UN/ECE Task Force on Monitoring & Assessment

under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 1992)

Work Programme 1996-1999

# Guidelines on Monitoring and Assessment of Transboundary Groundwaters

ISBN 9036953154

Lelystad, March 2000

# Colofon

**Lay-out:**
Thieme Deventer

**Cover design:**
Panthera BNO
G.E. Arnold (RIZA)

**Cover pictures:**
KNMI
NITG-TNO
Leon Lamers (KUN)
Srécko Božičević

**Printed by:**
Thieme Deventer

**Editorial:**
Editorial assistance was given by the UN/ECE Secretariat, members of the Core Group on Groundwater and Ilonka Záborszky



Additional copies of these Guidelines or the 4 volumes can be ordered from RIZA, Institute for Inland Water Management and Waste Water Treatment, UN/ECE Task Force on Monitoring and Assessment project-secretariat, P.O. Box 17, 8200 AA Lelystad, Netherlands. Fax: +31 (0)320 247642

| | |
|---|---|
| - Volume 1: Inventory of transboundary groundwaters | (ISBN 9036952743) |
| - Volume 2: Problem-oriented approach and the use of indicators | (ISBN 9036952751) |
| - Volume 3: Application of models | (ISBN 903695276X) |
| - Volume 4: State of the art on monitoring and assessment of groundwaters | (ISBN 9036952778) |

# Preface

These Guidelines on monitoring and assessment of transboundary groundwaters were finalised by the former ECE Task Force on Monitoring and Assessment with the Netherlands as lead country (now known as the Working Group on Monitoring and Assessment) and adopted at its seventh meeting in Bled (Slovenia) as part of the 1996-1999 work plan under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki,1992). These Guidelines were endorsed by the Parties to the Convention at their second meeting (The Hague, Netherlands, 23-25 March 2000).

To implement the Task Force's programme on transboundary groundwater monitoring and assessment, a Core Group, led by G.E. Arnold (Institute for Inland Water Management and Waste Water Treatment (RIZA), Netherlands) was established.

The Guidelines were drawn up by J.J. Ottens (Institute for Inland Water Management and Waste Water Treatment (RIZA), Netherlands), G.E. Arnold (Institute for Inland Water Management and Waste Water Treatment (RIZA), Netherlands), Zs. Buzás (Ministry of Transport, Communication and Water Management, Hungary), J. Chilton (British Geological Survey/United Kingdom-Collaborating Centre of the World Health Organisation, R. Enderlein (ECE secretariat), E. Havas-Szilágyi (Ministry of Transport, Communication and Water Management, Hungary), P. Rončak (Slovak Hydrometeorological Institute, Slovakia), O. Tarasova (Ministry for Environmental Protection and Nuclear Safety, Ukraine), J.G. Timmerman (Institute for Inland Water Management and Waste Water Treatment (RIZA), Netherlands), B. Toussaint (Hessian Agency for the Environment, Germany) and M. Varela (Ministry of Environment, Spain).

The Guidelines draw on studies of current monitoring and assessment practices and on the results of sub-projects, led by various core group members, which have been compiled into four background reports:

- Inventory of transboundary groundwaters (sub-project leader Zs. Buzás);
- Problem-oriented approach and the use of indicators (sub-project leader J.J. Ottens);
- Application of models (sub-project leader P. Rončak);
- State of the art on monitoring and assessment of groundwaters (sub-project leader G.E. Arnold).

These Guidelines are intended to be tested in a series of pilot projects.

# Contents

# 1. Introduction

## 1.1 Background

The Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 1992) include important provisions on the monitoring and assessment of transboundary waters, the assessment of the effectiveness of measures taken to prevent, control and reduce transboundary impact, and the exchange of information on water and effluent monitoring. Other relevant aspects deal with the harmonisation of rules for setting up and operating monitoring programmes, which includes measurement systems and devices, analytical techniques, data processing and evaluation techniques. Further needs for monitoring arise, because the Convention aims to protect ecosystems, which may be closely connected with groundwaters and the protection of sources of drinking-water supply.

Monitoring and assessment are also part of the 1999 Protocol on Water and Health to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes. This Protocol contains provisions regarding the establishment of joint or coordinated systems for surveillance and early-warning systems to identify outbreaks or incidents of water-related diseases or significant threats of such outbreaks or incidents (including those resulting from water pollution or extreme weather). It also foresees the development of integrated information systems and databases, the exchange of information and the sharing of technical and legal knowledge and experience.

## 1.2 About these Guidelines

These Guidelines refer to transboundary groundwaters. They form part of a series of Guidelines for the monitoring and assessment of rivers, groundwaters, lakes and estuaries.

The character of these Guidelines is strategic rather than technical[1]. They are intended to assist ECE governments and joint bodies in developing harmonised rules for the setting up and operation of systems for transboundary groundwater monitoring and assessment. The target group comprises decision makers and planners in ministries, organisations and institutions responsible for environmental, water or hydrogeological issues and all those who are also responsible for managing transboundary groundwaters. The Guidelines also aim to provide advice to those who are responsible for or involved in the development of sustainable water management schemes.

**Note:**
[1] For technical details, the background reports prepared by the Core Group Groundwater, and international literature and handbooks on operational practices of monitoring and assessment (see further reading) should be consulted.

The Guidelines are intended to be concise and realistic; they are not intended to be prescriptive. They provide an approach for the identification of problems and guidance to meet information needs. The Guidelines deal mostly with monitoring and assessment needs that arise from the Convention. As far as possible, monitoring and assessment needs that arise from the Protocol on Water and Health are also considered. However, a full consideration of the latter will be possible only when more experience has been gathered on issues linked to water and human health.

**Definitions used in these Guidelines:**

- *monitoring*

Monitoring is the process of repetitive observing, for defined purposes of one or more elements of the environment according to pre-arranged schedules in space and time and using comparable methodologies for environmental sensing and data collection. It provides information concerning the present state and past trends in environmental behaviour.

- *assessment*

The evaluation of the hydrological, chemical and/or micro-biological state of groundwaters in relation to the background conditions, human effects, and the actual or intended uses, which may adversely affect human health or the environment.

- *survey*

A finite duration, intensive programme to measure, evaluate and report the state of the groundwater system for a specific purpose.

The general approach of the monitoring cycle (figure 1.1), as presented in the Guidelines on monitoring and assessment of transboundary rivers[2], will be followed in these Guidelines as well.

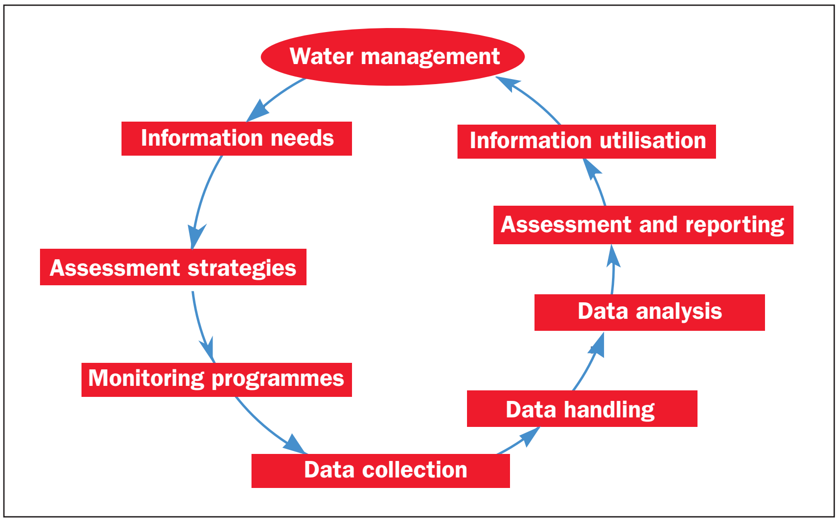
The monitoring cycle offers a readers' guide for these Guidelines and an valuable approach when drawing up programmes for the monitoring and assessment of transboundary groundwaters.

An exchange of information (and joint assessment/modelling) between riparian parties is meaningful only if the data are comparable. This can be achieved when all components of groundwater monitoring activities on both sides of the border use similar principles or adopt an approach such as the monitoring cycle presented below.

**Note:**

[2] In these Guidelines, as much use as possible has been made of the experience with the implementation of the Guidelines on Monitoring and Assessment of Transboundary Rivers in pilot projects and their updated version.

Figure 1.1
Monitoring cycle




## 1.3 Specific aspects of groundwater monitoring

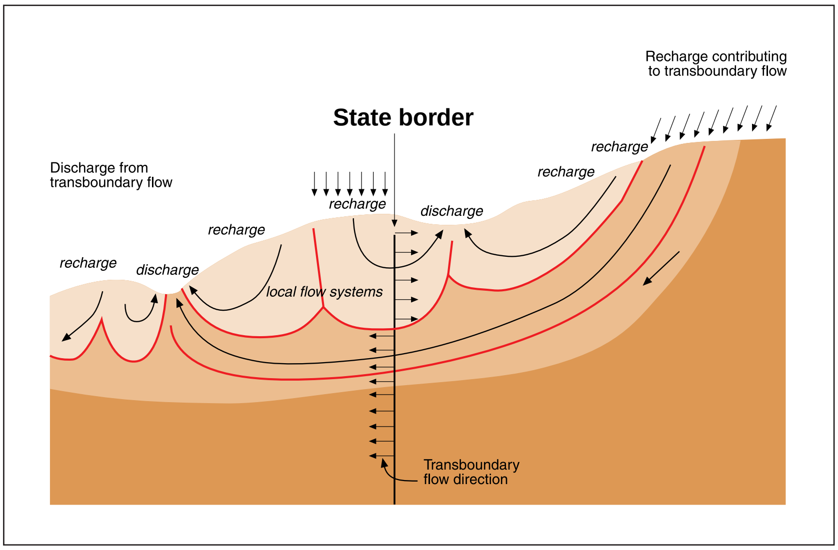
When implementing transboundary monitoring and assessment programmes, it is essential to present the hydrogeology in conceptual models and/or in graphic schemes. This should comprise a characterisation of the transboundary aquifer (geometry), the flow conditions, including recharge and discharge areas, and the evolution of the groundwater quality.

The characterisation and description of relevant transboundary aquifer systems are a prerequisite for the monitoring and assessment of transboundary waters in general and of transboundary groundwaters in particular. Features that influence the way groundwaters are monitored and assessed and that distinguish them from surface waters are:

- slow movement (long residence times) of groundwaters increases the potential for their quality to be modified by the interaction between the water and the surrounding aquifer material. Also, once groundwaters are polluted, they may remain so for many years and it is difficult to intervene effectively in this process;
- the interaction between aquifer material and water causes the natural hydrogeochemistry to evolve as the infiltrating groundwater moves down. To be able to detect and quantify the superimposed impacts of human activities, the "baseline" quality of groundwater with its spatial and depth variations must be assessed;
- groundwater flow can be intergranular and/or through fractures. Groundwater flow will be much more rapid but variable and difficult to estimate through intensely fractured rocks. Intergranular groundwater flow increases the potential for interaction between aquifer material and groundwater;
- recharge and discharge areas need to be determined and activities that might affect the quantity or quality of groundwater need to be understood. Knowledge of the groundwater flow system means in particular the locations of groundwater recharge and discharge zones, and the way groundwater flows through aquifers from zone to zone (figure 1.2). Activities in the recharge areas on one side of the border might adversely affect the quality of quantity of groundwater on the

other side (see figure 1.3). To determine recharge and discharge conditions in some areas, the interaction between surface and groundwaters need to be understood;

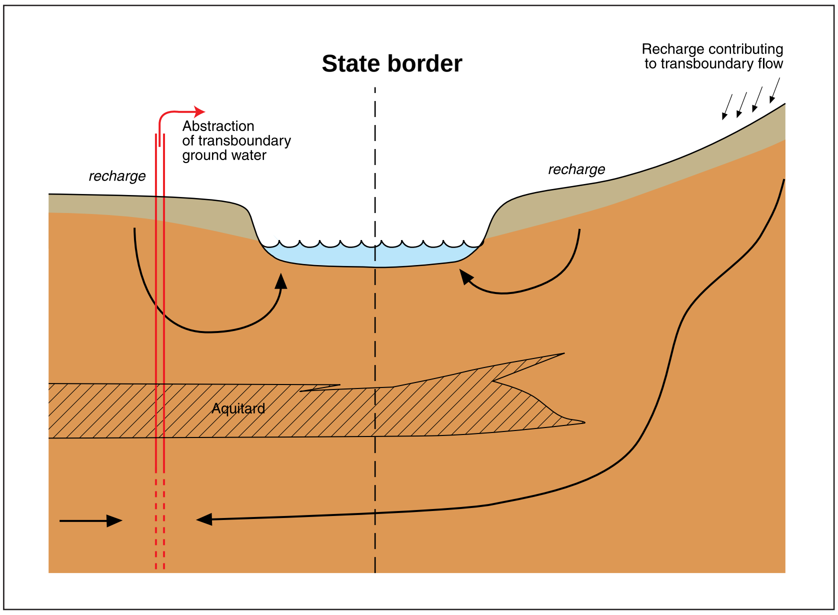
**Figure 1.2**
Transboundary groundwater flow systems




- background conditions change over time and these spatial, temporal and depth variations have to be determined before it is possible to detect any impact of human activity;
- multi-layered systems. When there is more than one aquifer separated by aquitards of less permeable material, the possible pathways or connections between them need to be understood.

