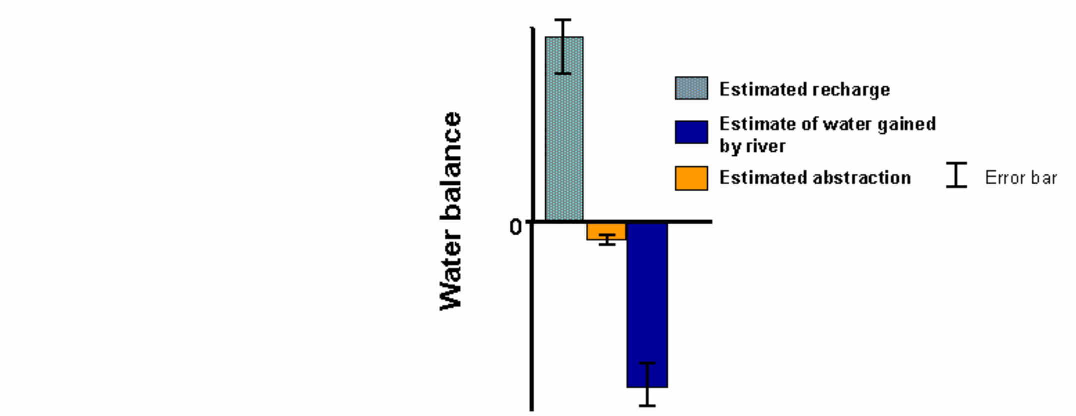


Figure 8: Water balance used to test the conceptual model/understanding illustrated in Figure 7.



The simple conceptual model/understanding illustrated in Figure 7 can be tested by lumped estimates of recharge, discharge and abstraction to see if it explains the bulk flows of water in the hydrogeological system (see Figure 8). If the water balance calculation balanced, and the model was adequate for use in assessing the status of the body of groundwater, no further development of the model would be necessary (see Figure 9). Where there is an apparent long-term water balance deficit, this could indicate over-abstraction but it could also result from errors in the conceptual model/understanding or the estimation of one or more of the components of the water balance (e.g. error in the recharge estimate). An improved, more detailed conceptual model/understanding would be required to enable a reliable assessment of status.

The level of precision required in the water balance will vary with the complexity, and likely significance, of the pressures to which a water body is subject (see Figure 10). For example, if a water body were subject to only minor pressures, provided there were no orders of magnitude imbalances in the water balance calculation, the model would be adequate. Where pressures were greater, in terms of numbers, distribution and/or significance, improvements to the conceptual model/understanding would be necessary in order to adequately assess status and design appropriate measures. Improving on a basic conceptual model/understanding involves reducing the errors in the estimates of recharge, groundwater discharge and abstraction, and appropriately refining its spatial and temporal resolution.

---

[21] Guidance Document No 2: Identification of Water Bodies. ISBN 92-894-5122-X

Figure 9: Considerations involved in determining the adequacy of a conceptual model/understanding.

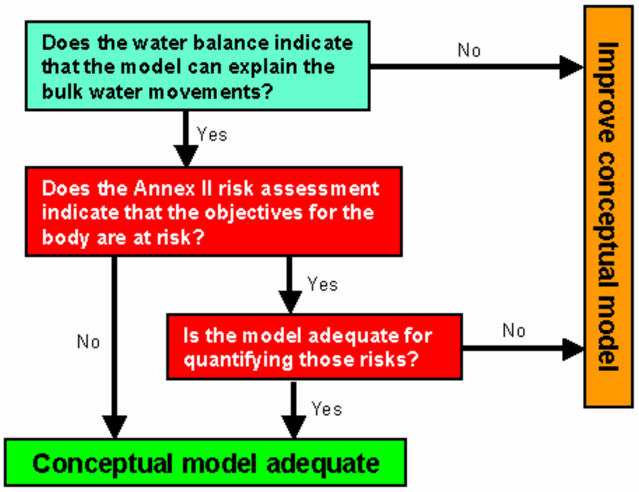
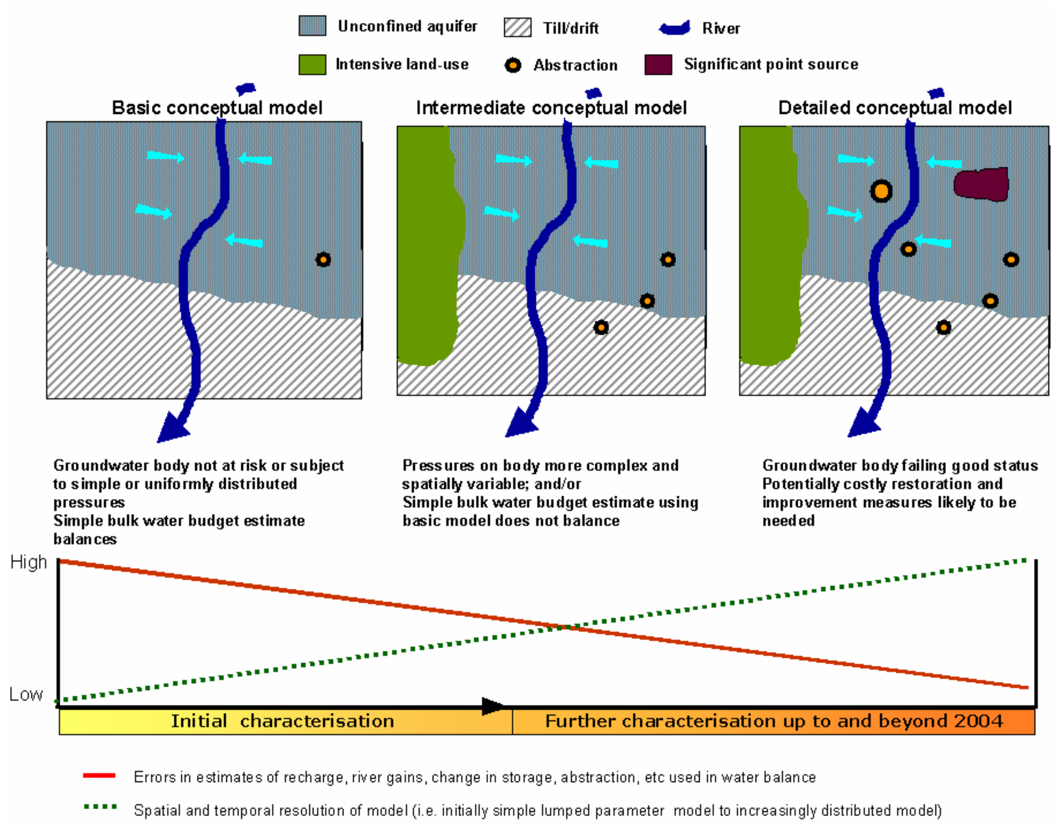


Figure 10: Development of a conceptual model/understanding in relation to the increasing complexity of pressures on the body and the cost of restoration and improvement measures.



For example, a complex quantitative model would tend to be based on (and tested), using estimates of the properties of different parts of the body of groundwater rather than relying on lumped estimates for the groundwater body's catchment. This produces a better understanding of spatial and temporal variability in the hydrogeological system and reduces the errors in the estimates of recharge and discharge used to test the model.

Table 1: Illustration of potential differences in data requirements for simple and best quantitative conceptual model/understandings

	Basic conceptual model/understanding	Best quantitative model
Recharge	- Precipitation	- Precipitation
	-	- Estimate of artificial sources of recharge (e.g. leaking drinking water supply pipes etc)
	- Lumped estimate of potential evapotranspiration	- Estimate of actual evapotranspiration based on properties of land cover (e.g. types of crops).
	- Recharge area based on simple assumption of unconfined/confined	- Detailed properties of overlying soils and sub-soils; land-sealing (sub-balances to test properties)
River Gain	- Use of river flow data if available - Standard length/gain coefficients for different geological settings - Expert judgement	- Naturalisation estimates of river flows (e.g. estimated hydrograph with all river abstractions and discharges (other than groundwater) removed. Hydrograph separation to determine groundwater contribution. - Estimate of change in storage.

Monitoring programmes should be designed to provide the data needed to appropriately test conceptual models/understandings (Table 1). The monitoring data needed to test any particular model will depend on the extent and quality of existing data and on the difficulty in assessing the status of the body, or group of bodies, and the implications of that assessment for the programmes of measures. Different types of monitoring data may be used in validating a conceptual model/understanding. For example, information on the physicochemical properties of the groundwater and the surface water body at low river flows may improve confidence in the estimates of the extent of groundwater–surface water connectivity.

Figure 11: Monitoring design in relation to conceptual model/understanding validation. Groundwater monitoring requirements will depend on the confidence required in the model and the extent and quality of existing data.

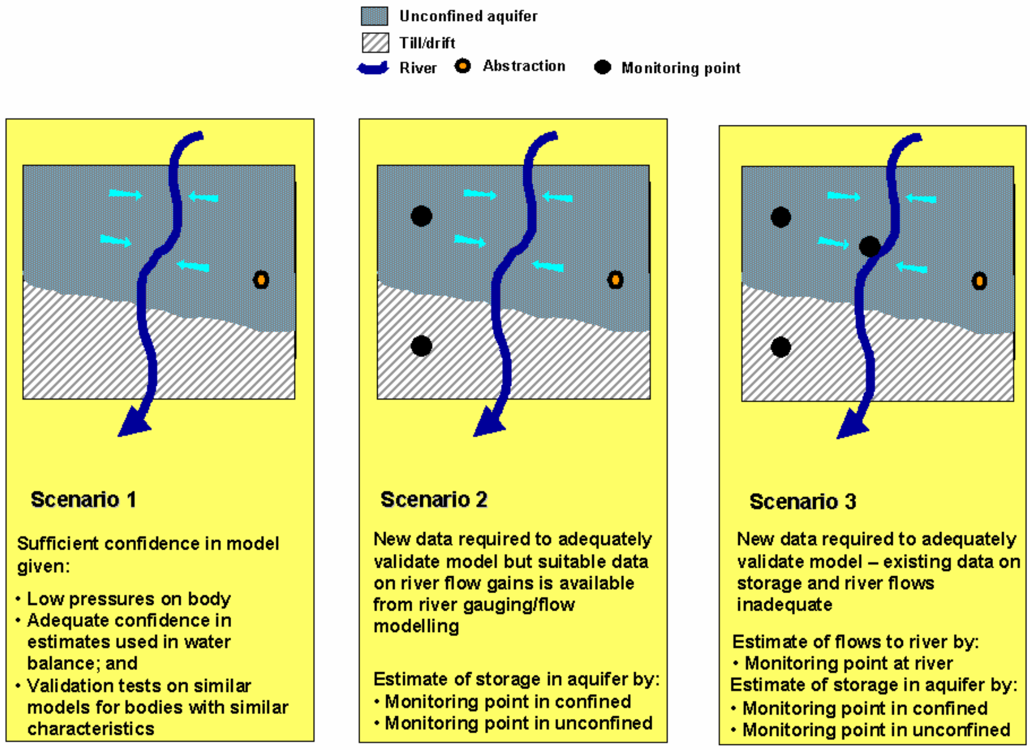
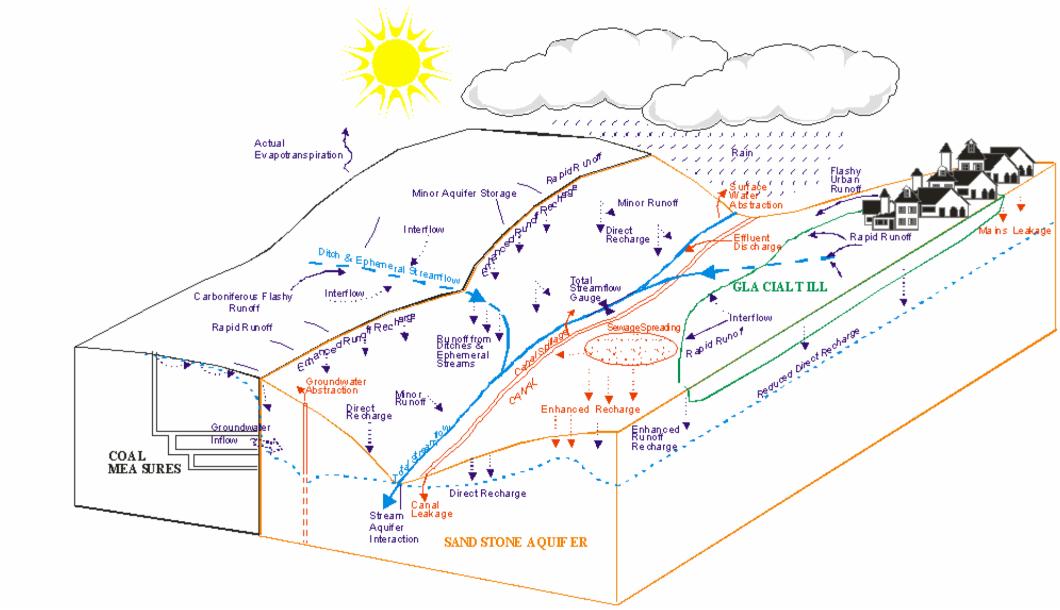