So, to characterise groundwater occurrence, information on geology, geophysics and hydrogeology in the transboundary area is needed. Also, the dynamics of the groundwater flow system, such as seasonal or longer-term responses and variations and changes in flow rate or direction caused by human activities, particularly groundwater abstraction, must be understood. Groundwater quality is infinitely variable in space and time, but on different spatial and temporal scales to surface waters, and this variability is made more complex by the interactions referred to above.

**Figure 1.3**
Effect of a transboundary aquitard on groundwater flow.



### 1.4 Integrated approach

The harmonisation of surface water and groundwater monitoring networks must be envisaged, in order to manage and protect transboundary water resources effectively. Basic/reference and compliance monitoring should be linked in the most appropriate way.

Groundwater should be assessed in an integrated manner, based on criteria that cover water quality and quantity for different human uses as well as requirements of ecosystems. Relevant issues and the cause-effect relations between issues and uses have to be understood.
The specification of information needs, which should lead to monitoring objectives, might be very similar for groundwater and surface water monitoring. When the information needs have been determined, the type of monitoring and assessment strategies can be chosen (groundwater/ surface water; water quality/water quantity, monitoring/surveys, etc.).

In developing monitoring programmes, the following aspects which allow for further integration, should be taken into consideration:

- *integration of data gathering and storage*

Monitoring of groundwater and surface water and of water quality and quantity is often performed by different authorities and the resulting information should be assessed in combination (and modelled jointly).

- *groundwater - surface water interaction*

Surface water and groundwater monitoring and assessment could be integrated further, especially when recharge is through seepage of surface waters or in the case of vulnerable ecosystems.

- *quantity - quality*

There are often clear relationships and interactions between quantity and quality of groundwater. Measurements of groundwater quantity, such as levels and discharges, are used to characterise the groundwater flow system, both in its natural state and under the superimposed influence of human activities, especially groundwater exploitation. Such exploitation may also have impact on quality, for example intrusion of saline water into a heavily exploited aquifer, and these impacts (and any measures to alleviate them) can therefore be assessed most effectively by observing groundwater quantity and quality together.

- *other sectors*

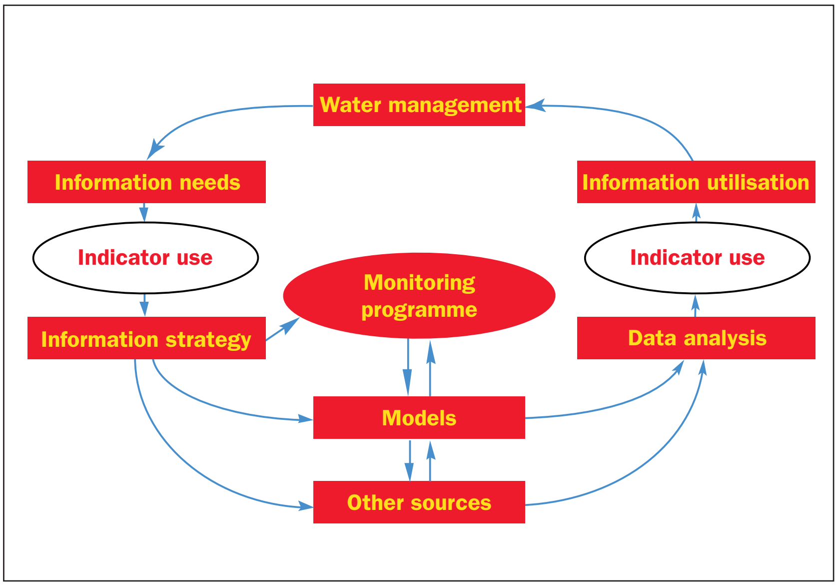
Integrated water management comprises water quality and quantity aspects. It focuses on the functions and uses of the water and relates to ecology and physical planning. Assessment linked to this purpose involves integrated monitoring that provides information on a wide variety of subjects/aspects (uses, functions, hydrogeology, flow regimes, progress towards policy goals). This integrated approach will be facilitated by the use of indicators.

Analysing, planning and managing water resources in a comprehensive transboundary way involve many disciplines, factors and actors. For transboundary aquifers and river basins with their dynamics and interrelated flow systems, this approach is and will become increasingly important, since water is one of the key factors for sustainable development in Europe. Sustainable management of water resources should link social and economic development with the protection of natural ecosystems. Effective management links land and water uses across the whole of a river basin or groundwater aquifer. This also forms one of the starting points of the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 1992).

### 1.5 Information sources

Information on transboundary groundwaters can be obtained from primary sources, such as monitoring programmes, computations and predictions with models, and other sources (e.g. databases) containing statistical or administrative information (figure 1.4).

**Figure 1.4**
Information flow




Not all information will ultimately be collected by monitoring networks. When specifying information needs (in which process indicators can be very helpful) the specific collection method will be made clear and documented in the information strategy.

Using these information sources, in combination with each other, offers optimal conditions for cost-effectiveness. In a transboundary context it should be emphasised that no combination or integration of these sources is possible, if the harmonisation of data(bases) has not taken place or been foreseen prior to the actual assessment or joint modelling activities.

Basic, general information is available in the European environmental database (CORINE, EIONET) in international atlases, and in a range of map series on geology, water balances, vegetation, soils and land use, and in numerous data from remote sensing (see also "Further reading"). Scales vary from 1:1,000,000 to 1: 20,000,000. In addition, other international and national series of maps and atlases can be used. The sub-project "Inventory of transboundary groundwaters" also includes informative maps for the ECE region as does the EEA "Monograph on groundwater quality and quantity in Europe".

However, some of these maps and databases provide information on a scale that is too broad for a particular transboundary problem. For background information like geology, hydrogeology and land use they may provide valuable background, but they cannot replace local or regional information sources.

In general, four different types of independent information sources can be distinguished: maps (areal information), records (point sources as e.g well logs), reports (comprehensive data) and miscellaneous (e.g. personal communication, field surveys and research of NGOs).

In recent years many inventories and studies related to the subject of monitoring and assessment of groundwater resources have been carried out. The main sources consulted for information about monitoring and assessment practices are listed below:

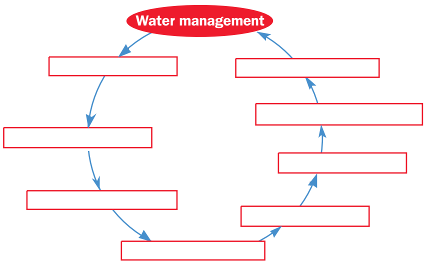
- the river programme of the UN/ECE study of Transboundary Watercourses and Lakes is the precursor of the present programme of transboundary groundwaters. In particular volume 5 "State of the Art on Monitoring and Assessment of Rivers" (Niederländer et al., 1996) gives an overview of the principles of monitoring network design. This report also contains information about the chemical analysis and treatment of samples according to international standards;
- the European Network of Fresh Water Research Organisations (EurAqua) dedicated its second technical review to "Optimizing Freshwater Data Monitoring Networks including Links with Modelling" (EurAqua, 1995). This technical review contains reports of 14 European countries about their monitoring networks, for both surface water and groundwater. The report gives an impression of the dimensions of the existing national networks (including their organisational structure), the underlying objectives and statements about the necessity of future research for monitoring;
- the report "Groundwater Monitoring in Europe" (Koreimann et al., 1996) is the result of an inventory conducted by the European Topic Centre on Inland Waters (ETC/IW) of the European Environmental Agency (EEA). It is specifically focused on groundwater monitoring, quality as well as quantity. It is an inventory of existing networks of the EEA member states (EU countries, Norway and Iceland) and contains much technical detail. Based on the previous inventory of Groundwater Monitoring in Europe, ETC/IW has made a proposal for the design of a groundwater monitoring network in the EEA countries that is presented in the report "European Freshwater Monitoring Network Design" (Nixon, 1996). The proposed design procedure is based on an overview and evaluation of the current monitoring practices;
- two conferences "Monitoring Tailor Made I" and "Monitoring Tailor Made II" took place in 1994 and 1996 respectively. The proceedings of both conferences, Adriaanse et al. (1994) and Ottens et al. (1997) respectively contain new developments in monitoring and assessment, both in surface water and in groundwater;
- the 'proposal for a Council directive establishing a framework for Community action in the field of water policy', hereinafter referred to as "Water Framework Directive" establishes in one of its annexes Guidelines for groundwater monitoring network design, with specific references to transboundary aquifers. Operational monitoring activities, to be undertaken in the periods between surveillance monitoring programmes, are detailed in the text.

### 1.6 Revision of the Guidelines

The Meeting of the Parties to the Convention should evaluate progress made in the implementation of the Guidelines and, if need be, make arrangements to revise them.

To this end, these Guidelines will be reviewed on the basis of experiences gained with their implementation in pilot projects in some transboundary aquifers in the ECE region. Also, the preliminary results of pilot projects for the implementation of the River Guidelines will help considerably in the set-up and review of the implementation of the Groundwater Guidelines. In some cases, it might be possible to incorporate these Guidelines in the river pilot projects to reach truly integrated transboundary water monitoring and assessment which can be based on the joint bodies already in place.

# 2. Identification of groundwater management issues

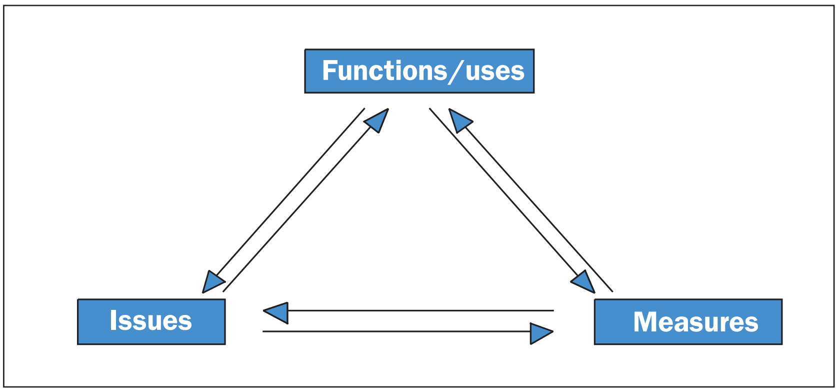



Functions, pressures and targets of transboundary aquifers should be identified and priorities should be set.

### 2.1 Functions, pressures and targets

Groundwater management is part of integrated water resources management and protection. The core elements in (ground)water management are the functions and uses of the groundwater bodies (aquifers), the problems and pressures (threats) and the impact of measures on the overall functioning of the water body (figure 2.1). Monitoring that satisfies the information needs should cover these core elements. It should also consider how information is used in the decision-making process. Measures can include investigations of the problems and threats, risk analyses, remediation, existing monitoring programmes, control of polluting activities or excessive withdrawal.

**Figure 2.1**
Core elements of water management




Examples of core elements of **groundwater** management:

- *functions/uses*: conservation of wetlands (function), drinking water or irrigation (use);
- *problems*: declining groundwater table, pollution with hazardous substances;
- *measures*: reduction in groundwater withdrawal and/or artificial recharge (infiltration), control or remediation of pollution.

When establishing transboundary groundwater monitoring strategies, the following need to be identified and jointly agreed:

a) the transboundary aquifer and relations to surface water and associated ecosystems;
b) specific human uses of transboundary groundwaters;

c) ecological function of transboundary groundwater resources;
d) pressures which have an impact on the above-mentioned human uses and on the functioning of ecosystems that are dependent on groundwater (table 2.1);
e) quantified, or otherwise clearly defined, management targets which should enable the establishment of restrictions and which can be implemented within a specified time period.

This joint approach allows for the progress achieved by riparian countries to be compared, taking into account the often country- or region-specific context.

**Table 2.1**
Functions/uses and problems of groundwater systems

| Problems | Functions/Uses | | | |
|---|---|---|---|---|
| | drinking water | industrial water | agricultural | ecosystems/ nature |
| Acidification | * | * | * | * |
| Excess nutrients | * | | | * |
| Pollution with hazardous substances | * | * | * | * |
| Salinization | * | * | * | * |
| Declining groundwater tables | * | * | * | * |

Some functions can also have an adverse impact on other functions, and problems are not necessarily confined to groundwater systems. Clearly, the list of table 2.1 is not exhaustive and can be tailored (or be made more specific) to specific transboundary regions.