Figure 12: Illustration of an intermediate conceptual model/understanding



5.2 Chemical status monitoring

5.2.1 Selection of chemical pollutants

Table 2 comprises an example of pollutant suites that have been used in monitoring programmes in the UK to provide data on the risks to groundwater objectives from particular types of land use. Table 3 gives examples of parameters that may be used in monitoring programmes to indicate a particular human activity affecting groundwater. The UN-ECE's guidelines also identify indicator parameters related to different problems, functions and uses. These are summarised in Table 4.

Table 2: Pollutant suites in relation to human activities (from UK)

	Land use					
	Arable	Managed grassland	Managed woodlands	Urban	Sheep	Amenity
Field parameters						
Major ions	✓	✓	✓	✓	✓	✓
Trace metals				✓		
Special inorganics				✓		
Organonitrogen pesticides	✓		✓		✓	
Organochlorine pesticides	✓					✓
Acid herbicides	✓	✓		✓		✓
Uron/urocarb pesticides	✓			✓		✓
Phenols				✓		
VOCs				✓		
PAHs				✓		
Special Organics	✓				✓	

Table 3: Useful indicators for monitoring indicating different types of human activity

Parameter(s)	Source
Nitrate	Agriculture
Ammonia	urban areas, agriculture, land-fill
Phosphorous	Agriculture
Pesticides	Agriculture, traffic areas (rail tracks)
Sulphate	Agriculture, atmospheric depositions (acid rain), urban areas
pH-value	Atmospheric deposition (acid rain)
Chloride	traffic (de-icing salt, road salt), agriculture, urban areas
Tetra- and Trichloroethene	housing area, small trade (e.g. dry cleaner), industry,
Micro-biological parameters	Animal or human waste disposal

Table 4: Parameter suites for groundwater quality assessment related to some problems and functions/uses. (After Chilton et al, 1994)

Problems	Functions and Uses	Suite/groups	Parameters
Acidification, salinization	Ecosystems, agriculture	1. Field parameters	Temperature, pH, Dissolved Oxygen (DO), Electrical Conductivity (EC)
Salinization, excess nutrients	Drinking water, agriculture, ecosystems	2. Major ions	Ca, Mg, Na, K, HCO_3, Cl, SO_4, PO_4, NH_4, NO_3, NO_2, TOC, EC, ionic balance.
Pollution with hazardous substances	Drinking water, ecosystems	3. Minor ions and trace elements	Choice depends partly on local pollution sources as indicated by land-use approach.
Pollution with hazardous	Drinking water, ecosystems substances	4. Organic compounds	Aromatic hydrocarbons, halogenated hydrocarbons, phenols, chlorophenols. Choice depends partly on local pollution sources as indicated by land-use approach.
Pollution with hazardous substances	Drinking water, ecosystems	5. Pesticides	Choice depends in part on local usage, land-use approach and existing observed occurrences in groundwater.
Pollution with hazardous substances	Drinking water, agriculture	6. Bacteria	Total coliforms, faecal coliforms.

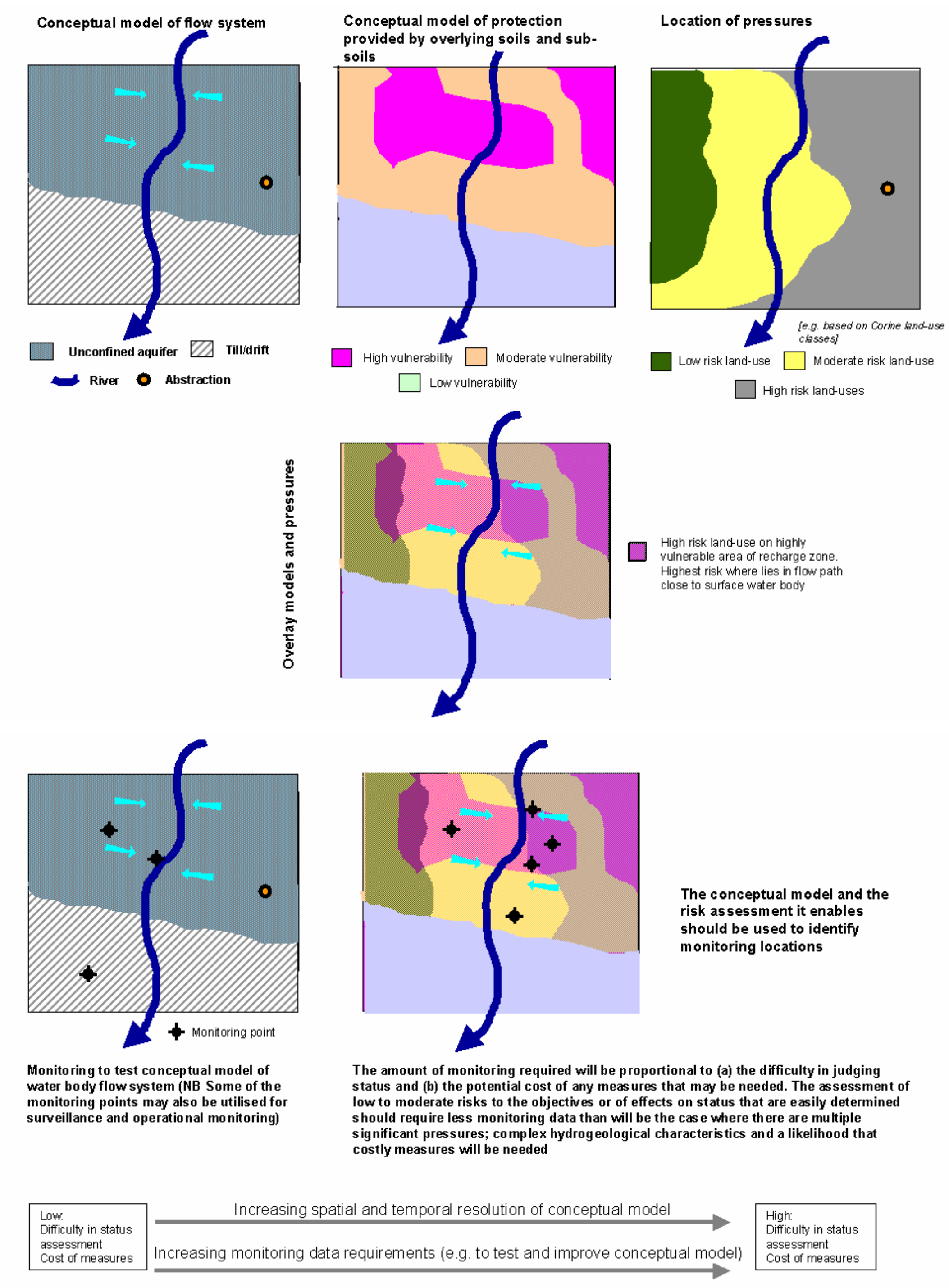
List II substances are Fe, Mn, Sr, Cu, Pb, Cr, Zn, Ni, As, Hg, Cd, B, F, Br and Cyanide.
(Drinking Water and Nitrate Directive)

5.2.2 Selecting monitoring sites and density in relation to risk

The assessment of chemical status and the identification of pollutant trends require a flexible, risk-based approach to selecting sites for monitoring. The conceptual model/understanding and the risk assessment it enables should be used to identify locations for, and the density of, monitoring points in relation to different land use pressures. The actual density of monitoring sites and location of individual sites will depend on the difficulty of reliably assessing the effects of pressures on the status of the body and the likelihood of costly measures being required. Such decisions must be made locally and be iteratively based on an appropriately detailed conceptual model/understanding of the groundwater system coupled with the assessment of risks to the Directive's objectives.

Where a body is at risk (illustrated in Figure 13) its status is difficult to determine because of its complex hydrogeological characteristics and/or the complex range of pressures to which it is subject; and costly measures may be required, improved conceptual models/ understandings and greater monitoring density will be necessary.

Figure 13: Monitoring locations for assessing chemical status should be selected on the basis of the Annex II risk assessments.



5.2.3 Approaches to determining monitoring frequencies in relation to groundwater body characteristics and the behaviour of pollutants

The sampling frequency for pollutants should be based on:

- the conceptual model/understanding of the groundwater system and the fate and behaviour of pollutants in it; and
- the aspect of the conceptual model/understanding being tested.

In the UK, a sampling frequency for groundwater quality is used that combines the requirements of the Directive with the main hydrogeological factors that influence groundwater flow. The framework ensures more frequent sampling in aquifers in which groundwater flow is rapid and less frequent in aquifers with slower movement (Table 5). It also builds in a less frequent requirement for sampling in confined aquifers than in unconfined aquifers, reflecting the greater degree of protection from pollution provided by the confining layers. The schedule is consistent with the Directive's requirements for operational monitoring to be undertaken at least annually between surveillance monitoring periods and for surveillance monitoring to be undertaken during each planning cycle. These frequencies may not be relevant for trend assessment. Guidance on monitoring frequencies for trend assessment are provided in WG 2.8[22].

Table 5: Sampling frequency for groundwater hydrogeology

			SURVEILLANCE	*OPERATIONAL*
Hydrogeology	SLOW	Unconfined	3 years	6 monthly
		Confined	6 years	Annual
	FAST	Unconfined	Annual	Quarterly
		Confined	3 years	6 monthly

In Germany, the following table (Table 6) provides guidance on monitoring frequencies in relation to aquifer properties. The table does not address monitoring frequencies in relation to point sources, especially infiltrating dense liquid phases.