The specification of the human uses and the ecological functioning, the identification of pressures and problems, and the determination of targets should include both quality and quantity aspects. Human uses of groundwater can be consumptive or non-consumptive. An example of the first use is as a resource for drinking water, industry or irrigation. Non-consumptive use can be water table control for construction management and for agricultural purposes, or maintaining a freshwater wedge in coastal zones as a barrier against salt water intrusion.

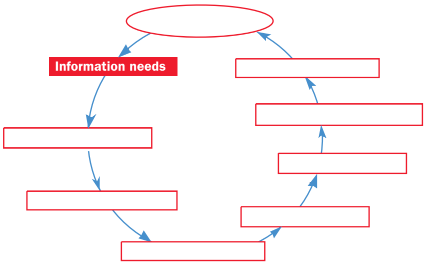
The problems mentioned above are generally on the political agenda. Often specific policies are being drafted to deal with them, including research, surveys, monitoring and measures.

## 2.2 Priority setting

The issues and targets of groundwater management should be prioritised - taking into account the Convention and other relevant agreements - at different levels/scales (i.e. ECE regionwide, regional and local transboundary level, aquifer level). These prioritised issues determine to a large extent the information needs, that will form the basis for monitoring. In the following chapter, methodologies and ways of prioritising issues and targets will be discussed.

Targets accounting for the Convention's objectives can be set for each transboundary aquifer. As with the surface water management, a management unit can be determined for groundwaters. This will be based on conceptual mathematical models and data sets on elements of the water cycle, topographical, pedological and geological information, land use and administrative/legal units. Supply and demand patterns linked to uses should also be included in this characterisation. Targets per unit can be laid down in a strategic action plan which is coordinated by a joint body, set up by the riparian parties, which should also be responsible for priority setting.

# 3. Information needs




Proper identification of information needs requires that the concerns and decision-making processes of information users are defined in advance.

## 3.1 Specification of information needs and monitoring

The information required for the monitoring and assessment of transboundary groundwaters should be structured on the basis of issues and on the stage the issue has reached in the policy life cycle (figure 3.1). In the first stage, the question is whether there is a true environmental problem. When admission of the issue grows, a policy will be formulated. In this second stage, the focus of the public on the problem-solving capacity of decision makers is high, which is reflected by the political weight. In the third stage, the policy is being implemented and measures are taken to solve the problem. The fourth stage is focused on the nearly solved environmental problem. The first and the second stages require rough data and research to recognise the problem and causal coherence.

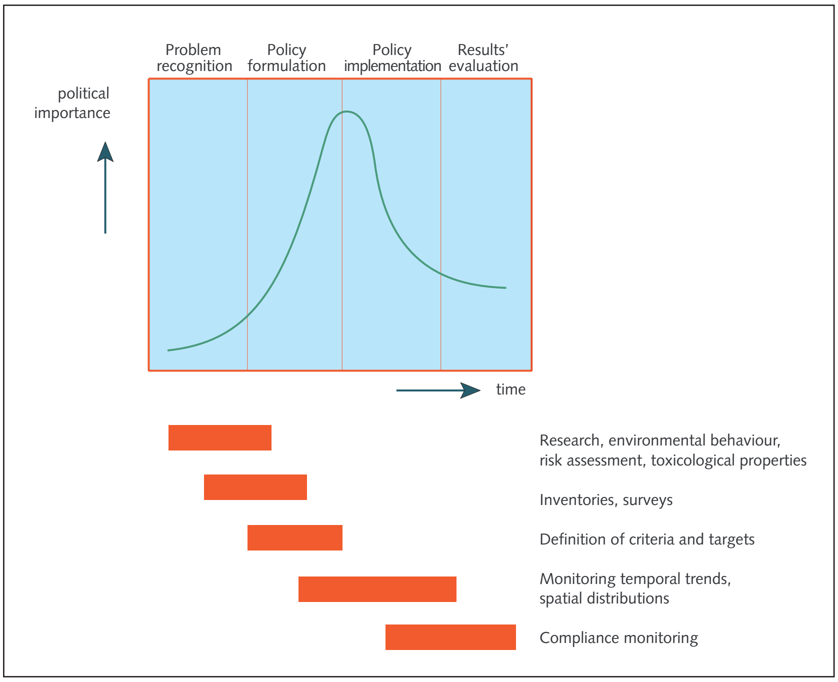



**Figure 3.1**
Policy life cycle (after Winsemius, 1986 and Cofino, 1995)

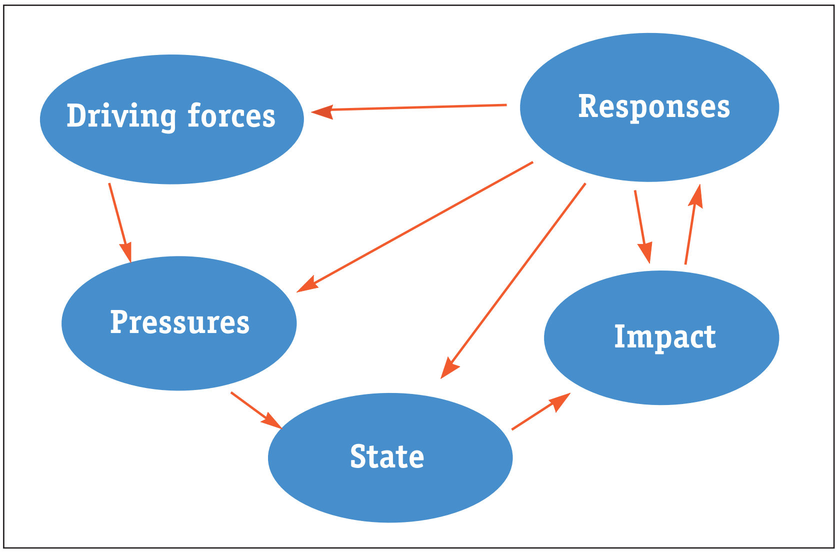
The third and fourth stages require more precise data to select most effective measures and to quantify their effect. In all stages some type of monitoring is required. In the first and second stages, this will be more focused on surveys, whereas in the later stages the focus shifts to compliance monitoring and to a lesser extent to surveillance, remediation and restoration monitoring.

The proper identification of information needs requires that the concerns and decision-making processes of information users are defined in advance. From the structured specification of information needs monitoring objectives will evolve. This approach also includes the use of a function/issue table to clarify the impact of pressures on functions.

Specification of information needs includes:
- The establishment of assessment criteria. These criteria should lead to the development of an assessment strategy. The assessment criteria, defined for each use, determine the choice of assessment methodology (e.g. considerations for the setting of standards, or criteria for the choice of alarm conditions for early-warning);
- the quantification of information needs to assess the effectiveness of the information product, making clear what degree of detail is relevant for decision-making. This will affect frequencies, accuracy of measurement etc.;
- the specification of requirements for reporting and presentation of the information product (e.g. visualisation, degree of aggregation, indices).

When focusing on a specific water management issue, information is needed on the origin and the effects of the problem and the measures taken. Causality chains, like the DPSIR framework (figure 3.2), distinguish between the different aspects of an issue. Information needs can be specified for one or more of these aspects.

**Figure 3.2**
The DPSIR framework




Driving forces describe the human activities, like the intensification of farming and chemical industry production, that are important sources of problems and threats. The pressures describe the stress that the problems put on the functions/uses of the aquifer. The state of the aquifer is described in terms of concentrations or hydraulic characteristics (groundwater level). The impact describes the loss of function/use like potability or use for drinking water supply). Responses describe the policies that have been or are being developed to deal with the problem.

The approaches summarised above can help in the specification of information needs. These are complementary, since part of one approach, such as issues, are also part of another approach, as in the function-issue table and policy life cycle. Pressures are part of DPSIR and part of "issue" (function/issue table) and part of the first stage of the policy life cycle.

**Steps in the specification of information needs:**

1. Identify functions or uses (such as drinking water supply) and issues (such as acidification and declining groundwater tables) of the groundwater system.

2. Establish a function-issue table to see whether the issues are in conflict with the functions of the groundwater systems.
   Management objectives should be formulated and agreed upon to protect these groundwater resources. When budgets are restricted, a function-issue table can be used as a tool for priority setting. The urgency of a problem and the available (technical and financial) means determine priorities.

3. Collect at least the following information about place- and time-dependent factors:
   - the hydrological and geochemical functioning of the groundwater system;
     - spatial and temporal scales,
     - chemical, physical and biological processes
   - the users of information (policy makers and/or managers at the operational level);
   - the stage of the management (problem identification, policy development, policy implementation and control).

4. Use the DPSIR concept for further specifying information needs. The system approach of this concept is helpful in finding causalities between environmental problems (pressure), the impact on groundwater resources (impact, state) and measures to be taken (response).

5. Tailor it at the organisational level, by using the policy life cycle. Information needed for policy-making differs from information needed for the evaluation of restoration measures.

6. Make a checklist with criteria that have to be met, linked to the factors mentioned in 3.

The approaches also provide different angles, since the DPSIR is mainly focused on the groundwater system, the policy life cycle on the socio-economic system and the function-issue table links the two.

### 3.2 Use of indicators

Indicators often refer to a set of core variables, thereby directing the monitoring strategy for a certain issue. Indicators can also be used to illustrate the different aspects of the desired information as presented in table 3.1.
Above all, indicators provide a means of communicating monitoring results to decision makers. When the selection or development of indicators is based on the aforementioned approaches, it will also result in more harmonised information, which is especially important when dealing with transboundary groundwaters.

**Table 3.1**
Problems for which indicators could be developed, using the DPSIR-concept.

*Ecosystem*

*Agricultural water use*

*Industrial water use*

*Drinking water supply*

| Problems | Driving forces | Pressure | State | Impact | Response |
|---|---|---|---|---|---|
| Excess nutrients | Intensification of farming | N-load on farms | Nitrate in groundwater | Nitrate in drinking water | Control of manure/ fertiliser use |
| Pollution with hazardous substances | Chemical industry production | Emissions of heavy metals | Concentration of heavy metals | Potability problems | Changes of toxic contents in products and production processes |
| Declining groundwater tables | Economic development | Drinking/ industrial water demand | Declining groundwater tables | Loss of yields | Control of abstraction Artificial recharge |
| Salinization/ salt water intrusion | Economic development | Over-exploitation | High chloride concentration | Impairment of drinking water quality | Artificial recharge |

Some current indicators used for groundwater quantity monitoring and assessment are groundwater levels (piezometric head), groundwater abstraction (water use) and some plant species (vanishing or coming up) in relation to declining groundwater tables. For groundwater quality it could be the Sodium Adsorption Ratio (SAR) for irrigation purposes, nitrate concentrations resulting from the issue of excessive use of fertilisers and pH or conductivity in relation to, for example, salinization.

## 3.3 Evolving information needs and monitoring

Information needs evolve during monitoring as water management develops, targets are attained or policies changed. Evolving information needs require a regular rethinking of the information-gathering strategy and the monitoring activities that arise from these in order to update the approach. Any adjustment of the information gathering should take account of the long residence times of groundwater and the time lag before the impact of human activities is observed.

## 3.4 Monitoring objectives and types

Within a national context, monitoring networks generally have two fairly broad categories of objectives. These are basic or reference monitoring networks and specific purpose monitoring networks. Their objectives (tables 3.2 and 3.3) are threefold: (1) providing data for characterising the groundwater regime, (2) providing data for detecting long-term trends in groundwater levels (quantity) or groundwater quality, and (3) serving as a reference network for the specific purpose networks.

**Table 3.2**
Objectives of groundwater quality monitoring and assessment programmes (Chilton and Foster, 1997).

| Objectives | Information output |
|---|---|
| Trends | Show trends in groundwater quality and or quantity changes derived from natural causes, the impact of diffuse pollution sources and changes in hydraulic regime. |
| Baseline for future issues | Provide background information on groundwater quality so that the impacts of future, as yet undefined, human activities can be detected. |
| Spatial distribution | Provide a picture of the three-dimensional distribution of groundwater quality within aquifers. |
| Early-warning | Provide early-warning in recharge areas of the impacts of diffuse sources of pollution. |

For transboundary groundwaters, statutory monitoring will primarily be linked to agreements, which evolve from the Convention or from other international agreements and directives and which apply to the specific area. The following five objectives for monitoring and assessment in transboundary groundwaters arise from the Convention:

- state assessment;
- compliance with standards or provision of the agreement (related to functions/use);
- emergency response;
- special protection areas;
- remediation and restoration.

These types are summarised in table 3.3.