Table 6: German guidance on monitoring frequencies in relation to aquifer properties

Scenarios	Frequencies					
	Monthly	Quarterly	Half yearly	Yearly	2 Years	5 Years
shallow groundwater (depth to table ≤ 3 m), unconfined porous aquifer	(x)	X	X	(x)		
deep groundwater (depth to table ≥ 10 m), unconfined porous aquifer				(x)	X	X
shallow ground-water (depth to table ≤ 3 m), unconfined fractured aquifer	(x)	X	X	(x)		
deep groundwater (depth to table ≥ 10 m), unconfined fractured aquifer		(x)	X	X		
karst aquifer (without more or less impermeable cover)	X	X	X			
karst aquifer (with more or less impermeable cover)	(x)	X	X	(x)		
confined groundwater (with more or less impermeable cover with thickness < 2 m)				X	X	(x)
confined groundwater (with more or less impermeable cover with thickness > 2 m)				(x)	X	X
high rate of recharge		(x)	X	X		
Trend assessment			X	X		
season-dependent human activities		(x)	X	(x)		

Note: X indicates the most likely frequency. (x) indicates the range of frequencies depending on the particular circumstances. The frequencies suggested may not be relevant for trend assessment.

[22] Technical Report No. 1. The EU Water Framework Directive: statistical aspects of the identification of groundwater pollution trends, and aggregation of monitoring results. ISBN: 92-894-5639-6

5.2.4 Intrusions

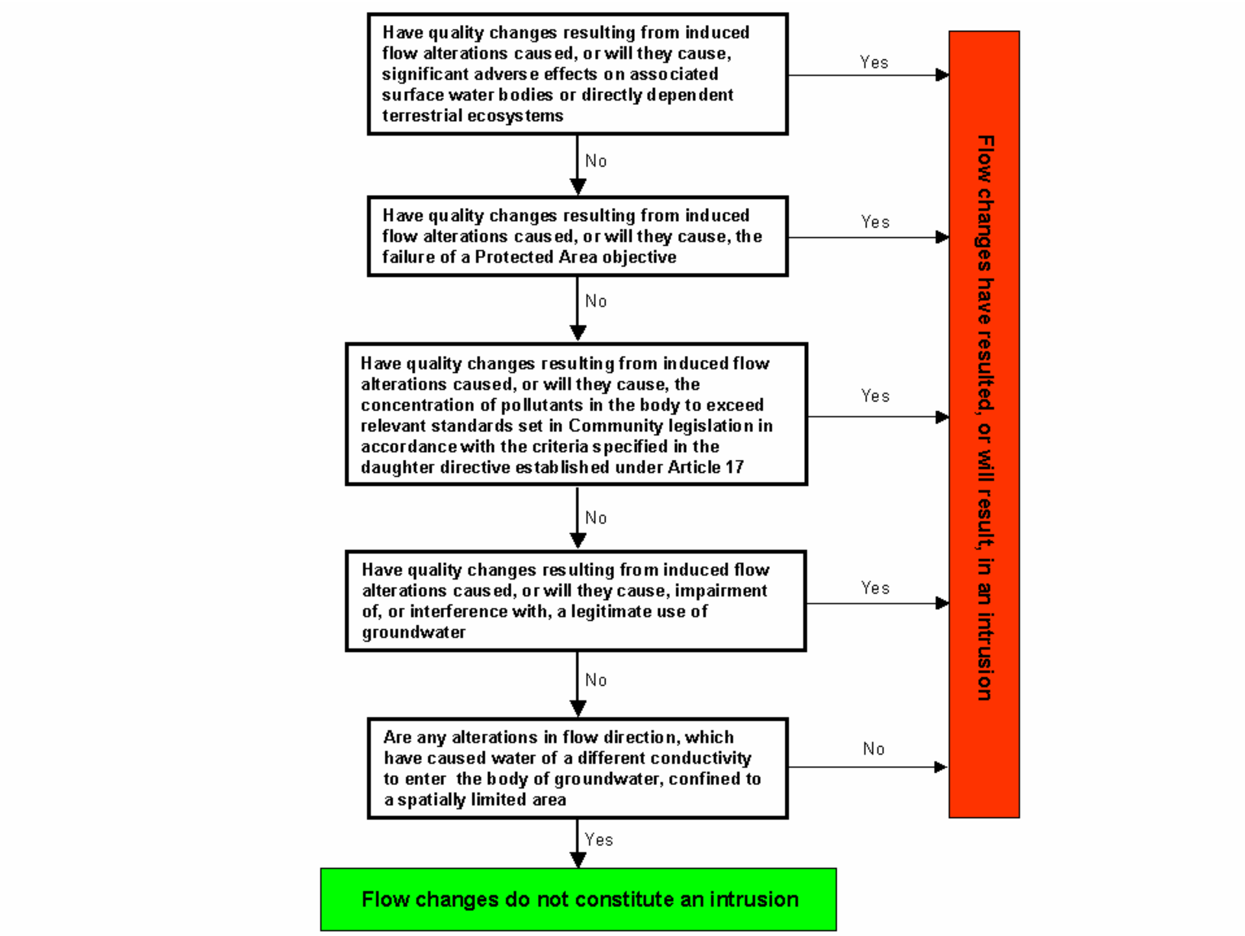
One of the criteria required to achieve both good groundwater quantitative status and good groundwater chemical status is that a body of groundwater is not subject to saline or other intrusions resulting from human induced changes in flow direction. Some alterations to flow direction, however localised, would be expected to accompany any abstraction. Sometimes these will induce movements of water into a body of groundwater from an adjacent groundwater body or an associated surface water body. This water may well have a different chemical composition to that of the body of groundwater, either because of the pollutant concentrations it contains or because of its natural chemistry. The Directive does not regard temporary or continuous changes in flow direction and their associated effects on chemical composition as intrusions so long as they are limited spatially and do not compromise the achievement of any of the Directive's other environmental objectives for the body of groundwater (see Figure 14).

An assessment of whether an intrusion is present requires:

- the development of a conceptual model/understanding of the groundwater system;
- the use of that model to predict whether the pressures on the water body may have caused an intrusion; and
- the testing of that prediction to the extent necessary to develop the required confidence in the model and in the classification decisions it enables.

The testing of the conceptual models/understandings and the validation of their predictions will require the use of monitoring data.

Figure 14: Criteria for defining a saline or other intrusions into groundwater bodies. Where one of the intrusions defined in the figure occurs, a body of groundwater will fail to achieve good quantitative status and good chemical status.



5.3 Sampling design - Implementation of QA programmes

Care should be taken in the construction and operation of sampling points and in the analysis of samples collected so that they do not inadvertently affect the data provided.

A definition of the purpose of groundwater sampling is an essential prerequisite before identifying the sampling strategies and methods. Sampling design includes: selection and design of sampling sites, frequency and duration of sampling, sampling procedures, treatment of samples and analytical requirements. ISO 5667-1 and EN 25667-1 give the principles on the design of sampling programmes in aquatic environments.

Errors inevitably occur both in the process of sampling and in the analysis of water samples. The aim of an appropriate quality assurance procedure is to quantify and control these errors. Quality assurance procedures may take the form of standardisation of sampling and analytical methods, replicate analyses, ionic balance checks on samples and laboratory accreditation schemes. Notwithstanding the benefits of the one-off intercalibration exercise for the purpose of classification and comparison with the results from other appropriate Member States, a continuous quality assurance system should be developed to ensure that all monitoring results meet assured target levels of precision and bias. Therefore, QA measures should be implemented for each monitoring institution as well as in data collection centres, and encompass all operational facets of a monitoring programme, including:

- Field sampling and sample receipt;
- Sample storage and preservation; and
- Laboratory analysis;

These measures are based on:

- Developing comprehensive and understandable Standard Operating Procedures (SOPs);
- Using validated monitoring methods (sampling, chemical analysis, reporting), that means experimental proof and related documentation confirms that each method is fit for its intended purpose;
- Establishing routine internal quality control measures (control charts, reference materials, internal QA audits); and
- Participation in external QA schemes (laboratory proficiency testing schemes, external QA audits, QA accreditation).

It is generally accepted that approximately 25% of a laboratory's effort is required to establish and maintain an effective quality assurance system.

Experimental evidence must be supplied and documented in SOPs such that:

- All methods possess sufficient sensitivity, selectivity and specificity;
- Method accuracy and precision meet the requirements (still to be established) for each programme of measures developed for implementation of the Water Framework Directive; and
- Analytical detection limits (i.e. the smallest concentrations that are quantitatively detectable with a defined uncertainty) do not jeopardise the assessment of compliance with quality limits/targets or decisions made between good and poor status.

In routine monitoring, quality assurance should ensure at any time that the methods used are strictly controlled and monitored. For that purpose, all monitoring institutions should have implemented an internal QA system according to ISO 17 025 (2000). To obtain long-term control of the performance of monitoring methods, results of internal QA measures (e.g. analysis of certified reference materials) must be recorded in control charts.

To evaluate the comparability of monitoring data throughout the Member States, participation in external quality audits and in external quality assessment schemes like international laboratory proficiency testing or taxonomical workshops is highly recommended.

An acceptable level of quality must be achieved for all monitoring data generated within the WFD Monitoring. It is possible to evaluate if monitoring data is fit for the intended purpose using the following QA criteria:

- Monitoring data are reported with an uncertainty estimate calculated from method validation or from inter-comparison exercises;
- Limits of detection are well below the principal levels of interest and allow the control of quality objectives;
- Satisfactory results can be obtained in analysing independent reference materials/samples, and this is demonstrated by appropriate control charts (or electronic equivalent) for the determinands of interest; and,
- Participation in relevant proficiency testing schemes at least once per year (with the proportion of results identified as outside limits of error being below 20% for all parameters) Quality Assurance

5.3.1 Monitoring points

The influence of the construction of a monitoring point and its condition and maintenance on the data obtained should be evaluated. For example, could the condition of the casing of the borehole be affecting the results? Are the intended geological strata exposed in the borehole? Is water entering the borehole from the surface?

5.3.2 Sampling methods

ISO 5667-11 (1993) gives the principles for groundwater sampling methods focused to survey the quality of groundwater supplies, to detect and assess groundwater pollution and to assist in groundwater resource management. ISO 5667-18 (2001) gives the principles of groundwater sampling methods at contaminated sites.

ISO 5667-2 gives the general information on the choice of material for sampling equipment. Generally polyethylene, polypropylene, polycarbonate and glass containers are recommended for most sampling situations. Opaque sample containers should be used if the sampled parameter degrades in light (e.g. some pesticides). Contamination or modification to the chemistry of groundwater samples should be minimised by selecting suitable materials for sampling equipment and borehole construction.

5.3.3 Sample storage, conditioning and transportation

Groundwater samples storage, conditioning and transportation from the sampling sites to the laboratory are extremely important, because the results of the analysis should be representative of the conditions at the time of sampling. General guidance on these aspects is given in ISO 5667-2 and ISO 5667-3. Specific indications for groundwater samples are given in ISO 5667-11.

5.3.4 Sample identification and records

An identification system that provides an unambiguous method for sample tracking should be adopted. It is crucial that a clear and unambiguous labelling system be used for samples to enable effective management of samples, accurate presentation of results and interpretation. ISO 5667-11 gives guidance on sample identification and record procedures. In addition, other relevant environmental data should be reported and recorded in order that any repeat sampling can be carried out and any variability in results examined.

5.3.5 Expression of results

The results of measurements must indicate any rounding of numbers, final units, ± combined uncertainty, confidence interval. The detection limit (limit of quantification) of the method should be reported. The procedure of calculation of the detection limit (limit of quantification) should also be clearly reported.