**Table 3.3**
Main types of groundwater monitoring arising from the Convention

| Objectives | Types of groundwater monitoring | Information |
|---|---|---|
| State assessment and compliance | (a) Basic/reference | - natural situation<br>- trends (natural, diffuse pollution, hydraulic regime)<br>- baseline (to detect human impact). Background levels<br>- spatial distribution<br>- compliance<br>- reference situation |
| Compliance special protection areas remediation and restoration | (b) Monitoring linked to functions/uses<br>(c) Specific purposes | - quality standards<br>- criteria, thresholds<br>- health risk<br>- environmental risk<br>- validation<br>- forecasting<br>- effectiveness of measures<br>- implementation monitoring |
| Emergency response | (d) Early-warning and surveillance | - early-warning<br>- thresholds<br>- trends<br>- risks<br>- effectiveness of measures<br>- impacts |

The specification of a monitoring objective should principally make clear why the information is needed (e.g. for what decision-making process). It should also show the intended use of the information (purpose) and the management concern of the riparian parties for the transboundary area (e.g. the protection of a specific use).

The monitoring types from table 3.3 are described below:

*a. Basic/reference monitoring*

Basic/reference monitoring includes monitoring for state assessment. This type of monitoring establishes a background (reference) situation to enable the determination of trends caused by 'beyond local' anthropogenic impacts and natural impacts.

For state assessment, long-term records are needed to determine the possible impact of changing land use and pumping patterns through statistical analysis. It is often performed on very different scales (national, regional, local) and is also prescribed by several international directives and conventions. In a transboundary context, monitoring networks on both sides of the border could be used, but the statistical analysis requires central guidance from a joint body. This body should also provide guidance on critical items to be monitored and the statistical organisation and interpretation of the raw data.

*b. Monitoring linked to functions and uses (compliance)*

This strategy is linked to regulations, laws and directives related to the use of groundwater. This type of monitoring serves as a protection of functions and uses. The monitoring should answer the question, of whether the groundwater use complies with these above-mentioned regulations and standards. For transboundary groundwaters, this means that riparian parties have to establish and agree upon the groundwater uses and functions in the transboundary aquifer.

Since monitoring results may be used as a basis for further action or measures, it is recommended that a transboundary quality assurance programme should be established to ensure the reliability of the water-quality laboratories of the parties concerned.

*c. Monitoring for specific purposes*

Some groundwater resource management activities require special types of investigation and monitoring. For instance:

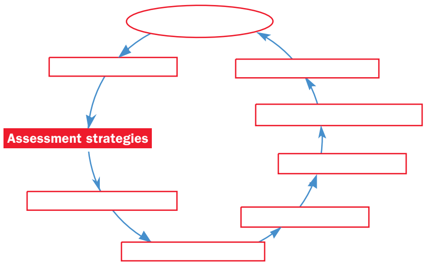
- the development and evaluation of special protection areas;
- the implementation and evaluation of remediation and restoration measures;
- the investigation of interconnection of surface water and groundwaters;
- modelling to predict migration of contaminants;
- the investigation of the possible sources of nitrate in groundwaters as a basis for pollution control measures.

*d. Early-warning and surveillance*

This strategy aims at collecting information on whether and where accidental spills may affect the drinking water supply, to determine public health hazards of "abandoned or illegal" land disposal sites, or to determine actual sources of groundwater quality deterioration. For early-warning, special wells may be drilled, whereas for surveillance production wells can often be used.

The resulting information should provide a sufficient basis for an emergency response, which can be either specific additional measures or remedial actions. Riparian parties should agree on all the aspects of this strategy as well as on the emergency response.

# 4. Strategies for monitoring and assessment




Monitoring strategies should serve as a guide in establishing realistic monitoring priorities, not only in terms of what should be monitored and where, but also in terms of timing and funding.
Joint bodies should periodically evaluate their monitoring activities to confirm that they are meeting their objectives in the most effective and economical manner.

### 4.1 Key strategic aspects

After the objectives have been derived, a more specific strategy has to be developed before starting the actual technical design of a monitoring network. The following aspects/questions have to be dealt with in a proper strategy.

*a. Existing information and monitoring systems*

Firstly, information should be gathered on the relevant parts of the transboundary aquifer subject to the Convention. Is relevant information already available from other sources (e.g. existing monitoring systems, specific surveys, models, other data suppliers)?
Can existing monitoring and information systems provide the information needed by adjusting their operation? Is it possible to use the existing database information system? What does this require from a new monitoring system?

*b. Required assessments*

What kind of assessments have to be carried out (e.g. natural situation, background situation, compliance with requirements of uses and functions, pollution levels, risk assessments with regard to public health and/or environment, early-warning assessment)?

*c. Type of monitoring*

If monitoring is needed, what type of monitoring will be required? Will a single survey be sufficient or is more extended monitoring necessary?

*d. Monitoring techniques*

What are the available and suitable monitoring techniques (e.g. surface water monitoring, meteorological monitoring, remote sensing techniques, early assessment monitoring (for example the use of pesticides), water use, geo-physical methods, unsaturated zone monitoring network system, continuous recording monitoring system)? (See also chapter 5).

*e. Stepwise approach*

Is a stepwise approach to develop a monitoring network system, leading from coarse to fine assessments, worthwhile?

*f. Responsibilities*

Who will be responsible for the organisation of the monitoring system (for the design, implementation, operation and evaluation)? Institutional arrangements related to these responsibilities are discussed in chapter 8.

*g. Financial and human resources*

What is the available budget and, consequently, what human resources can be made available? The responsible authorities should realise that groundwater monitoring should most often be guaranteed for a long time.

*h. Integration*

According to the Guidelines on water-quality monitoring and assessment of transboundary rivers (UN/ECE, 1996), the integration of monitoring activities for reasons of cost-effectiveness in an early stage of the monitoring cycle may cause an over- or undersizing of monitoring networks. Therefore, it is recommended that an information strategy should be developed per monitoring objective or information need. Integration of monitoring efforts may be considered in the implementation phase.

The outcome of the development of the monitoring strategy should be the specification of one or more monitoring options for which a system should be designed. The following sections deal with the design of the different components of a monitoring system.

## 4.2 Elements of monitoring and assessment strategies

*a. Inventory and preliminary surveys*

Inventories and other preliminary activities should be carried out by riparian parties prior to a monitoring effort in transboundary aquifers. The extent of these activities depends on the objectives of the programme, the complexity of the hydrogeology and the number and nature of issues to be addressed. Surveys provide the basic information needed to set up the monitoring as effectively and efficiently as possible. Inventories include a general screening of all available information relevant to the aspect under consideration, an evaluation of aquifer characteristics, the hydrogeologic setting, a screening of the occurrence of pollutants by surveys or of adverse impacts at varying groundwater levels. Moreover, the need - if any - for other data will become more clear as a result of these inventories. Surveys should be undertaken where the inventory shows that data are lacking. Surveys are also helpful in determining the variability of monitoring parameters in time and space.

*b. Stepwise approach*

As monitoring serves different aims and as the information needs vary from broad indications to fine-tuned diagnostic features, the choice of parameters and methods also depends on them. Especially for groundwater quality monitoring, step-wise approaches, which will lead from general to more detailed assessments, are recommended. Each step should be concluded with an evaluation of whether or not the information obtained is sufficient. Such stepwise testing strategies can ultimately lead to a reduction in information needs for further routine monitoring and mapping.

In general, a phased approach to bring into operation monitoring efforts, going from simple to advanced, is advisable for reasons of cost-effectiveness. Additionally, for developing countries and countries in transition, prioritisation in time is recommended for the introduction of new monitoring strategies, going from labour-intensive to technology-intensive methods. In many cases, the lack of appropriate and reliable data and the absence of an adequate baseline against which progress can be measured make this approach the most realistic.

The cost-effectiveness of monitoring could be improved further by:

- agreeing to specify information needs and monitoring objectives;
- setting up accountable monitoring programmes which are closely linked to the above-mentioned information needs;
- further integrating monitoring (quality and quantity; integrated in terms of ecosystem approach; clear connection with socio-economic system), which can increase both the effectiveness of monitoring (cause-effect relations) as well as its efficiency;
- using models, which can assist in the integrated modelling assessment of the transboundary area (large-scale groundwater flow system analysis), in screening alternative policies, in optimising monitoring network design, and in assessing the effectiveness of implemented measures;
- using springs as observation wells, since no well drilling has to take place and they reflect an undisturbed, representative groundwater sample. Furthermore, spring-related data usually reflect aggregated information, whereas a monitoring well delivers only point (well-related) data;
- using a stepwise approach for screening to gain more information at lower cost.

*c. Aquifer vulnerability mapping*

In general, more vulnerable aquifers or parts of aquifers will require greater monitoring efforts and therefore aquifer vulnerability mapping can provide a means for prioritising monitoring efforts. The monitoring intensity is related to those parts of an aquifer, where an impact is most likely to occur. For groundwater quality monitoring, vulnerability mapping will be generally be based on soil type and aquifer characteristics.

Collecting all necessary information to produce vulnerability maps that could be used in the design of monitoring networks or for risk assessment is a lengthy process.

Aquifer vulnerability should also be taken into account when interpreting and reporting monitoring results to assess whether groundwater resources are adequately protected or whether measures taken as a part of groundwater action plans are sufficient.

### *d. Risk assessment*

Risk assessment can help considerably in prioritising the monitoring activities. For example, a relatively small transboundary aquifer in a sparsely populated area is hardly affected by threats. If there is plenty of surface water and therefore no use of groundwater, there are almost no functions linked to this aquifer. Through a very simple risk assessment (considerations of functions and threats in a specific context - low population density) the authorities may decide that monitoring elsewhere has higher priorities. This could be quantified or made visible by estimating the possible damage if no groundwater monitoring takes place.

Risk assessment can also be used to determine whether the chosen monitoring strategy will cover most of the information need. The use of models will help in screening alternative policies. The optimisation of a network design will also include an element of risk assessment; if the number of wells is decreased, will the resulting information still cover most of the information needs?

### *e. Models*

Models, especially mathematical models, play several roles in the monitoring and assessment of transboundary groundwaters. They can assist in the integrated modelling of the transboundary area (large-scale groundwater flow system analysis), in screening alternative policies, in optimising monitoring network design, and in assessing operative actions, such as: the effectiveness of implemented measures, the determination of the impact on groundwater systems and the risks to human health and the ecosystem. Integrated modelling of transboundary areas should be preceded by a large-scale regional groundwater flow system analysis. The objective of this modelling should be to establish a conceptual (or identification) model, which requires a rather simplified modelling approach.

Models can be used in addition to monitoring, but also as part of monitoring optimisation programmes. Successful mathematical modelling is possible only if the methodology is properly integrated with data collection, data processing and other techniques/approaches for the evaluation of groundwater system characteristics.

When riparian parties decide on the modelling of transboundary aquifers, they should realise that the standardisation and the accessibility of data (interfaces to databases and to GIS) are of the utmost importance, rather than the standardisation of software.

### *f. Indicators*

Monitoring and assessment should be designed to increase the capacity to tailor monitoring objectives to the information needs of the riparian parties or the responsible water management bodies and also to analyse the resulting information in a way that is relevant. This should include a synthesis and appreciation of the information in an integrated way. Indicators will help this integrated assessment, as will the specification of information needs prior to the setting of monitoring objectives.

Finding the right indicators requires a balanced approach between information needs of decision makers and the costs and constraints of obtaining the appropriate data. A stepwise approach to select and develop indicators is emphasised. It can be based on the core elements of groundwater management; problems, pressures (threats) and the impact of measures on the overall functioning of the groundwater system (see also table 3.1).

When the information needs are sufficiently specified and before indicators can be selected or developed, information on the following is needed: hydrological and geo-chemical characteristics of the groundwater system, the information users, the available technical and financial means. This approach will help in a tailor-made selection or development of the most useful and cost-effective indicators in monitoring and assessment programmes.

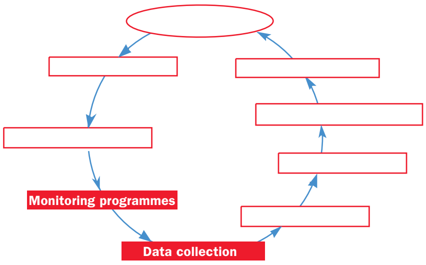
*g. Integrated assessment*

The need to integrate the monitoring of groundwater and surface water will depend on the extent to which processes and variables in groundwater and surface water are interrelated (e.g. seepage). If groundwater management measures lead to a substantial change in the surface water system that is connected to this particular groundwater system, and if these changes have an impact on specific functions or uses, then integration of the assessment of both systems is recommended.

It is also recommended that in micro-biological assessments (including the identification of potential sources of contamination) should be integrated with risk assessment (quantification of the level of risk), when there is a risk of pollution of drinking water (WHO Guidelines for drinking water quality, 1993). This approach is very suitable for rural water supplies and it should preferably be combined with a stepwise risk assessment and a monitoring infrastructure that provides some relevant basic information.

The above-mentioned elements require appropriate access to and a certain harmonisation of related data, which can be the result from research and surveys, or/and data from monitoring programmes.