5.3.6 Key sources of information on sampling protocols and QA

- UN/ECE Task Force on Monitoring and Assessment provides practical Guidance on methods and quality assurance for monitoring transboundary groundwaters (www.iwac-riza.org).
- The European Environment Agency provides technical Guidance on design and operation of groundwater monitoring networks through its EUROWATERNET initiative (www.eea.eu.int).
- The AMPS working group under the EAF Priority Substances aims to ensure "the availability of good quality data..." and could deliver useful input on quality assurance requirements. http://forum.europa.eu.int/Members/irc/env/wfd/library?l=/experts_advisory/advisory_substances/monitoring_substances&vm=detailed&sb=Title

Annex 1 – Summaries of the Workshop on Groundwater Monitoring

SESSION 1. GENERAL FEATURES OF GROUNDWATER MONITORING

A reminder of previous CIS recommendations: Statistics (WG 2.8) and Monitoring (WG 2.7) - Andreas SCHEIDLEDER

CIS WG 2.7 developed a guidance paper on monitoring and stated key principles for the development and design of monitoring networks and their operation. The guidance offered an overview of best practice in monitoring and provided a tool box. The main key principles are:

- The amount of groundwater monitoring that is required will be proportional to the difficulty in judging:
    - the status of a body or group of bodies;
    - the presence of adverse trends; and
    - the implications of errors in such judgments.
- The design and operation of groundwater monitoring programmes should be informed by:
    - the **objectives** applying to the body;
    - the **characteristics** of the groundwater body, or group of bodies;
    - the existing **level of understanding** (i.e. the confidence in the conceptual model/understanding) of the particular groundwater system;
    - the type, extent and range of the **pressures** on the body, or group of bodies;
    - the **confidence in the assessment of risk** from pressures on the body, or group of bodies; and
    - the level of confidence required in the assessment of risk.

GW-Bodies may be grouped (on a scientific basis) provided that reliable assessment of each body of the status and the trends is obtained. Designing and operating integrated groundwater and surface water monitoring networks will produce cost-effective monitoring information for assessing the achievement of the objectives.

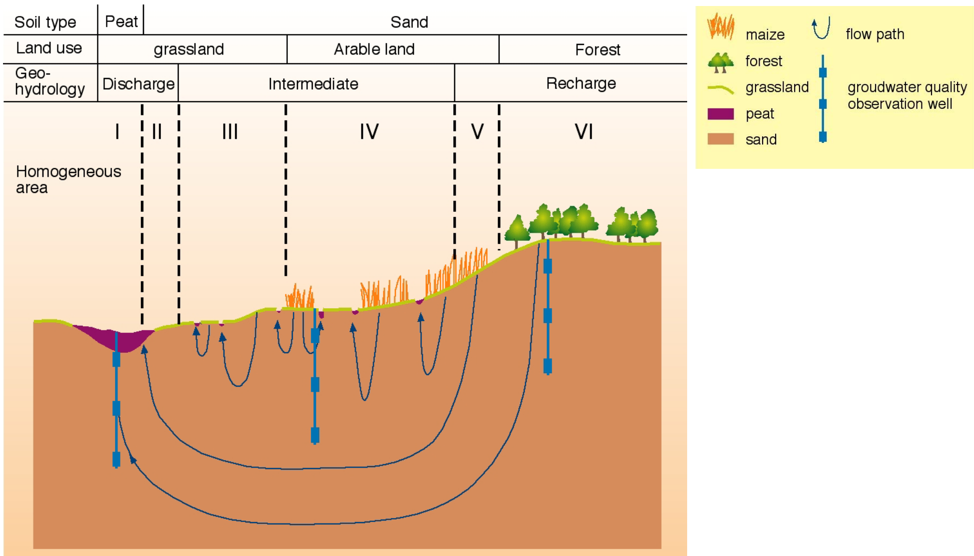
WG 2.8 developed appropriate algorithms for data aggregation, trend and trend reversal assessment which had to be pragmatic solutions, statistically correct and only one method applicable to different groundwater body sizes, different hydrogeological conditions, different site densities, all parameter types and diffuse and point source pollution. The findings regarding the monitoring network, the monitoring frequency and the quality assurance were:

- **Distribution of monitoring sites** as well as the **selected number and types of sites** was highlighted as important with regard to the applicability of the proposed statistical methods and the comparability of the assessment.
- Minimum requirements (distribution and number of sites) depend on the algorithm.
- **Importance of continuity** with regard to selected sampling sites - changes should not affect the outcome of the assessment.
- Sampling frequency should be in accordance with the **natural conditions** of the GW-body
- In the time series some observations may be missing, but the **missing of two or more subsequent values should be avoided** for trend assessment - risk of bias due to extrapolation
- **Take care of the sampling time or period** to avoid bias by seasonal effects which reduces the power of the trend analyses and to avoid induced trend phenomena
- In case of yearly measurements it should be guaranteed that the **measurements are taken in one and the same quarter** or within a certain time period of the year
- Need of sufficient information on LOD (limit of detection) and LOQ (limit of quantification)

- The sampling procedure itself and chemical analysis should ensure continuity in results and comparability. (Relevant norms/standards should be applied)

Monitoring and trend analysis techniques - Hans Peter BROERS

Groundwater monitoring can be distinguished into stratified random sampling (groundwater quality) and an interpolation approach (groundwater quantity). For groundwater monitoring the landscape could be stratified into homogeneous areas according to land use, soil type, hydrogeology etc. There are two approaches regarding the sampling depths, to distinguish between upper and deep groundwater or to apply mixed sampling. The regional network of the Netherlands samples upper most groundwater (5–15 m) and deeper groundwater (15–30 m).



Trend analysis

It is not a simple task to aggregate individual trends per site to an overall trend per groundwater body as all kinds of temporal developments might be present within a groundwater body. Furthermore, complicating factors for trend analysis are long residence times to observation screens, that reactive processes might obscure trends, spatial variations in historical inputs, groundwater age (especially deeper groundwater) and reactive properties in the subsurface (especially in deeper groundwater) and finally temporal variations e.g. meteorological effects (especially on uppermost groundwater).

For the theoretical propagation of trends effects of age and reactions like dispersion, cation-exchange, sorption, retardation, degradation and combinations thereof are to be taken into account. For flat areas (e.g. NL) the age distribution for recharge areas seems rather simple. The effects of age and reactive processes were demonstrated by nitrate concentrations in 3 different layers in the Netherlands. The age of the uppermost groundwater is up to 4 years, in 10 m depth groundwater is at least 8–15 years old and in 25 m depth the water age is expected to be at least 20–30 years. The proportion of contaminated groundwater decreases with the depth. Furthermore, meteorological effects on pollutants concentrations and resulting temporal variations in pollutants time series complicate trend detection. Comparisons between precipitation and nitrate concentration in groundwater show that the concentration is higher in dry years.

Following approaches might be applied in order to tackle trend assessment: the assumption of homogeneous travel time distribution at fixed depth or the use of modern age dating. Such an age-depth relation was demonstrated by age dating with tritium. The objective of trend detection is to relate changes in the quality to human activities. By applying an age-depth transformation historical inputs (human activities) over the time are related to expected concentrations over the depth.

Proposed procedure for trend detection

- Step 1: Time series analysis of individual wells (correction for time changing detection limits)
- Step 2: Stratification (optional, by land use, groundwater age, hydrogeology)
- Step 3: Aggregation to an average trend per area or groundwater body
  - test statistical significance at 95% confidence level
- Step 4: Assess practical relevance and environmental significance
  - compare trend slopes with threshold values and EU standards

Choosing monitoring frequencies & depths

- Tune frequency and depth to physical and chemical characteristics of the natural system
  - groundwater flow conditions
  - recharge rates
  - reactive processes
- Tune frequency and sampling support scale
  - shorter screen lengths -> higher frequencies required
- Justify chosen frequencies, depths and sampling supports
- Choose evaluation period (max. 12 years?, less than 10 years not recommended)

Proposed procedure for trend reversal assessment

- Step 1: Calculate mean concentration within a moving time window for each individual well
  - constant window width
  - detect trend first, then trend reversal
  - annual evaluation possible
- Step 2: Stratification (optional)
- Step 3: Aggregate individual changes of trends to an average change of trends for the groundwater body
  - test statistical significance at 95% confidence level
- Step 4: Assess practical relevance and environmental significance
  - compare trends with EU threshold values

Technical conclusions

- The aggregation of trends is necessary.
- The uppermost groundwater shows fast response and high temporal and spatial variations.
- In deeper groundwater the mixing of groundwater ages hampers trend detection. Therefore, the age dating is crucial. Reactive processes have effects on trend detection as well.

Recommendations

- Trends and monitoring are strongly connected to each other
  - trend detection has highest demands on the monitoring design
  - networks for the purpose of trend detection should be designed (considering depths, frequencies, locations)
- tune monitoring frequency and screen depth on physical and chemical properties of the natural system (travel time distributions, expected reactive processes, temporal variation)
- don't mix groundwater ages, use advanced tracers (tritium-helium etc.)
- consider age dating which makes trend detection much more efficient

The integral groundwater investigation method: motivation, principles and application - Thomas PTAK

Problems of monitoring are the heterogeneous distribution of aquifer parameters and contaminants, the uncertainty of investigation results, megasites and that present approaches for site investigation and remediation are either not reliable enough or not cost effective. In order to improve monitoring considering the WFD framework the following approach is proposed:

- New integral investigation based methodology (mass flow rate and concentrations)
- Assessment of the effects of aquifer parameter uncertainty on the estimates of mass flow rates and concentrations
- Assessment of the natural attenuation potential, assessment of remediation measures
- Delimiting of contaminant source zones and of zones without a source

Due to the physical and hydrogeochemical heterogeneity and the irregular distribution of contaminant release the distribution of contaminants in the subsurface is rather complex. The challenge of taking right decisions at megasites comprises that there are multiple sources, multiple plumes, limited information, multiple remediation options and multiple cost functions. Plume detection and characterisation would need an unusually high monitoring resolution. The explanatory power of a single monitoring well or a single concentration measurement is rather limited. Pumping test would therefore offer the possibility of an integral investigation where concentrations and mass flow rates can be obtained which should be considered in decision making. High concentrations in an aquitard (low conductivity) mean low mass flow rates with no action required whereas low concentrations in high conductive aquifers meaning high mass flow rates requiring immediate action.

A cyclic approach is proposed with the principle "from large scale to small scale":

- Integral investigation at large scale
  - Delineation of zones of low and high impact (integral assessment)
  - Delimiting of source zones using backtracking techniques
  - Assessment of the natural attenuation potential (multi-CP approach)
  - Assessment of uncertainty
  - Development of priorities for clean-up and / or further investigations
  - Cumulative receptor approach
- Investigation at small scale (near the source):
  - Evaluation of individual source zones (integral pumping tests to estimate source strength and plume backtracking, direct push methods, laboratory and on-site analytical methods, contaminant fingerprinting etc.)
  - Development of clean-up priorities and optimized strategies
  - Polluter pays principle

Summary and outlook

Start with an integral view and consider both concentrations and mass flow rates (pumping tests and inversion, backtracking, catchment outflow (rivers, springs, ...) and back calculation; direct push arrays, horizontal wells, barriers, trenches, ...).

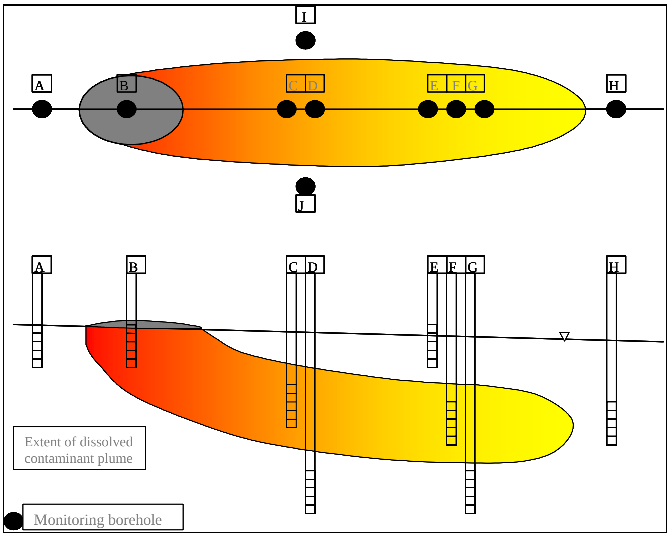
Demonstration and pilot projects are a main key to overcome barriers for future applications (development, testing and improvement of methods and tools under 'real world' conditions, communication with end-users, problem owners and administrators, and improvement of acceptance, introduction into WFD based rules).

Connections and differences on monitoring of groundwater bodies and monitoring point sources - Dietmar MÜLLER

The most important key question for monitoring is: Why? Before designing the monitoring it is essential to clarify the monitoring objectives. Designing a monitoring should cover the questions: What, Where, How and When. The environmental objective of the WFD defines the monitoring tasks. It is required to control the input of pollutants into the groundwater locally (point sources) and to control the status ('overall health') of all bodies of groundwater.

Point source relevant monitoring design considerations are:

- Does the monitoring network allow a plume to be defined, as well as background conditions?
- Are appropriate horizon(s) being monitored?
- Are sufficient monitoring data available to define seasonal and mid-term trends?
- Are the right parameters being measured and to an adequate degree of accuracy e.g. parent and daughter compounds, electron acceptors, hydrochemical indicators?

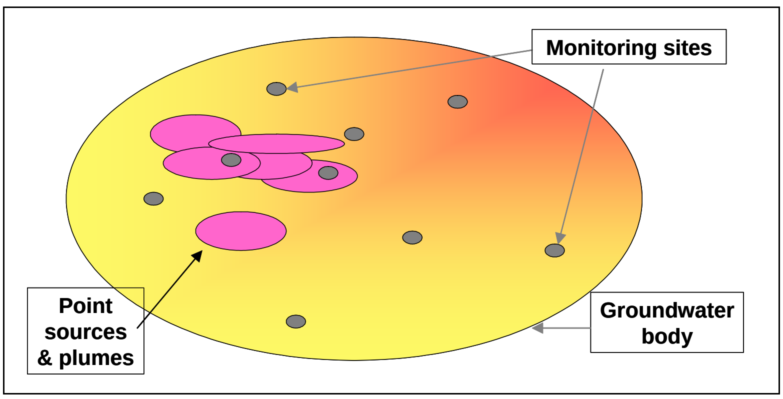


- Background (A)
- Source (B)
- Plume (C-G)
- Migration (H-J)

- Design considers
  - receptor location
  - travel times
  - stratigraphy & hydrogeology
  - NO minimum number

Groundwater body relevant monitoring design considerations are:

- Does the monitoring network provide a coherent and comprehensive overview of the groundwater status within a river basin / groundwater body?
- Is the appropriate horizon being monitored?
- Are sufficient monitoring data available to define mid- to long-term trends?
- Are the right parameters being measured and to an adequate degree of accuracy e.g. core parameters, contaminants (parent and daughter compounds)?



The monitoring approaches for point sources and for groundwater bodies refer to the same objectives and they consider the same factors (e.g. geology, hydrogeology, contaminant(s), known impacts, receptor(s), system dynamics & travel times, size of plume or monitoring areas, regulatory requirements). But the monitoring approaches differ in intensity and detail e.g.: how many boreholes and location of boreholes, borehole construction/depth, which parameters e.g.: contaminant, breakdown products, indicators (DOC, NO3, ...), duration and frequency of monitoring, environmental standards. Do we want the same standards for point sources as for groundwater bodies?

Both monitoring approaches tuned together will support coherent assessment results.

Set-up of monitoring schemes to characterise groundwater quality in groundwater bodies - Kees MEINARDI

In the Netherlands the following decisions were taken within the implementation of the WFD regarding groundwater:

- Determination of Groundwater Bodies (GWB) in the Netherlands situation;
- Quality stratification and compliance checking levels;
- Groundwater quality monitoring networks;
- Fluxes from the soil to draining surface water;
- Monitoring frequency and monitoring costs

In principle, the Netherlands consist of one single sandy aquifer. This aquifer was divided into 20 groundwater bodies based on the consideration of the hydrogeological situation, the status and the protection and finally water management aspects. Stratification was performed on the basis of travel times with a vertical flow near the surface of about 1 m/year which is decreasing with depth.

In the clay and peat areas the upper layers (about 3 m) were treated as separate groundwater bodies as the rainfall excess is discharged in that layers and the ecosystems are predominately influenced by this zone.

The Dutch groundwater network focuses on 4 levels, the upper groundwater (down to 1 m below groundwater level), shallow groundwater (-10 m), Intermediate groundwater (- 25 m) and deep groundwater (at depth of abstraction). Monitoring level 1) is compliance checking level for clay GWB and an early warning level for sand GWB and Levels 2), 3) and 4) are compliance checking levels for sand GWB

The flux of water and chemicals from soil to draining surface water in sandy areas was calculated by a model by determining long-year averages of precipitation and actual evapotranspiration, surface flow components, overland flow and interflow, groundwater recharge and travel times and average flux from varying routes to the surface water.

The first characterisation of groundwater quality for the WFD shows that in fact the full Netherlands territory is at risk not to fulfil the objectives.

The National and Provincial Groundwater Quality Network has a site density of about 1 site / 100 km² and the operational costs are about:

- land surface minus 10 m; Euro 10 / km²
- land surface minus 25 m; Euro 10 / km²
- public water supply wells; Euro 5 / km²

Information on the IGRAC network - Gerrit JOUSMA

IGRAC is an initiative of and operated under the auspices of UNESCO and WMO (1999). Its principle is global sharing of information and knowledge for optimal and sustainable groundwater resources development and management. The IGRAC centre is non-profit and hosted by the Netherlands Institute of Applied Geoscience TNO at Utrecht. It received financial support from the Dutch government for the initial years.

There are 3 main activities:

- Establishing a web-based Global Groundwater Information System (GGIS) by:
  - Providing a map of countries and groundwater regions of the world with lumped attribute sets for each of the spatial units and
  - Selected (and standardised) information and meta-information on groundwater systems or themes
- Promoting use of Guidelines and/or protocols for groundwater data acquisition and groundwater monitoring (G&P) by:
  - Improved access to guidelines and protocols (web site), inventory reports on guidelines and protocols and by developing new guidelines and protocols.
- Co-operate in global or regional projects or programmes with a significant groundwater component

IGRACs role regarding the implementation of the WFD could be to assist in exporting WFD experience to other continents, provide information on experiences from elsewhere (e.g.: "HP-India") and use IGRAC on-line facilities to promote and support international co-operation and discussion on water-related issues.

SESSION 2. RESEARCH AND TECHNOLOGICAL DEVELOPMENT IN SUPPORT OF GROUNDWATER MONITORING

The second session was devoted to monitoring relevant research projects, mainly under the 6th European Framework Programme for RTD (FP6)

SWIFT-WFD - Thomas DWORAK

SWIFT-WFD is an EU R&D project under FP6 and stands for "**S**creening methods for **W**ater data **I**n**F**orma**T**ion in support of the implementation of the Water Framework Directive".

It aims to support the Water Framework Directive (WFD) by the production of quality control tools for validation purposes of screening methods, an inventory of existing screening methods currently used or under development for water monitoring, the comparison of screening test (chemical and biological) methods through laboratory-based (tank experiments) and/or field interlaboratory studies based on a selection of reference aquatic ecosystems at European scale, and with classical laboratory-based analyses to validate their results and demonstrate their equivalence (in terms of statistical comparison procedure) for parameters regulated by the WFD.

In parallel, the project should consider the development of new "low-cost", innovative screening techniques, both for chemical as hazardous priority substances and biological parameters, for example composition and quality of biomass, and their validation using the same approach (interlaboratory testing and comparison with laboratory-based methods). In addition, exchange of knowledge, transfer of technologies and training related to water monitoring will represent a key issue for ensuring the comparability of data produced by screening methods

Potential links to policy implementation process are the integration of SWIFT innovation & technical findings to EU/national/regional level by supporting policy "awareness" within the SWIFT-Consortium based on Policy Briefs, reports and workshops, etc., by building a bridge to policy makers through reports, newsletters, workshops and presentations and by discussion of (preliminary) results with policy makers/steering committee.

Further information is available: **www.swift-wfd.com**

BRIDGE - Stéphane ROY

BRIDGE is an FP6 project and stands for "**B**ackground C**R**iteria for the **ID**entification of **G**roundwater thresholds".

It aims to define a common methodology for the establishment of threshold values by:

- studying and gathering scientific outputs to set out criteria for the assessment of the chemical status of groundwater
- deriving a plausible general approach based on scientific results and defined at national river basin district or groundwater body level
- checking the applicability and validity by means of case studies at the European scale
- identifying and undertaking additional research studies to complete available data
- carrying out an environmental impact assessment taking into acount the economic and social impacts

The consortium consists of 28 partners from 17 countries. The structure of the work is divided into 6 work packages.

- WP1: Survey of representative groundwater pollutants
  - State of the art and relation with on-going national and EU-funded RDT projects for pollutants: *Metals, anions and organic compounds of the GWD (trichlo, tétrachlo); 33 priority substances (2001); Emerging pollutants.*
- WP2: Study of groundwater characteristics
  - State of the art about groundwaters: *Hydro-geological characteristics of groundwaters; Soil/groundwater interactions and groundwater/surface waters interactions; Quantitative aspects and links with qualitative aspects.*
- WP3: Criteria for environmental thresholds and methodology to define a good status
  - Propose a practical and common approach: *Review of national methodologies of groundwater protection; Take into account sampling, measuring and quality assurance; Monitoring networks and integrated data aggregation.*
- WP4: Representative sites / water body studies and compliance testing
  - Evaluate the approach defined in WP3 : *Selection of representative sites; Linked with RTD projects (Swift, Aquaterra, Snowman, ….); Case studies and compliance testing.*
- WP5: Economic and social costs linked to the establishment of groundwater threshold values
  - Estimation of the socio-economic impact of these values : *Development of a methodological framework; Integrated socio-economic assessment of groundwater threshold values (5 case studies).*
- WP6: Information and dissemination
  - Organisation of workshops and final conference; Communication among partners / EU commission; Dissemination and link with CIRCA.

4D Groundwater Monitoring - Angeline KNEPPERS

Like in a petroleum reservoir, when an aquifer is exploited, pore fluid undergoes changes in temperature, pressure and composition. Even more when contamination is present or artificial recharge. Fluid changes can alter the formation and its properties.

In petroleum exploration although every survey records "time" frequency information, many prospects or areas have seen successive surveying in 2D, 3D and later in 4D. The benefits for 4D (time series + vertical gradient) are illustrated by 2 case studies which led to the following conclusions:

- High resolution monitoring is the key to understanding flow paths
- Multiple zones monitoring provides clear 4D understanding of contaminant distribution
- Discovered seawater intrusion at higher concentrations than previously recognized.
- Discovered that seawater intrusion moved inland against expectations
- Human activities generated vertical gradients much higher than expected.
- Remediation is finally progressing
- High resolution 4D monitoring is the basis for improved modeling of the groundwater basin
- The model is the basis for a long-term plan that includes maximizing the sustainable pumping capacity

Today's technology allows much improved characterization and monitoring of groundwater conditions but it is very rarely used. Better monitoring forms the basis of better management decisions – whether managing groundwater resources (recharge and production) or understanding, remediating, or avoiding contamination problems but again it is very rarely used. The success of 4D monitoring depends on: accurate and repeatable measurements representing groundwater properties changes, the ability to measure against a baseline to analyze variations and the willing to invest.