# 5. Monitoring programmes




Groundwater monitoring and assessment programmes will develop gradually, because of administrative, budgetary and personnel constraints. The allocation of monitoring resources should follow a tailor-made approach.
Ranking and sectioning areas where potential pollution sources are located, or where groundwater use is high, will make the programme more effective.

## 5.1 General aspects

Once the technical objectives have been established and specific strategies have been developed for the respective monitoring programme, each strategy can be linked to a monitoring network design.

The design of monitoring networks includes the determination of:

- the network density and location of measuring points;
- monitoring parameters;
- types of monitoring points;
- the measuring and sampling frequency.

The design is a function of the selection of sampling-point type, density and location, sampling method and frequency and the choice of parameters. Table 5.1 shows the principal factors that influence these choices.

**Table 5.1**
Factors that determine network design
(After Chilton et al., 1996)

| **Sampling point/ measurements** | | **Sampling/ measurement frequency** | **Choice of parameters/ water heads** |
|---|---|---|---|
| Type | Density | | |
| Hydrogeology (complexity) | Hydrogeology (complexity) | Hydrogeology (residence time) | Water uses |
| | Geology (aquifer distribution) | Hydrology (seasonal influences) | Water quality issues |
| | Land use | | Statutory requirements |
| | Statistical considerations | Statistical considerations | |
| Costs | Costs | Costs | Costs |

The hydrogeological characteristics of the transboundary aquifers, water use and land use, and the availability of funds are among the basic factors to be considered when constructing a monitoring network. The technical aspects of monitoring programmes are discussed below.

*a. Network density*

The desirable or target density of a network is basically determined by the hydrogeological and the hydrochemical complexity of the aquifer. Hydrogeological units with a high degree of heterogeneity will require a denser network of monitoring sites.

In aquifers affected by intensive exploitation and/or other anthropogenical impacts (industry, intensive agriculture, landfills, abandoned municipal or industrial sites, etc.), the network density should be higher. As a general rule, weighting factors as aquifer characteristics, vulnerability, groundwater exploitation, water use and land use, and population served with groundwater can be used as a reference in network design.

Densities of basic groundwater level and groundwater quality networks in some European countries (density figure based on total land area) (Jousma and Willems, 1996)

| | Average groundwater level network density (N/100 km$^2$) | Average groundwater quality network density (N/100 km$^2$) |
|---|---|---|
| Sweden | 0.11 | 0.04 |
| Finland | 0.02 | 0.02 |
| Denmark | 0.15 | 0.26 |
| United Kingdom (England/Wales) | | 0.40 |
| Netherlands | 10.70 | 1.07 |
| Belgium/Flanders | 1.61 | 1.61 |
| Germany/Bavaria | 1.00 | 0.47 |
| Germany/New states | | 0.33 |
| Hungary | 2.27 | 0.55 |
| Spain | 1.95 | 0.22 |

*For groundwater quality (basic) networks, the density is often lower than for groundwater level networks. An investigation in nine European countries shows that the difference in network densities ranges from 0.02 locations per 100 km$^2$ in thinly populated Finland to 1.61 in densely populated Flanders. The differences in network density reflect the size of the countries, the population density, the contrasts in vulnerability of the groundwater systems to contamination, the intensity of groundwater exploitation and related conflicts of interest, and priority given to environmental protection (Jousma and Willems, 1996).*

*b. Selection of sites*

The choice of both the type and location of observation points is usually governed by two interrelated criteria:

- the specific representativeness of the observation points in the aquifer;
- the possibility of determining the spatial trend in the groundwater levels or hydraulic head pressures on the required scale.

The sites or observation points of a network should be representative of:

- the delineation of the relevant groundwater flow systems;
- the extent of aquifers, aquitards and aquicludes or the delineation of geohydrological units;
- additional information.

When selecting a site, different activities should be carried out:

- characterisation of the groundwater systems and of the geometry of the principal water-bearing formations;
- vulnerability assessment, mainly based on the groundwater flow conditions, soil composition and geology;
- identification of the threats to which the groundwater system is exposed (in particular reflected in land use: agriculture, industry, waste sites, military sites);
- identification of the problems which affect the aquifer (e.g. acidification, nutrients, salinization, pollution).

Monitoring sites for groundwater level observation can be wells or boreholes, provided that they are not substantially affected by groundwater abstraction in the neighbouring areas. For groundwater quality networks, use can be made of observation boreholes or pumping wells. It should be noted that springs can also be used as monitoring sites, in particular for groundwater sampling purposes. With regard to representative data, one spring can replace a number of monitoring wells.

*c. Parameters*

The choice of the monitoring parameters can be linked to the core elements of (ground)water management and will depend on:

- the requirements of the defined functions and uses of the groundwater system;
- the threats to which the groundwater system is exposed;
- the problems which are already occurring.

Prior to the selection of parameters an inventory should be drawn up. It should include the following:

- aquifer characterisation, quantitative and qualitative *(basic/reference networks)*;
- identification of the actual groundwater functions, uses and quality requirements (e.g. ecological function, water supply for drinking purposes, agriculture and industry) *(compliance networks)*;
- specification of the threats to which the groundwater system is exposed (e.g. generally reflected in land use: agriculture, industry, waste sites, military sites) *(early-warning and surveillance networks)*;

- specification of the problems already experienced by the groundwater system (e.g. acidification, desiccation, nutrients, salinization, pollution) *(monitoring for specific purposes)*.

Table 5.2.a shows a basic set of parameters for groundwater quantity assessment in relation to some issues and functions/uses.

**Table 5.2.a**
Parameters for groundwater quantity assessment related to some issues and functions/uses

| Issues | Functions and uses | Parameters |
|---|---|---|
| Desiccation | Ecosystems, agriculture | Groundwater levels |
| Water logging | Ecosystems, agriculture | Surface water and groundwater levels |
| Water supply | Drinking water, agriculture, ecosystems | Groundwater levels, discharge (abstraction) |
| Water quality aspects | Drinking water, ecosystems | Groundwater levels/heads, discharge (abstraction), surface water levels |
| Land subsidence | Urban area, agriculture | Groundwater levels and surface water levels, discharges (abstractions) |
| Salinization/ salt water intrusion | Agriculture, drinking water | Groundwater levels/heads, discharges (abstractions) |

Table 5.2.b gives a basic set of parameters for groundwater quality assessment. These parameters are grouped into inorganic and organic compounds and also by method of analysis. This table, important with respect to information needs, outlines only an approach, but is not sufficiently detailed to be of direct use. Further subdivision is required, as it is highly desirable to have a formal approach within which metals, pesticides and other organic compounds can be chosen, so that suites 3, 4 and 5 can be related to local conditions.

**Table 5.2.b**
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)

The results of the inventory, as described above, will help in choosing the parameters. In this table, the group of parameters is linked to some of the problems mentioned in table 2.1.

*d. Quantity measurement and sampling procedures*

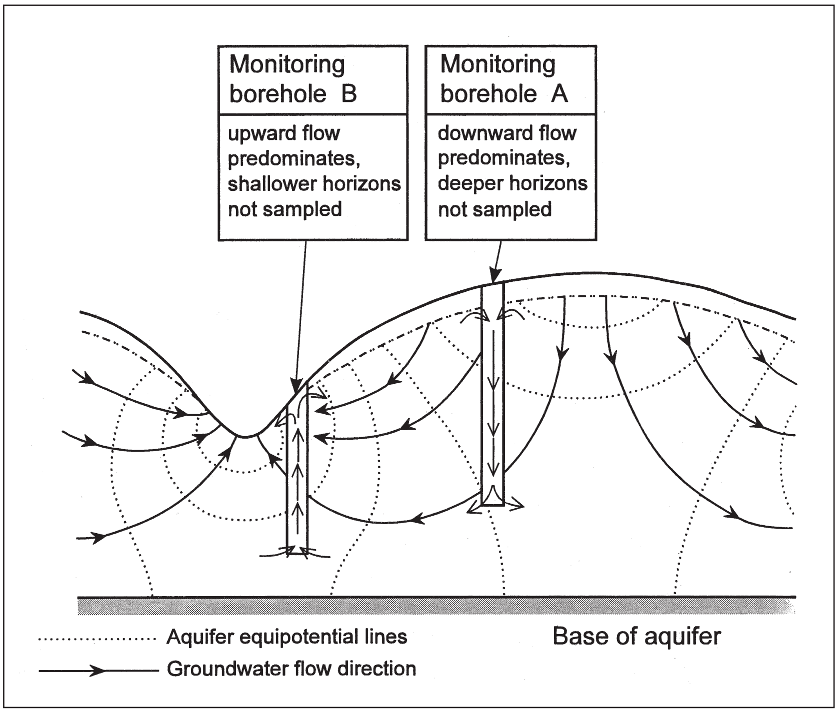
Groundwater levels have to be measured in relation to a fixed reference point. The observed level data from the wells should be written on special forms and mailed to the institution involved.

Consideration needs to be given to the degree to which the measured water level is representative of the actual hydraulic head conditions. For example, where groundwater abstraction occurs, the influence of this pumping on groundwater levels should be taken into account. In confined or multi-layered transboundary aquifers, the construction of clusters of monitoring points at different depths should be envisaged. This may also apply to quality networks.

Sampling procedures vary, depending on which parameter or group of parameters is to be measured. Some parameters, like temperature, pH, Dissolved Oxygen (DO) and Electrical Conductivity (EC), can be measured directly on the spot. Other parameters have to be analysed in the laboratory. In this case samples have to be taken and must be transported, sometimes under special conditions. When a large suite is required, several samples may be necessary, each stored in a different type of container and using a different preservation technique.

Water samples can be drawn from wells, abstraction boreholes and/or from observation boreholes. Samples of raw water from boreholes or springs operating more or less continuously at relatively high discharges can provide reasonable aggregate samples of water quality, especially if the boreholes more or less fully penetrate the aquifer and are screened through a significant proportion of its thickness (figure 5.1).

**Figure 5.1**
The effect of vertical flow components on fully-screened or open monitoring boreholes (After Foster and Gomes, 1989)



These samples are less representative if there are vertical variations in groundwater chemistry. A water sample drawn from an abstraction borehole can also be a variable mixture of the groundwater which has entered the screened or open section of the borehole, which can be quite long. In this case water is drawn from a considerable thickness of the aquifer or perhaps more aquifers. Discharge samples from this type of borehole may be an insensitive indicator of possible deterioration in groundwater quality arising from activities on the land surface.

Another problem of sample representativeness is related to the borehole itself when it is situated in groundwater recharge or discharge areas with significant vertical components of groundwater flow.

Sampling from observation boreholes has similar limitations with respect to hydrogeological representativeness and sample modification.
An appropriate method for sampling observation boreholes is the use of a small, portable electric submersible pump.

The collection of groundwater samples in monitoring wells must be taken in two steps. The first step is to remove standing water from the well and the second is to take the sample itself. For removing the standing water a powerful electrical pump can be used, but the pumping capacity has to be adapted to the hydrogeological conditions. In general, the lowering of the groundwater level may not exceed 2 metres or more than 10% of the thickness of the saturated zone of the aquifer. For the sample itself a small pumping rate is usual to prevent air getting in. The pump is lowered into the well down to the screen, but still above it (to avoid damage to the pump with sand input but also due to well hydraulics). The removal of standing water must be controlled by measuring pH value, groundwater temperature and/or electrical conductivity. Samples should be taken when these parameters have stabilised.

Samples for inorganic analysis should usually be filtered before preservation to remove suspended particulate matter, which could dissolve when acid preservatives are added, causing distorted values of solution concentration.

Riparian parties should agree on standard methods of sampling. Sampling should be carried out by trained staff. The chemical analyses should be performed by licensed laboratories.

### e. Frequency of sampling and quantity measurements

Sampling frequencies in groundwater quality monitoring programmes are usually based on budgetary and resource considerations, as well as on strategies. However, there are also scientific and technical considerations. Sampling frequency has hydrogeological and hydrological dimensions (table 5.1).

The hydrological dimension implies the possibility of seasonal variations in some quality parameters. Groundwater recharge occurs seasonally and its distribution varies within the ECE region according to climatic patterns. The onset of recharge may produce increased leaching of solutes from the land surface and (or be followed by) greater dilution. Seasonal considerations may also be important in relation to parameters whose use is strongly seasonal, for example agricultural and non-agricultural pesticides.

Observation frequencies for groundwater levels depend largely on groundwater fluctuation, which is determined by the hydrogeological situation (type and depth of the aquifer), hydrological circumstances (meteorology) and human impact (groundwater abstractions, induced recharge, return flow from irrigation, surface water level control). Some specific factors to be considered are:

- the frequency of measurement should be adjusted to the temporal fluctuation of the levels and the required accuracy in identifying fluctuation patterns;
- monitoring long-term variations and trends requires a relatively low frequency of observation, whereas accurate identification of seasonal fluctuations demands a higher frequency;
- network design should be tailored to the relevant set of objectives and the design criteria must be appropriate, given the available funds.