ERANET-SNOWMAN: Content, objectives, perspectives - Stefan VETTER

SNOWMAN stands for "Sustainable Management of soil and groundwater under the pressure of soil pollution and soil contamination" which is an ERANET project.

The objective of the ERA European Research Area initiative combines three related and complementary concepts:

- the creation of an "internal market" in research, an area of free movement of knowledge, researchers and technology, with the aim of increasing cooperation, stimulating competition and achieving a better allocation of resources;
- a restructuring of the European research fabric, in particular by improved coordination of national research activities and policies, which account for most of the research carried out and financed in Europe;
- the development of a European research policy which not only addresses the funding of research activities, but also takes account of all relevant aspects of other EU and national policies.

The objective of the ERA-NET scheme is to step up the cooperation and coordination of research activities carried out at national or regional level in the Member States and Associated States through the networking of research activities conducted at national or regional level, and the mutual opening of national and regional research programmes.

The scheme will contribute to making a reality of the European Research Area by improving the coherence and coordination across Europe of such research programmes. The scheme will also enable national systems to take on tasks collectively that they would not have been able to tackle independently.

Both networking and mutual opening require a progressive approach. The ERA-NET scheme therefore has a long-term perspective that must also allow for the different way that research is organised in different Member States and Associated States.

The outcome of SNOWMAN will be:

- a database of national research programmes,
- a vision paper outlining a coherent direction for a pan-European research policy on groundwater and soil pollution,
- prepare for the implementation of transnational research programmes.

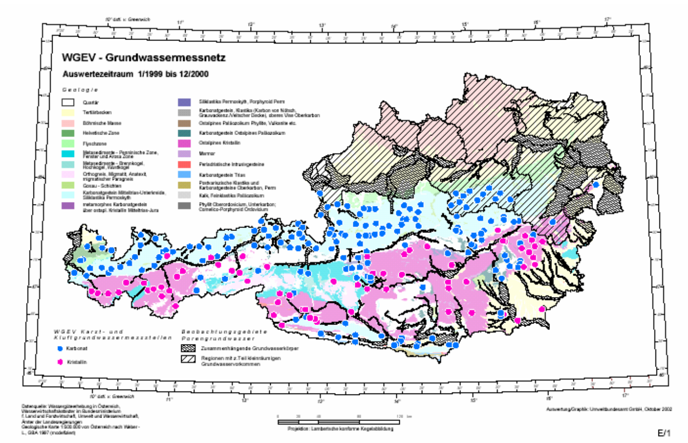
SESSION 3. GROUNDWATER MONITORING APPROACHES IN THE LIGHT OF THE WATER FRAMEWORK DIRECTIVE

Austria

Monitoring networks (general, introduction)

Monitoring of groundwater chemical status

The legal background of the Groundwater Quality Monitoring Network are the Federal Water Act, the Hydrography Act, the Ordinance for Water quality Monitoring and the Ordinance for Groundwater Threshold Levels. In general, the costs of analyses and data transfer are met by federal (2/3) and provincial (1/3) authorities. The costs for selection and establishment of sampling sites are totally met by federal authorities. The total costs per year are about 2.2 to 2.9 mill. Euro. The partners involved have to carry out an intensive Quality Assurance Programme which concentrates on standardised procedures for the laboratory and field work. The programme is based on a cyclic procedure of six years. An extended investigation period is carried out in the first year. In the remaining five years the monitoring programme depends on the result of the first years monitoring, but at least a minimum programme is ensured. The quality data are publicly available via internet.



Number of monitoring sites

About 2000 monitoring sites

Parameters

Block 1 - most important inorganic parameters: NO_3, NO_2, NH_4, P, B, Na, Ca, Mg,…

Block 2 – heavy metals and VHCs: As, Hg, Cd, Tetrachlorethylene,…

Block 3 – pesticides, PAHs: Triazine, Phenoxy alkane carbon acids,…

Frequency

4/year

Monitoring of groundwater quantitative status

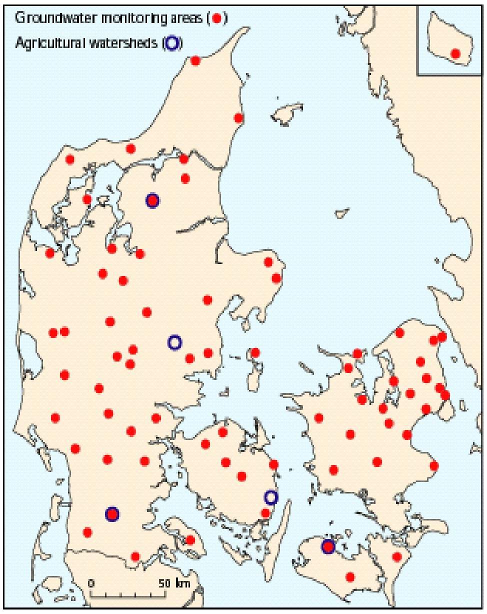
Adaptation to monitoring requirements by the WFD

Until 2006 the existing Groundwater Quality Monitoring Network will be adapted according to the new Groundwater bodies and the WFD as far as required. The analysis for adaptation needs to new WFD groundwater bodies is mainly based on the information of the Art. 5 Analyses.

Denmark

Monitoring networks (general, introduction)

Monitoring of groundwater chemical status



The National Groundwater Monitoring was established in 1987. It will be revised according to the WFD until 2006.

The groundwater monitoring programme is part of the national Monitoring and Assessment Programme for the Aquatic and Terrestrial Environment.

Number of monitoring sites

- Ca. 6084 wells/areas
  (70 groundwater monitoring areas (GRUMO), 5 agricultural watersheds, ca. 6 000 water supply wells, 6 redox wells, 3 vadose zone wells)

Parameters

Frequency

Monitoring of groundwater quantitative status

The Danish quantity monitoring programme focuses on water resource modelling. One modelling project concentrates on 12 main catchment areas. Another one is based on climate, precipitation, evaporation, piezometric network, water abstraction and water flow.

Number of monitoring sites

- GEUS piezometric network – 53 wells
- Counties network – unknown number
- Register of water abstraction
- Water resource modelling – 12 catchments

Parameters

Frequency

Adaptation to monitoring requirements by the WFD

Remarks

Finland

Monitoring networks (general, introduction)

Nationwide groundwater monitoring networks are run by:

- Finnish Environment Administration (since 1975): The monitoring stations are located in areas without human impact to get background values as a basis for threshold values. The areas represent a range of geological and climatic conditions.
- The Geological Survey of Finland (since 1969): The aim is to measure the impact of geological factors and anthropogenic activities on groundwater.
- The Finnish Road Administration (starts end of 2005): focusing on the impacts of road salting on groundwater.

Further monitoring networks are related to:

- Groundwater abstraction: Approximately 1500 water works monitor groundwater quality and quantity.
- Sand and gravel extraction: Based on licenses granted by municipal authorities about 1500 operators are obliged to monitor groundwater quantity and quality.
- Environmental permits:

Monitoring of groundwater chemical status

Number of monitoring sites

Finnish Environment Administration **The Geological Survey of Finland** **The Finnish Road Administration**

53	50 groundwater basins	200 (50 more frequently)

Frequency

4/year	1-4/year

Monitoring of groundwater quantitative status

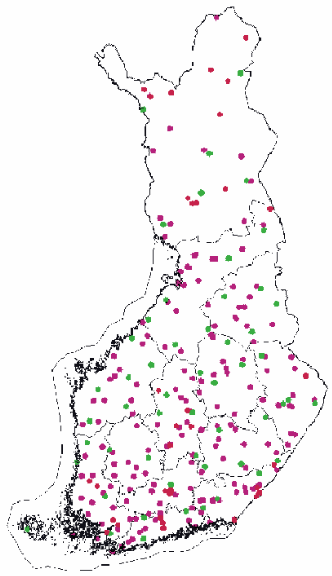
Number of monitoring sites

53	50 groundwater basins

Frequency

24/year	1-4/year

Adaptation to monitoring requirements by the WFD



The proposed surveillance monitoring network for groundwater will be based on the monitoring networks of the Finnish Environment Administration and The Geological Survey. About 180 sites in aquifers used for water abstraction will be added. The Finnish Environment Administration (POVET) will manage the database for groundwater quality and quantity data.

The existing monitoring networks will be used for groundwater monitoring programmes according to the WFD. Some additions will have to be made.

Due to the large number of groundwater bodies in Finland it is essential to group the groundwater bodies for monitoring purposes. The methodology is under development. To make use of all monitoring data more efficiently data management will have to be improved.

- Finnish Environment Administration
- Geological Survey of Finland

Remarks

France

Monitoring networks (general, introduction)

In 2003 the French Guidance document on Groundwater Monitoring was published as well as the national groundwater database was made available (ADES: http://ades.rnde.tm.fr).

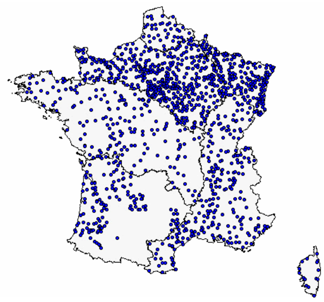
Monitoring of groundwater chemical status

Three types of existing networks have been streamlined.

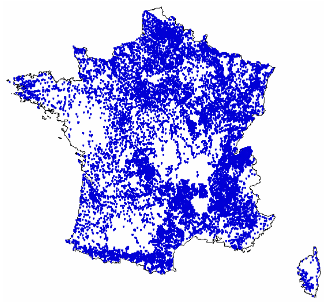
- Patrimonial Network: covers all groundwater bodies and is intended to be used as the WFD Surveillance Monitoring Network.
- Sanitary Network: is based on the Drinking Water Directive requirements and monitors untreated water.
- Impact Networks: are intended to represent the WFD Operational Monitoring Network. They are investigating on nitrate (Nitrate Directive), on pesticides and on point sources of pollution. The aim of the Nitrate Network is the delineation of vulnerable zones.

The networks design is based on the understanding of the hydrogeological system, the geological type of the groundwater body, on environmental objectives and on the type and level of pressures.

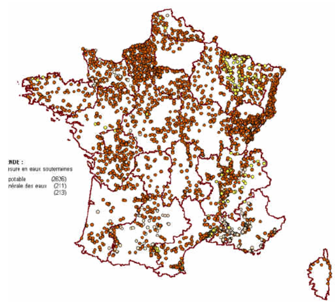
Surveillance Monitoring



Sanitary Network



Nitrate Network (Impact)



Number of monitoring sites

Surveillance Monitoring Network (Patrimonial) **Sanitary Network** **Nitrate Network (Impact)**

1240 sites (about 1500 in 2006) About 34 000 3052 (network is not representative)

Parameters

parameters are linked to the frequency parameters are different for GW and surface waters Impact, one programme for 4 years

In situ parameters: Temp., pH, el. conductivity, Eh

Major elements

Mineral pollutants

Organic pollutants, Pesticides, VOCs, Phenols

PAHs

Biological parameters: E. Coli, Enterococci, Alpha and beta activity

Frequency

1/year in confined, 2/year in unconfined bodies 4/year every 4 years	From 1/5 years to 12/year

Monitoring of groundwater quantitative status

Two monitoring networks exist:

- Patrimonial Network: covers all groundwater bodies and observes the general state of the water quantity.
- Impact Network: is divided into the
  - Network for Water Policy: its objective is to share information on water abstraction within different users on the local scale
  - Warning Networks: concentrates on flooding and lowest water level

Number of monitoring sites

Patrimonial Network	**Impact Network**
1073 (about 1500 in 2006)	

Parameters

Water table level

Spring or river flow

Frequency

1/month (confined), 1/week (unconfined)

Adaptation to monitoring requirements by the WFD

A working group was established for the period of 2002–2006. in order to improve the networks according to the requirements of the WFD.

Remarks

Besides the adaptation to WFD requirements main goals are the improvement of knowledge on site level, the usage of the data provided by the networks including data processing methods and the harmonisation of analytical methods especially for pesticides.

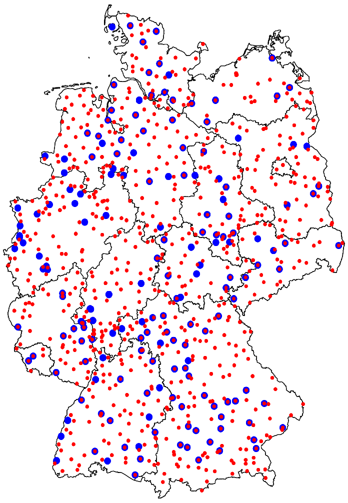
Germany

Monitoring networks (general, introduction)

In Germany the monitoring networks are in the responsibility of the Länder and each of the Länder runs its own monitoring network. Currently two transnational networks exist:

The EEA network and the EU Nitrate Network.

Monitoring of groundwater chemical status



□ EEA Network

• EU Nitrate Network

The EEA Network was designed in order to meet the data requests of the European Environment Agency.

The network is designed in order to give a representative overview of the state of groundwater in the whole country.

The sampling sites are evenly distributed and focus on the upper main aquifer level.

The EU Nitrate Network serves to fulfil the reporting obligation of the Nitrate Directive. The network reflects the worst case scenario and includes sampling sites in the upper main aquifer influenced by agricultural land use.

Number of monitoring sites

EEA Network	**EU Nitrate Network**
About 800 sites	About 180 sites

Parameters

General groundwater data:
Temperature, pH, electrical conductivity

Main components: O2, NH_4, NO_2, NO3, o-PO_4, Cl, SO4, B, DOC, K, Na, Ca, Mg

Metals

Aliphatic halogenated hydrocarbons

Pesticides

Characterisation of site and catchment area

Frequency

2 times per year	2 times per year

Monitoring of groundwater quantitative status

Adaptation to monitoring requirements by the WFD

The EEA monitoring network is a good starting point. It will be extended by the GWB approach in the near future. The number of sampling sites might increase or GWB will be grouped together.

Italy

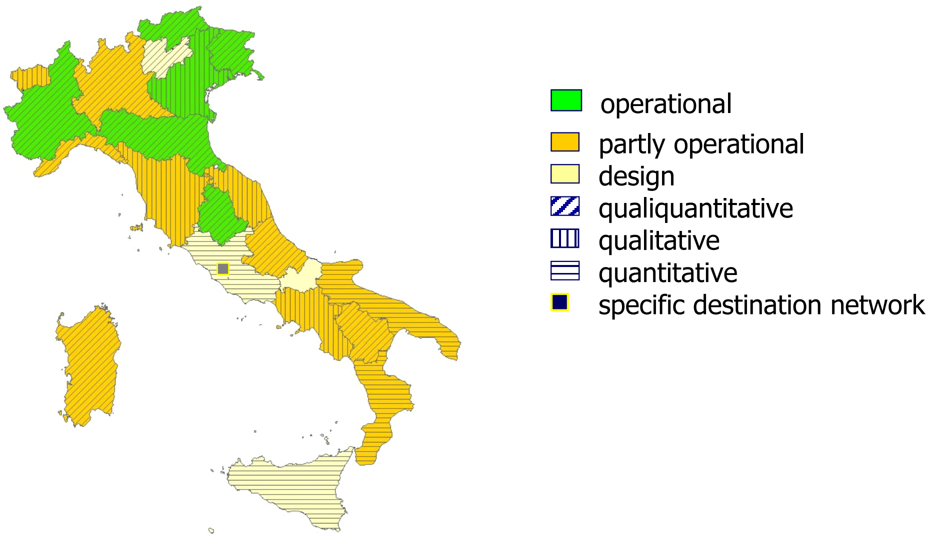
Monitoring networks (general, introduction)

Groundwater monitoring is based on the groundwater body characterisation. Available information and pressure analysis are basis for defining groundwater bodies at risk. The implementation of the groundwater monitoring network is the first step in monitoring. Based on these results groundwater is subject to a general classification concerning chemical status and vulnerability. The optimisation of the groundwater monitoring network is the second monitoring step and the groundwater environmental status classification is carried out based on chemical and quantitative status.

Existing monitoring networks cover different scales of areas. On the national level the monitoring programme focuses on national important groundwater resources, control of measurement programmes and on the functions of groundwater systems. The programme is a permanent one and will be operational in 2006.

On the regional level qualitative and quantitative monitoring as well as groundwater modelling are the main focuses. It's a permanent programme and already operational.

On the local level the monitoring programmes concentrate on specific occurrences and on risk warning. They are limited in time and operational when needed.



Monitoring of groundwater chemical status

Number of monitoring sites

Parameters

Frequency

Monitoring of groundwater quantitative status

Number of monitoring sites

Parameters

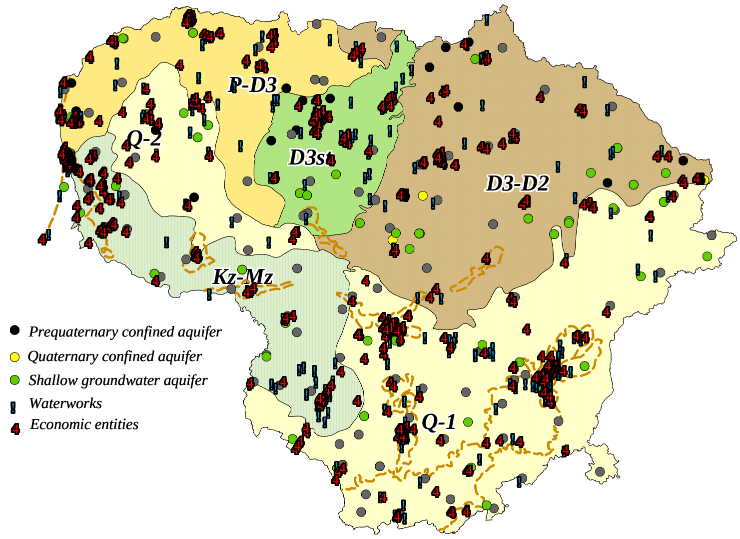
Frequency

Adaptation to monitoring requirements by the WFD

Remarks

Lithuania

Monitoring networks (general, introduction)



The National Monitoring represents the surveillance monitoring network. It is supplemented by the monitoring on the municipal level which can fill the gaps of information between the national level and the level of economic entities (water users, potential polluters). The latter is intended to represent the operational monitoring network.

Monitoring of groundwater chemical status

Number of monitoring sites

Surveillance monitoring	Operational monitoring
284	1461/217 (potential polluters / water users)

Parameters

Main ions, Specific compounds

Frequency

1-2/year, main ions

every 2–3years, specific compounds 2-4/year

every 2–3years

Monitoring of groundwater quantitative status

Number of monitoring sites

284	1461/217

Parameters

Water level	Water level, Water abstraction

Frequency

12-120/year water level 60-120/year water level users

4/year water abstraction

1-4/year potential polluters

Adaptation to monitoring requirements by the WFD

Remarks

Malta

Monitoring networks (general, introduction)

For Malta including Gozo four main groundwater bodies are defined. The Malta Mean Sea Level groundwater body is by far the largest yielding about 66 % of the total Maltese GW abstraction.

Monitoring of groundwater chemical status

Currently the groundwater network is run and samples are analysed by the Water Services Corporation. Sampling sites are not monitored in that period where wells are not in use.

Number of monitoring sites

92 stations

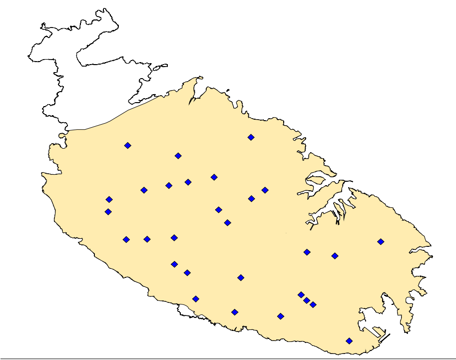
Parameters

Temperature, pH, turbidity, conductivity, hardness, TDS, Nitrate, Chloride

Frequency

12/year

Monitoring of groundwater quantitative status



The monitoring network which was established in the late 1940s is managed by the Water Services Corporation. In vertical boreholes level recorders are used for the monitoring. As the network is not representative it will be redefined based on a 4x4 km grid. Additionally it is proposed to deepen the boreholes to include the Transition Zone.

Number of monitoring sites

38 gauging boreholes

Parameters

Frequency

Adaptation to monitoring requirements by the WFD

The groundwater monitoring strategy will be amended in order to be in line with the requirements of the WFD.

A geometrically based network of abstraction sources has been proposed, where the quality of the extracted groundwater will be measured. Additionally the groundwater quality at the gauging stations will be measured, since this is expected to be more representative of the status of the groundwater body. The results obtained will be used to formulate the basic monitoring network.

Remarks

Netherlands

Monitoring networks (general, introduction)

In principle, the Netherlands consist of one single sandy aquifer. This aquifer was divided into 20 groundwater bodies based on the consideration of the hydrogeological situation, the status and the protection and finally water management aspects. Currently the various monitoring networks focus on 4 different vertical levels of groundwater: upper groundwater, shallow groundwater, intermediate groundwater and deep groundwater.

Monitoring of groundwater chemical status

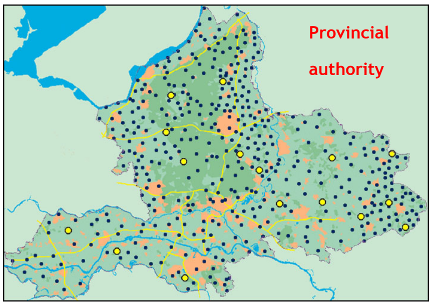
Number of monitoring sites

340 wells (national GW quality network) + 267 wells (provincial GW quality network), 246 water supply well fields

Parameters

Major components: Ca, Cl, HCO_3, K, Mg, Mn, Na, NH_4, NO^-, O_2, P, SO_4
Trace elements: Al, As, Ba, Cd, Cr, Cu, Ni, Pb, Sr, Zn

Monitoring of groundwater quantitative status - e.g. Gelderland



Monitoring programmes are handled on various scales. On the regional level monitoring concentrates on strategic water management purposes. The aim of the "backbone" network is to characterise the groundwater regime and serve as reference allowing links to local monitoring networks. The regional networks focus on operational water management. All quantity data is stored in one national database which is publicly accessible.

The following details are provided for the province of Gelderland as an example of monitoring on regional scale and beyond.