In practice, a wide range of frequencies is used, from once a year through twice a month to continuous monitoring.

### *f. Statistical methods*

For network design, there are several approaches and statistical methods (Loaiciga et al., 1992). Two general areas can be identified:

- *representativiness*: to optimise the network to ensure the hydrogeological complexity and quality variables are adequately represented;
- *reliable assessment*: to give guidance on the required sampling frequency to detect changes in the mean concentration of any parameter over time.

An example of a statistical method is the so-called Kriging technique, which is often applied to optimise quantitative groundwater networks. This technique is usually applied to reduce the number of monitoring wells.

It should be emphasised that statistical techniques have their limitations and should be applied only by experts with a long experience in hydrogeology because:

- most methods make important simplifying assumptions about the hydrogeological environment;
- most methods are targeted at the assessment of potential or actual contamination from point sources of pollution on a relatively local scale;
- a general limitation of such methods is the difficulty of finding a statistical objective(s) that adequately represent(s) the often complex objectives of the monitoring programme, and take(s) account of the resource constraints;
- most methods assume that monitoring strategies are fixed initially and do not change. There is a limited scope for the feedback and adjustment that are essential in groundwater quality assessment programmes.

Moreover, a comparative evaluation of different sampling densities requires large volumes of actual quality data.

g. *Indirect methods of groundwater quality monitoring*

In some circumstances, for specific objectives and parameters, indirect methods of monitoring groundwater quality may be used. The use of fluid conductivity logging in observation wells to monitor the three-dimensional development of saline intrusion is a case in point. The use of geophysical methods is most effective where groundwater quality differences are sufficiently big to cause physical contrasts. The measurement of ground resistivity by surface geophysics may be used in some hydrogeological situations to assess the lateral spread of salinity through an aquifer.

For point source pollution involving volatile hydrocarbons, the use of soil gas detection methods may provide a cost-effective means of studying the development of a contaminant plume. Both of these indirect methods depend, as all such methods do, on adequate control being provided from some direct sampling by investigation drilling and the construction of permanent monitoring points.

h. Costs

Existing monitoring sites or production wells located in the transboundary aquifer should always be considered at the initial stage of the monitoring programme, in particular for groundwater sampling purposes. Where possible, publicly owned wells should be selected to ensure continuity of access.

Considering the financial aspects of network design, a distinction can be made between capital, sampling and analytical components.

Table 5.3.a concerns groundwater quantity networks. For groundwater quantity networks in general the capital costs and also the sampling (observation) costs will be somewhat lower than for groundwater quality networks. The processing on groundwater observation data (levels), like verification and quality control, is considered part of data management. So, in this case there are no analytical costs.

**Table 5.3.a**
Influence of groundwater quantity network design on monitoring costs

| Cost component | Measuring points | | Measuring frequency |
|---|---|---|---|
| | Type | Density | |
| Capital | ++ | ++ | - |
| Observations (measurements) | + | ++ | ++ |
| Data management | - | + | + |

++ major influence + minor influence - negligible influence

Improving groundwater quantity monitoring has major observation costs implication if a higher density of measuring points and a higher measuring frequency are needed. The extra data management costs are relatively modest in comparison with measurement costs.

Table 5.3.b concerns groundwater quality monitoring. Improving groundwater quality monitoring has major capital cost implications only if significant numbers of newly constructed sampling points are required to replace unsuitable points or to provide additional coverage. In comparison, capital cost requirements for additional sampling pumps or field equipment are relatively modest. There always needs to be some long-term capital cost provision to keep up with developments in instrumentation and to meet ever-lower detection limit requirements.

**Table 5.3.b**
Influence of groundwater quality network design on monitoring costs (Chilton and Milne, 1994)

| Cost component | Sampling points | | Sampling frequency | Choice of parameters |
|---|---|---|---|---|
| | Type | Density | | |
| Capital | ++ | ++ | - | +[1] |
| Sampling | + | ++ | ++ | +[2] |
| Analysis | - | ++ | ++ | ++ |

++ major influence  + minor influence  - negligible influence

**Notes:**
[1] may have some influence on instrument requirements in laboratory.
[2] introduction of field parameters increases sampling costs.

### 5.2 Specific design requirements for different monitoring types

Different monitoring and assessment strategies often mean different monitoring networks and monitoring programmes. In developing monitoring programmes for transboundary aquifers, the purpose and requirements of each monitoring programme should be established and agreed upon by the riparian parties.

*a. Basic/reference monitoring*

For basic/reference monitoring, a basic network should be installed or existing networks can be sampled. The measuring and sampling points act as reference stations and are regularly monitored at moderate intervals. The frequency of monitoring is about one to four times a year, depending on the characteristics of the aquifer. In an unconfined aquifer the measuring and sampling frequency will be higher than in a confined aquifer. Also, the density of this type of network is moderate. The parameters to be sampled are normally the field parameters and major ions (table 5.2.b) but they also depend on the targets, land use and the type of well. For transboundary groundwaters, riparian parties should agree on the objectives and the resulting consequences for the network design.

*b. Monitoring linked to functions and uses (compliance)*

The density of the networks and the sampling frequency depend on the functions and uses of the groundwater. One example is the quality-assurance monitoring of drinking water supplies, involving periodic sampling of public wells to determine whether drinking water standards are met. As for drinking water supplies, each function has its own standards.

*c. Monitoring for specific purposes*

The density of the network and the frequency of measuring and sampling will often be higher than of the previously mentioned monitoring networks and are closely related to land use and the type of aquifer. In a transboundary context, this type of monitoring requires close cooperation between the riparian parties.

*d. Early-warning and surveillance monitoring*

Early-warning and surveillance monitoring activities are mostly performed at a local level and have a higher density than the basic or reference networks. The sampling and observation frequencies are often somewhat higher too. Specific parameters have to be sampled, depending on the threats and land use.

**Nine basic rules for a successful monitoring programme**

1. The objectives must be defined first and the programme adapted to them, and not vice versa (as is often the case with multi-purpose monitoring). Adequate financial support must then be obtained.

2. The type and nature of the aquifer must be fully understood (most frequently through preliminary surveys), including the spatial and temporal variability within the aquifer. Very helpful information sources are maps of an appropriate scale (e.g. : 1:200,000) of the transboundary aquifer concerned:
   - hydrogeological and vulnerability map of the area (if it exists);
   - isoline maps of the aquifers' underlying and overlying geologic formations;
   - maps of changes in groundwater levels;
   - maps and lists of the hydrogeological boreholes (characteristic profiles and hydrogeological parameters), monitoring wells (with their basic data), significant groundwater abstractions (wells or well fields), location and abstraction data, and wells of regular water quality sampling (list of parameters);
   - all isotope data concerning the age and origin of the groundwater.

3. The appropriate well type (or spring) must be chosen (or spring).

4. The parameters, type and frequency of measurements and sampling, and the locations must be chosen with respect to the objectives.

5. The analytical field equipment and the laboratory and data analysis facilities (e.g. models) must be selected in relation to the objectives and not vice versa.

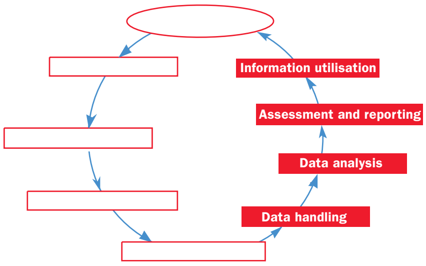
6. A complete and operational data treatment scheme (DAP) must be established.

7. Groundwater monitoring should be coupled with surface water monitoring when applicable.

8. The quality of the collected data must be regularly checked through internal and external control. The data should be given to decision makers, not merely as a list of variables and their concentrations or levels, but interpreted and assessed by experts with relevant recommendations for management action (such as indicators or indices).

9. The programme must be evaluated periodically, especially if the general situation or any particular influence on the groundwater flow system has changed, either naturally or by measures taken.

# 6. Data management




Monitoring data collected by riparian countries in transboundary aquifers should be comparable, available for integration with information from a variety of sources and easily aggregated spatially and temporally.
Data produced by groundwater monitoring programmes should be validated, stored and made accessible. The goal of data management is to convert data into information that meets the specified information needs and the associated objectives of the monitoring programme.

### 6.1 Data management steps

Collecting and processing data is expensive. The key aspects are collecting the right data in a quality-controlled manner, using the appropriate statistical tools and techniques and communicating the messages in a timely and understandable fashion. Although these appear to be simple requirements, they are not often met and require considerable investment in knowledge and equipment to ensure the desired return on the investment in data collection. Riparian parties should harmonise monitoring methods and agree on standard forms.

To safeguard the future use of the collected data, several data management steps are required before the information can be properly used:

- data should be analysed, interpreted and converted into defined forms of information using appropriate data analysis techniques;
- collected data should be validated or approved before they are made accessible to any user or entered into a data archive;
- information should be reported to those who need to use it for decision-making, model validation, management evaluation or in-depth investigation. The information should also be presented in tailor-made formats for different target groups (e.g. GIS maps are easily accessible);
- data and information necessary for future use should be stored, and the data exchange should be facilitated not only at the level of the monitoring body itself, but also at all other appropriate levels (international, ECE regionwide, aquifer, etc.).

### 6.2 Data dictionary

The first archiving of monitoring data generally takes place at the monitoring agencies in each riparian country. Transboundary cooperation will involve the exchange of data, especially when modelling is used in joint assessments. Then databases should be harmonised to the necessary extent. To facilitate the comparability of data, strict and clear agreements should be made on the coding of both data and meta-information. If data are to be stored, attention should be given to standardised software packages for data management, and to data storage formats to improve the possibilities for data exchange. Furthermore, agreements regarding the availability and distribution of data may facilitate the data exchange. A data dictionary containing this information and agreements on the definitions of terms used for the exchange of information or data should be agreed and jointly drawn up.

### 6.3 Data validation

Notwithstanding the quality control of separate procedures (well drilling, sampling, analysis), data validation should be an intrinsic part of data handling. The regular control of newly produced data should include the detection of outliers, missing values and other obvious mistakes (mg/l versus μ/l). Computer software can help to perform the various control functions, such as correlation analysis and application of limit pairs. However, expert judgement and thorough knowledge of the groundwater systems are indispensable for this validation. Where the data have been thoroughly checked and the necessary corrections and additions made, the data can be approved and made accessible.

### 6.4 Data storage and meta-information

To be available for future use, data should be stored in such a manner that they are accessible and complete with respect to all the conditions and qualifiers (e.g. detection limits) pertaining to data collection and analysis. Information on the dimensions and units ($NO_3$-N or $NO_3$) should be stored.

Furthermore, a sufficient amount of extra data ('meta-information'), which is necessary for interpretation, has to be stored. Characteristics regarding place and depth of sampling, type of observation point, preconditioning and analytical techniques are commonly stored.

For modelling purposes of transboundary aquifers, the standardisation of the accessibility of data (interfaces to databases and GIS) is more important than the standardisation of the software used. If both the conceptual model and the basic data are reliable, the results will be comparable even when the software used is not the same.

The huge amounts of data collected from groundwater monitoring networks are preferably stored in relational databases, which should be the cornerstone of an integrated Geographical Information System (GIS). Although stored in a well designed database, an information system is needed to manage, retrieve and visualise the stored data in such formats as maps, graphs, diagrams, and reports. Graphical interfaces will make the information management system more user-friendly as knowledge of the physical structure of the database is no longer necessary. GIS can act as a shell around the database.

It is essential that any database system is safeguarded against the entering of data without proper meta-information. Often joint modelling by riparian parties has to be performed and this requires agreed upon digital data exchange formats.

### 6.5 Data analysis and data interpretation

The conversion of data into information involves data analysis and interpretation. The data analysis should be embedded in a Data Analysis Protocol (DAP) which clearly defines a data analysis strategy and takes into account the specific characteristics of the data concerned, such as missing data, detection limits, censored data, data outliers, non-normality and serial correlation. The adoption of DAPs gives the data-gathering organisation or joint body a certain flexibility in its data analysis procedures, but requires that these procedures should be documented.

In general, data will be stored on computers and the data analysis, mostly a statistical operation, can make use of generic software packages and/or GIS. To achieve standard automated data analysis, the use of tailor-made software is recommended. A DAP should comprise procedures for processing the monitoring data in order to meet the specific needs for data interpretation (e.g. calculations based on individual measurement data or yearly averages, and statistical techniques used to remove non-relevant deterministic influences). Such procedures should also include accepted methods for trend detection and testing for compliance.

### 6.6 Data exchange

There is a need for a standard (or format) for the purpose of exchanging digital data. The data dictionary should be the basis for the definition of such a standard or format. Data storage systems of riparian countries should be able to handle the agreed data exchange format and ideally allow data to be imported into modelling or analysis packages. For storage purposes, a common system could be envisaged, under the coordination of a joint body. See also chapter 8.