Number of monitoring sites

Gelderland – regional scale	Gelderland – local scale
447 monitoring points	
15 real time monitoring points	4 water boards + municipalities + water supply companies: e.g. ~ 800 sites (Apeldoorn, municipality); ~ 2500 (Vitens)

Frequency

24/year – manual registration
continuous – on-line registration

Adaptation to monitoring requirements by the WFD

The stratification in groundwater quality due to human activities should be represented by Compliance Checking Levels and an Early Warning Level in the uppermost groundwater level. The monitoring frequency required by the WFD is once a year. But based on an efficiency study the current frequency is less than that. The quantity monitoring programme in the province of

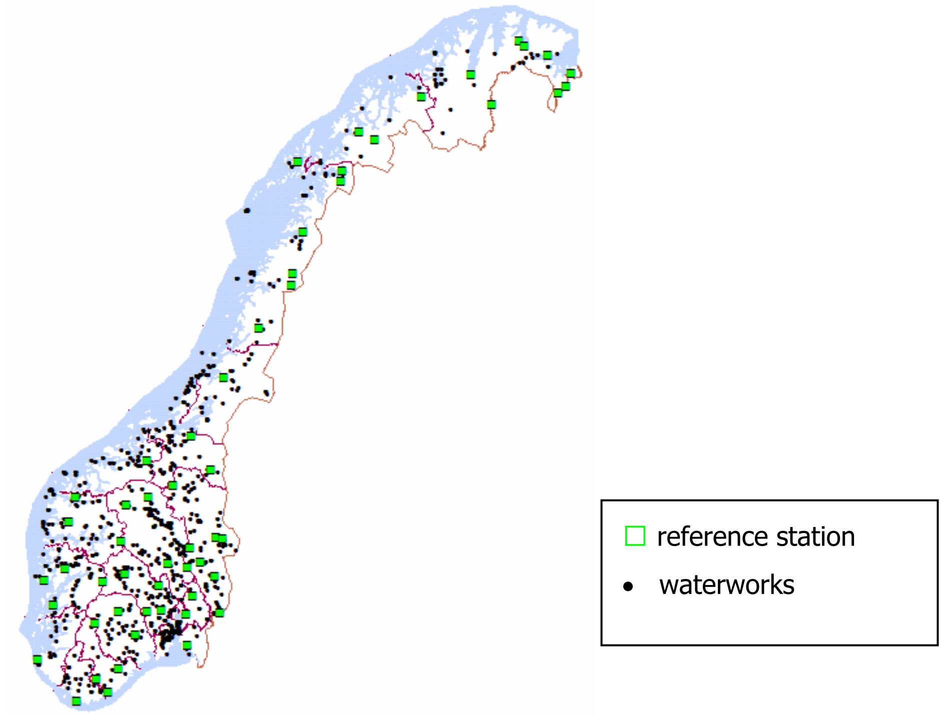
Gelderland can serve as an example for the evaluation of the monitoring network. On the regional scale the number of monitoring wells can be reduced and the quality of the network can be improved by introducing data loggers instead of manual registration. Finally the costs of the regional network will reduce.

Norway

Monitoring networks (general, introduction)

The National Network with reference stations has been existed since 1977. A national monitoring plan is under development. The total number of individual groundwater bodies is estimated to be about 8 000–10 000. Based on classification and grouping about 965 groundwater units will remain.

Monitoring of groundwater chemical status



Number of monitoring sites

Surveillance	Operational	Investigative
55 reference stations	1500 waterworks	

Parameters

Frequency

Monitoring of groundwater quantitative status

Number of monitoring sites

Parameters

Frequency

Adaptation to monitoring requirements by the WFD

Due to the large number of groundwater bodies a grouping of bodies is necessary. Especially in the northern part of the country few monitoring stations will represent a large number of groundwater bodies. The existing monitoring stations will be used for the surveillance monitoring. Monitoring sites run by water works will complete the network.

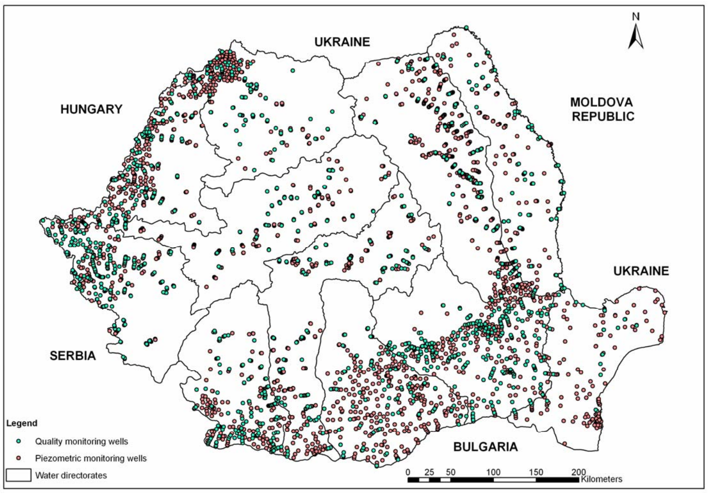
Remarks

Romania

Monitoring networks (general, introduction)

In Romania two main monitoring programmes exist. The National Hydrogeological Network and Local Monitoring Networks.

- National Hydrogeological Network: The objectives are to improve the knowledge of the structure and the aquifer potential of phreatic and deep aquifers and to gain more information on the groundwater level regime and on the physical and chemical characteristics of the groundwater. The responsibility for the programme lies within the Romanian Waters National Administration where the data are stored in the hydrogeological database.
- Local Monitoring Networks: The objectives are to improve the information both on the development of the groundwater quality and on the groundwater quantity on local scale. The level of monitoring concentrates on certain pollutant sources or/and on important groundwater catchment areas.



Monitoring of groundwater chemical status

Number of monitoring sites

National Hydrogeological Network **Local Monitoring Networks**

Ca. 1200 phreatic aquifers, ca. 500 deep aquifers

Parameters

NO_3, NO_2, NH_4 etc. (22 at all)

Frequency

2/year phreatic aquifers, every 2–3 years deep aquifers

Monitoring of groundwater quantitative status

Number of monitoring sites

Ca. 4000 phreatic aquifers, ca. 500 deep aquifers

Parameters

Water level, Water temperature

Frequency

120/year phreatic aquifers, 12/year deep aquifers

Spain

Research programme on land use and water consumption

The Research programme concentrated on one groundwater body, El Guadiana, with an area of 280 000 ha. Main goals are to keep the agricultural activity as well as to maintain the environmental resources. The latter should be achieved by reducing the water consumption and reducing the use of fertilisers and pesticides.

Each farmer in the area could participate and decide whether to reduce the water abstractions or the use of fertilisers and pesticides. An intensive control programme reviewed the water abstraction, the kind of the arable crops and the use of fertilizers. The results of the programme were:

- 300 Mio m³ less water abstraction per year
- less use of fertilisers
- replacement of very water intensive crops by less water intensive.

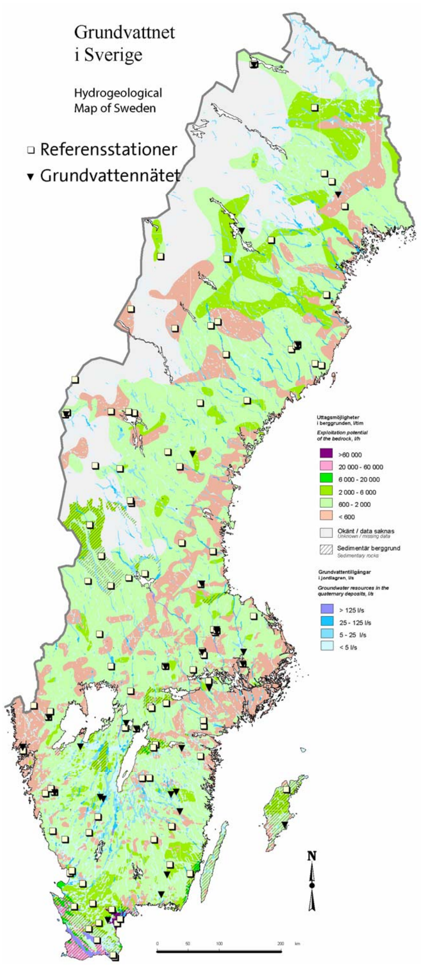
Additionally, information and training programmes for farmers were initiated. Since the start of the programme in 1993 the irrigation systems have been modernized and as a consequence permits for water abstraction for irrigation purposes are granted again.

Sweden

Monitoring networks (general, introduction)

In Sweden three reference systems for groundwater monitoring exist.

- Reference stations for groundwater
- Groundwater network of the Geological Survey
- Integrated Monitoring



Monitoring of groundwater chemical status

Number of monitoring sites

Reference Stations **Groundwater**
Network **Integrated Monitoring**

118 34 24

Parameters

Frequency

Monitoring of groundwater quantitative status

The Groundwater Network includes monitoring of the groundwater level.

Number of monitoring sites

350 sites

Parameters

Frequency

Adaptation to monitoring requirements by the WFD

About 50 groundwater bodies are covered by the current monitoring network. Grouping of bodies in the northern part of Sweden will make it possible that stations represent a large number of groundwater bodies. At the moment the network is not designed to validate the impact assessment. Neither can the network serve as operational monitoring network. Background values will serve as basis for threshold values.

Remarks

Due to different criteria the grouping of groundwater bodies will be carried out. The surveillance monitoring will include municipal wells.

United Kingdom

Monitoring networks (general, introduction)

Monitoring programmes should be based on the conceptual understanding of groundwater bodies at regional and local scale. The monitoring should be proportional to the difficulties in the assessments. There is a need to consider local factors. The monitoring should be representative and due to the diverse range of aquifers they require different approaches for both chemical and quantitative monitoring.

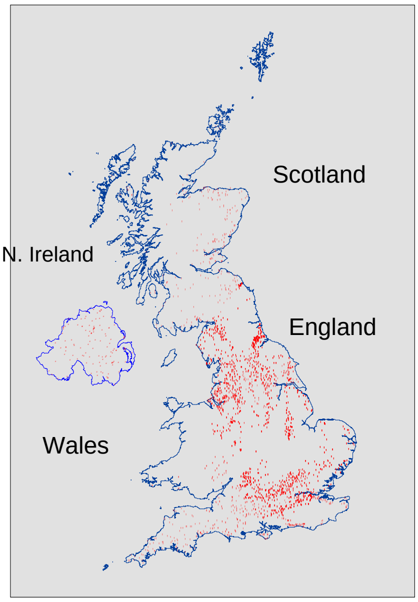
The design of a monitoring network should be guided by the relevant objectives, the characteristics of the body, the level of understanding, the range and extend of pressures and the confidence of the risk assessment.

Monitoring of groundwater chemical status

The groundwater Quality Monitoring Network is focussed on water supply aquifers but is being modified to take account of the WFD.

Number of monitoring sites

About 4000 are planned.



Planned number of sites

Scotland: ~ 400 sites
England & Wales: ~ 3500 sites
N. Ireland: ~120

Parameters

Core parameters: WFD mandatory parameters, indicators and parameters for Quality Assurance

Selective parameters: parameters representative of land use/pressures, refined by output from risk assessment, local knowledge and regular review.

Surveillance monitoring will comprise core + occasional selective parameters for validation of risk assessments

Operational monitoring will consist of core + selective at sites in groundwater bodies "at risk"; for diffuse/widespread impacts at all monitoring sites; for point sources targeted monitoring.

Drinking Water Protected Areas as for surveillance and operational monitoring but focus on parameters that are driving any treatment of the water

Frequency

4/year – 1/6 years (surveillance)

1-4/year (operational)

Monitoring of groundwater quantitative status

Parameters

Water levels, Spring and surface waters flow

Frequency

12-4/year

Adaptation to monitoring requirements by the WFD