### 6.7 Reporting

The DAP may be extended to reporting formats for the resulting information (e.g. GIS maps). A reporting protocol can help to define the different characteristics for each use or audience and should include certain Guidelines regarding frequency of production, information content/detail and presentation format. Monitoring objectives should always be presented as part of the reported information.

Standardisation of reports and maps is encouraged for each transboundary aquifer. Reliable reports from countries, Parties to the Convention describing the state of their transboundary groundwaters as regards safe human uses and ecological functioning will require improvements in data comparability (e.g. standardisation of well drilling, sampling and modelling), and the development of a DAP.

Reporting information is the final step in the data management programme and links the gathering of information to the information users. To distribute the information, reports should be prepared on a regular basis. The frequency and the level of detail depend on the use of the information. Technical staff will need detailed reports more frequently than policy makers. It is recommended that (annual) state reports should be provided for each transboundary groundwater system to focus on the link between policy measures (societal response) and the state of the groundwaters concerned.

A Convention-wide reporting which would cover all identified transboundary groundwater aquifers of the Parties is also recommended (e.g. every three years) to encourage the evaluation of progress made under the Convention, stimulate commitment of the members involved, and make results available to the public.

# 7. Quality management

Quality management comprises the definition of a quality policy and a quality system. The harmonisation of methods and the use of international standards are essential for a useful exchange of information.

### 7.1 Goals of quality management

The primary goal of quality management in monitoring and assessment can be expressed in the terms ‘effectiveness’ and ‘efficiency’. Effectiveness is the extent to which the information obtained from the monitoring system meets the information need. Efficiency is concerned with obtaining the information at as low a financial and personnel cost as possible.

Traceability, the secondary goal of quality management, is concerned with defining the processes and activities that lead to the information and how the results are achieved. When the processes are known, measures can be taken to improve them.

### 7.2 Quality policy

The quality policy defines the level of quality to be reached. The joint body should declare the quality policy and thus set the prerequisites for quality management. Striving for quality involves investments in quality systems and in staff training. Quality management can therefore be put into practice only when the management of responsible monitoring organisations is committed to it and provides sufficient funds.

Since many organisations may be involved in groundwater management, the role of the joint body is essential. Moreover, the commitment of all the organisations involved in performing quality management is imperative.

### 7.3 Quality system

The quality system should document the relevant activities, the interactions between these activities and the relevant products in the form of procedures and protocols, dealing with every element of the monitoring cycle. Also, the quality system should document the responsibilities with regard to the distinguished procedures. In drawing up procedures, special emphasis should be laid on responsibilities at points of decision, such as approval of the monitoring strategy or acceptance of samples at a laboratory. Procedures and protocols should describe what documentation should be produced about the process, for instance loss of sample trays or weather conditions during sampling.

Adherence to procedures should be checked periodically. Evaluation of the usefulness of procedures is essential, procedures should support the making of products of the required quality.

## 7.4 Protocols

Protocols for the specification of information needs, defining monitoring strategies, network design, sampling, sample transport, sample storage, laboratory analysis, data validation, data storage, data analysis and data presentation should be drawn up and agreed upon by the riparian countries. These protocols are the operational steps in a process where insufficient quality control may lead to unreliable data. By following protocols, mistakes are minimised, and any mistakes can be traced and undone.

Since much of the data collection in groundwater monitoring is done on-site, special emphasis should be put on protocols describing sampling and data analysis. It is essential to sampling conditions in these protocols. Also, one should realise that the act of sampling may disturb the local groundwater situation, for instance by bringing air into an anaerobic situation. Protocols should provide for the specific situation of groundwater reservoirs. The level of accuracy and reliability of the data should be presented.

## 7.5 Product requirements

Requirements for all relevant products should be made explicit and documented. The quality system describes how the requirements are integrated into the processes and how deviations from the requirements are dealt with. Standard requirements on recurrent products are set out in the quality system.

Much of the groundwater data are used as input for models and GIS presentations: therefore, data resulting from the monitoring network should be suitable for this purpose. The network design should take this situation into account. Also, data storage and analysis should prepare for this use.

## 7.6 Standardisation and harmonisation

Standards should be used for methods and techniques for, among other things, well drilling, measurements, samples, transport and storage of samples, laboratory analysis, data processing and validation, data storage and exchange, calculation methods and statistical methods. Preferably, international standards should be used. If international standards are not available, or for whatever reason, the use of an international standard is not adequate, alternatives should be developed by the joint bodies.

Standards used by riparian parties should be comparable. They should not necessarily be equal, but for the sake of the exchange of information, they should provide comparable data. The joint body should agree on the standards to be used by the riparian parties.

The activities under the joint body should be harmonised. Riparian countries should cooperate in choosing the locations, variables, etc., in order to avoid duplication and reduce the monitoring effort.

# 8. Joint or coordinated action and institutional arrangements

The successful drawing-up and implementation of policies, strategies and methodologies on groundwater management crucially depends on institutional aspects. These include the organisation, structures, arrangements for cooperation and the responsibilities of institutions and organisations involved. In transboundary groundwater management, international cooperation is governed by the provisions of the Convention, which stipulates that the socio-economic conditions in the riparian countries should be taken into account when deciding on the specific institutional arrangements.

### 8.1 Concerted action plans and programmes

Riparian parties should agree on quantified management targets. These targets should become part of a concerted action plan or programme. This plan or programme should also cover other measures aimed at achieving an ecologically sound and rational groundwater management, conserving groundwater resources and protecting the environment. This action plan or programme should include provisions for mutual assistance, where necessary. It should be subject to approval at ministerial or senior official level.

The action plan or programme can either be derived from existing national plans or programmes or set the preconditions for the establishment of such national plans or programmes.

The concerted action plan should at least include such items as:

(a) Land and groundwater uses, taking into account that restrictions, and in some cases even bans, on land use should be imposed for mining and processing industries, intensive agricultural practices, including fertiliser and pesticide use, solid wastes, and hazardous chemicals.

(b) Zoning criteria, taking into account that zoning criteria depend on environmental quality and the importance of underlying aquifers.

(c) Protection zones, taking into account that these should help to prevent pollution of groundwaters in current and future groundwater abstraction areas for supplying drinking water. Necessary measures should be taken to minimise the accidental pollution from non-point sources in protection zones.

(d) Economic activities, whereby particular attention should be paid to the transboundary impact of economic activities on groundwater quality and quantity. At present there are few examples of effective coordination between transboundary land development and groundwater protection planning. An exchange of necessary information and bilateral and multilateral cooperation are needed to this end. The establishment of effective and harmonised monitoring programmes should be an effective tool to coordinate these activities.

(e) Groundwater pollution, taking into account that both pollutant discharges and concentrations in transboundary aquifers shall be regularly monitored.

(f) Groundwater abstractions, taking into account that groundwater abstractions for economic needs should be agreed upon to ensure the sustainability of groundwater use.

(g) Wetlands, taking into account that groundwater monitoring should be comprehensive and should address the qualitative as well as the quantitative characteristics of transboundary aquifers, providing reliable tools for the integrated management of groundwaters. Data collection and monitoring programmes should be tailored to the required information level, which is determined by the assessment goal.

### 8.2 Joint bodies and their activities

*a. General recommendations*

Governments should set up joint bodies, where these do not yet exist, and include monitoring and assessment of transboundary groundwaters in the activities of these joint bodies. It is of less importance whether riparian countries set up separate joint bodies responsible for either transboundary surface waters or transboundary groundwaters, or whether they entrust one body with activities both linked with surface waters and groundwaters. However, it is of the utmost importance that, where two or more joint bodies have been set up by riparian countries in the same catchment area, these countries agree on ways and means to coordinate the activities of these joint bodies.

Riparian countries should, where appropriate:

- assign to the joint body the task of transboundary groundwater monitoring and assessment following the recommendations of these Guidelines;

- make the joint body responsible for assessing the effectiveness of the agreed measures and the resulting improvements in groundwater management.

**Joint bodies**

According to the Convention, a joint body means any bilateral or multilateral commission or other appropriate institutional arrangements for cooperation between the Riparian Parties. In general, the tasks of joint bodies include the following:

- collect, compile and evaluate data in order to identify pollution sources likely to cause transboundary impact;
- develop joint monitoring programmes concerning water quality and quantity;
- draw up inventories and exchange information on the pollution sources mentioned above;
- establish emission limits for waste water and evaluate the effectiveness of control programmes;
- elaborate joint water-quality objectives and criteria for the purpose of preventing, controlling and reducing transboundary impact, and propose relevant measures for maintaining and, where necessary, improving the existing water quality;
- develop concerted action programmes for the reduction of pollution loads from both point sources (e.g. municipal and industrial sources) and diffuse sources (particularly from agriculture);
- establish warning and alarm procedures;
- serve as a forum for the exchange of information on existing and planned uses of water and related installations that are likely to cause transboundary impact;
- promote cooperation and exchange of information on the best available technology in accordance with the provisions of article 13 of the Convention (exchange of information between the Riparian Parties), as well as to encourage cooperation in scientific research programmes;
- participate in the implementation of environmental impact assessments relating to transboundary water, in accordance with appropriate international regulations;
- where two or more joint bodies exist in the same catchment area, they shall endeavour to coordinate their activities in order to strengthen the prevention, control and reduction of transboundary

*b. Drawing-up and implementation of action plans*

Riparian countries should, where appropriate, entrust the joint body with the drawing-up and supervision of the concerted action plan or programme outlined in paragraph 8.1.

Where appropriate, riparian countries should also establish a technical working group under the joint body which is responsible for ongoing investigations under the action plan related to monitoring and assessment as well as for defining and implementing the monitoring and assessment strategy, including its technical, financial and organisational aspects.

Riparian countries should, through their respective joint bodies, establish close cooperation 'across the border' between administrative authorities dealing with land-use planning and development, the rational use and the protection of groundwater and groundwater monitoring at the early stages of the planning process and at all levels of administration. This will help to overcome conflicting interests in sectoral planning both in the national and in the transboundary contexts.

Because of differences in the organisation of licensing procedures, riparian countries should jointly agree on a harmonised system of licensing procedures which does not conflict with the existing national legislation systems or adapt the national systems accordingly.

### *c. Access to information*

Through their joint bodies, riparian countries should give each other access to relevant information on surface water and groundwater quality and quantity. This should include, for example, information on surface water quality when surface water has been used as infiltration water for drinking water purposes.

Through their joint bodies, riparian countries should make arrangements so that the public has access to relevant information, collected both by riparian countries and by joint bodies.

To be effective, arrangements for the exchange of information among riparian countries and arrangements for the provision of information to the public should be governed by rules jointly agreed by the riparian countries. These arrangements should specify the format and frequency of reporting. The creation and maintenance of a joint database could also be useful. In drawing-up these arrangements, account should be taken of obligations under other international agreements and supranational law, such as European Community directives, to monitor, assess and report on groundwater quality and quantity.

### *d. Quality system*

Riparian countries should, where appropriate, assign to their joint bodies responsibilities related to quality systems. Particular attention should be paid to the harmonisation of sampling and data-processing methodologies, as well as laboratory accreditation. Cooperation on the local level for carrying out monitoring practices should be encouraged and promoted including direct contacts between laboratories and institutions involved.

## 8.3 Other arrangements at the national and/or local levels

### *a. Institutional, legal or administrative arrangements*

The lack of proper institutional, legal or administrative arrangements at the national and local levels may considerably hamper international cooperation. Such arrangements include the cooperation between local governments, the responsibility for and ownership of groundwater, legislation and regulations (e.g. abstraction permits, protection areas), the coordination of quality and quantity monitoring by various national institutes and the appointment of a national reference laboratory.

Riparian countries should adapt existing agreements to the obligations set out in the Convention and draw up new agreements for establishing and maintaining harmonised or joint monitoring programmes in transboundary aquifers. These programmes should use standardised sampling and laboratory procedures.

*b. Financial arrangements*

Riparian parties should provide sufficient funding for the execution of monitoring and assessment activities and joint research within the framework of the Convention. This funding could be part of the regular budget. Each country should take care of its own requirements. Funding can, for example, be based on pollution charges or fees. The establishment of an environmental fund, from which companies can take loans for investments, may accelerate improvements. Other possibilities for funding are applying for EU budgets (TACIS, PHARE) or other funds (GEF, World Bank). Generally, joint proposals are recommended because they are accepted more easily by the institutions involved.

# Further reading

The Core Group drew up background reports on which the draft Guidelines are based. These include:

- Inventory of transboundary groundwaters
- Problem-oriented approach and the use of indicators
- Application of models
- State of the art on monitoring and assessment of groundwaters

As a part of the project two cases were described:
*(available upon request)*

- Aelmans, F., 1997. Digital Waterway Vechte
- De Louw, P.G.B. and R.J. Stuurman, 1997. Cross-border (ground)water; Water system optimisation of the Merkske catchment area at the Dutch-Belgian Border.

Basic literature on monitoring and assessment was also used. It includes:


- WHO, 1992 GEMS/WATER Operational Guide. Third Edition. GEMS/W.92.1 WHO, UNEP, UNESCO, WMO.

- WMO, 1994. Guide to hydrological practices. Fifth edition. WMO-No. 168. Geneva.

- WMO, 1996. Technical Regulations. Volume III, Hydrology, WMO-No. 49. Geneva.

- UN/ECE, 1989. Charter on groundwater management. ECE/ENVWA/12. New York.

- UN/ECE, 1992. Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

- UN/ECE, 1993. Protection of Water Resources and Aquatic Ecosystems, Water series No. 1. ECE/ENVWA/31, New York.

- UN/ECE, 1995. Protection and sustainable use of waters - recommendations to ECE Governments. Water series No. 2. ECE/CEP/10. New York and Geneva.

- UN/ECE, 1996. Protection of transboundary waters. Guidance for policy and decision-making. Water series No. 3. ECE/CEP/11. New York and Geneva.

- UNESCO, 1992. International glossary of hydrology.

- UNESCO-UNEP, 1983. Hydrological principles of groundwater protection. Handbook of scientific methods, vol. 1.

- Chapman, D. (Ed.), 1992. Water quality assessments. A guide to the use of biota, sediments and water in environmental monitoring. UNESCO, WHO, UNEP.

- ISO 5667-11:1993, Water Quality Part 11: Guidance on sampling of groundwaters

- ISO standards handbook 16, 1983.

- ISO standards compendium, 1994. Environment, water quality, first edition.

- ISO guide 9000 Quality management and quality assurance standards 1994.
  Part 1 : Guidelines for the selection and use
  Part 2 : General Guidelines for the application of ISO 9001, 9002 and 9003
  9001 : 1987 Quality systems - Model for quality assurance in design, development, production, installation and servicing
  9002 : 1987 Quality systems - Model for quality assurance in production and installation
  9003 : 1987 Quality systems - Model for quality assurance in final inspection and test.

- EN 45001: 1989 General criteria for the operation of testing laboratories.

- EN 45002: 1989 General criteria for the assessment of testing laboratories.

- Organisation for Economic Cooperation and Development, 1989, Water resources management. Integrated policies, Paris, 199 pp.

- United Nations, 1991. Groundwater in Western and Central Europe. Natural Resources Water Series no. 27, ST/TCD/12, UN Dept. of Techn. Cooperation for Development, New York, 363 pp.

And various papers from the proceedings of the international workshops Monitoring Tailor-made I and II:

- Adriaanse, M., J. van de Kraats, P.G. Stoks, and R.C. Ward (Eds.), 1995. Proceedings, Monitoring Tailor-made, an international workshop on monitoring and assessment in water management. September 20-23 1994. Beekbergen, Netherlands

- Ottens, J.J., F.A.M. Claessen, P.G. Stoks, J.G. Timmerman, R.C. Ward (Eds.). Proceedings of Monitoring Tailor-made II, an international workshop on information strategies in water management, September 1996, Nunspeet, Netherlands.

And some other books and papers:

- Chilton, P.J. and C.J. Milne, 1994. Groundwater quality assessment: A national strategy for the NRA. Technical report WD/94/40C.

- Chilton, P.J. and S.S.D. Foster, 1997. Monitoring for groundwater quality assessment: current constraints and future strategies. British Geological Survey. Proceedings of the international workshop Monitoring Tailor-made II, September 1996, Nunspeet, Netherlands.

- Domenico, P.A. and F.W. Schwartz, Physical and Chemical Hydrogeology, John Wiley & Sons, Inc, New York, 1990.

- Edmunds, W.M., 1996. Indicators in the groundwater environment of rapid environmental change. In: Geo-indicators, assessing rapid environmental change on earth systems. Balkema, A.A., Rotterdam, Netherlands.

- EEA, 1998. EUROWATERNET. The European Environment Agency's Monitoring and Information Network for Inland Water Resources. Technical Guidelines for Implementation. Technical Report no. 7.

- EEA, 1999. Groundwater quality and quantity in Europe.
  - Environment assessment report, no. 3. ISBN 92 9167 146
  - Data and basic information. Technical report, no. 22.

- EIW, Preparation of a Network on Monitoring, Final Discussion Report on groundwater monitoring related to the proposed EC Groundwater Action programme; European Institute for Water (EIW), Paris/Brussels, 1992.

- EurAqua, 1995. Proceedings: Optimizing Freshwater Data Monitoring Networks including Links with Modelling. Second technical review. European Network of Fresh Water Research Organisations. Paris, La Defense, Octobre 18 - 20, 1995.

- IAHS Press, 1991. Hydrological interaction between atmosphere, soil and vegetation. Institute of Hydrology, Wallingford, IAHS publication No. 204, 1991.

- IAHS Press, 1996. Models for assessing and monitoring groundwater quality. Institute of Hydrology, Wallingford, IAHS publication No. 227, 1996.

- Intergovernmental Task Force on Monitoring Water Quality, 1995, Final report of the Intergovernmental task force on monitoring water quality.

- Jousma, G. and J.W. Willems, 1996. Groundwater monitoring networks. European Water Pollution Control, Vol. 6, no. 5, 1996.

- Loaiciga, H.A. et al., 1992. Review of groundwater quality monitoring net work design. ASCE Task Force Committee on Groundwater Monitoring Network Design. Journal of Hydraulic Engineering, 118(1): 11-37.

- Miller, D.W., 1981. Guidelines for developing a state-wide groundwater monitoring programme. Ground Water Management Research (GWMR) 32-33.

- Nyer, E.K. and L. Stauss, 1997. Monitoring Plans. Ground Water Management Research (GWMR), 67-70.

- REGIS, REgional Geohydrological Information System, Netherlands Institute of Applied Geoscience TNO Brochure nr. 5.02, June 1998.

- Uil, H., R. Mulder, W. van der Linden and F. Aelmans, 1999. Digital Waterway Vechte, Set up and implementation of a transboundary geohydrological information system between Germany and Netherlands for the catchment of the river Vechte. International Conference On Quality, Management and Availablity of Data for

Hydrology and Water Resources Management, Koblenz, Federal Republic of Germany, 22-26 March 1999.

- U.S. Intergovernmental Task Force on Monitoring Water Quality, 1995. The strategy for improving water-quality monitoring in the United States. Final report, February 1995.

- Van Bracht M.J., H.P. Broers, J.H. Hoogendoorn, W. van der Linden and F. Waardenburg, 1993. REGIS/Digital Groundwater Map; Construction of a Visualization and Manipulation Tool for Groundwater Related Problems on a Regional Scale. HydroGIS 93 conference, UNESCO/IAHS.

- Van der Heijde, P.K.M., A.I. El-Kadi and S.A. Williams, 1998. Groundwater modelling: An overview and State report, CR-812603, GWS, Indianapolis, Indiana 42208, USA.

Map series:

- UNESCO's Geological World Atlas UNESCO, 1976

- UNESCO's Atlas of World Water Balance, 1 : 20,000,000 UNESCO, 1974-1977

- Vegetation maps of the Council of Europe, 1: 3,000,000 Council of Europe, 1979

- Soil map of the European Communities, 1:1,000,000 (Tavernier et al. 1985.) - Commission of the European Communities

- Land use maps of Europe, 1:2,500,000 (source unknown)

- The international Geological Map of Europe, 1:1,500,000 UNESCO, 1974-

- The international hydrogeological map of Europe, 1:1,500,000 UNESCO, 1970-

- the international Quaternary map of Europe, 1:2,500,000 UNESCO, 1967

- maps of Groundwater resources in the EC in 38 sheets, 1:1,000,000 European Communities, 1992

- EEA Monograph on groundwater quality and quantity in Europe, European Environment Agency, July 1998.

# Glossary of terms

- **aquiclude**
  A formation with a very low permeability with respect to surrounding formations.
- **aquifer** *syn*. groundwater reservoir
  Permeable water bearing formation capable of yielding exploitable quantities of water.
- **aquitard**
  A formation with a relative low permeability with respect to surrounding formations.
- **discharge area**
  An area where groundwater leaves the aquifer by springs, swamps and baseflow to streams or to the ocean.
- **groundwater**
  All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil (definition from the Protocol on Water and Health).
- **indicators**
  A piece of information that a) is a part of a specific management process and can be compared with the objectives of that management process and b) has been assigned a significance beyond its face value. Indicators always correspond to a specific view and serve a specific use community. This makes indicators different from general purpose statistics.
- **intake area** *syn*. **recharge area;** replenishment area
  An area where water percolates from the surface into the saturated zone.
- **issue**
  An environmental problem which is generally recognised (it is on the political agenda). Often a specific policy has been drafted for it, which includes: research, surveys, monitoring and measures.
- **joint bodies**
  Bodies that are set up by riparian parties in accordance with the Convention to coordinate the execution of relevant provisions of the Convention, as targets mentioned in a strategic action plan or in the applicable bilateral and/or multilateral agreements.
- **recharge area** *syn*. **intake area**
- **transboundary groundwaters**
  Any groundwaters which cross or are located on boundaries between two or more States.
- **transboundary impact (in case of transboundary aquifers)**
  Any significant adverse effect on the environment resulting from a change in the conditions of transboundary groundwaters caused by a human activity, the physical origin of which is situated wholly or in part within an area under the jurisdiction of a Party, within an area under the jurisdiction of another Party. Such effects on the environment include effects on human health and safety, flora, fauna, soil, water, climate, landscape and historical monuments or other physical structures or the interaction among these factors; they also include effects on the cultural heritage or socio-economic conditions resulting from alterations to those factors.

**Note:**
More definitions related to groundwater can be found, for example, in the UNESCO International glossary of hydrology) (See also "Further reading").

# Annex Internationally used indicators

**Table a.**
Possible indicators of rapid environmental change in groundwater systems as developed in Great Britain (Edmunds, 1996)

| issue | indicators | | | |
|---|---|---|---|---|
| | *primary indicators* | | *secondary indicators* | |
| | | | saturated zone | unsaturated zone |
| desiccation | water level | | spring discharge | |
| groundwater resource | | | index of water storage change | |
| acidification | water level | DO | Al, Ca | Al, Ca |
| salinization | $NO_3$ | | Mg/Cl, Br, $\partial^{18}O$ (TDS, SEC) $\partial^2H$ | Mg/Cl, Br, $\partial^{18}O$ (TDS, SEC) $\partial^2H$ |
| pollution linked to agriculture | DOC | pH | K, Na, $PO_4$, pesticides | K, Na, $PO_4$, pesticides |
| industrial pollution | $HCO_3$ DOC | Cl | B, $PO_4$, solvents, metals | |
| radioactive contamination | | | $^3H$, $^{36}Cl$, $^{85}Kr$ | $^3H$, $^{36}Cl$, $^{85}Kr$ |
| aquifer redox state | $HCO_3$ | DOC | Eh, Fe(II), HS | |
| deforestation | $NO_3$ | Cl | Cl | Cl |
| depletion paleo water | | | $\partial^{18}O$, $\partial^2H$, $^{14}C$ | $\partial^{18}O$, $\partial^2H$, $^{14}C$ |
| over-exploitation | | | $\partial^{18}O$, $\partial^2H$, | |
| climate change | | | | |
| pollution by mining | pH | $SO_4$ | metals | |

**Table b.**
Indicators used by the US EPA Office of Water, 1995

| issue | function | indicator |
|---|---|---|
| impaired drinking water | drinking water | number of protected sources<br>number of cases of waterborne diseases<br>blood lead levels in children<br>violations of drinking water standards<br>% of water that meets standards |
| desiccation declining groundwater tables | ecosystem | species at risk<br>biological integrity of the water |
| | agricultural irrigation | wetland acreage<br>50% of groundwater wells support intended use |
| | industrial processing | 50% of groundwater wells support intended use |
| diffuse pollution | drinking water<br>ecosystem<br>agricultural irrigation<br>industrial processing | % reduction of farmland erosion |
| point source pollution | drinking water<br>ecosystem<br>agricultural irrigation<br>industrial processing | reduction in pounds of pollution discharge |

**Table c.**
Examples of PSIR indicators for different issues (OECD, 1993 and 1994; Knoop, 1994; Buijs and Dogterom, 1995; Bakkes et al., 1994; US EPA, 1993 and 1995; Krol, 1994; RIKZ, 1995)

PSIR indicators

| issue | pressure | state | impact | response |
|---|---|---|---|---|
| excess nutrients | use of fertiliser (N,P)<br>discharge of N and P to groundwater<br>density of cattle<br>type of agricultural method<br>type of crop | BOD, DO, N, P in water<br>% of $m^3$ of water not in compliance with drinking water standards | effect on ecosystem<br>vegetation change<br>soil detoriation<br>salinization | cost of purification for designated use |
| acidification | deposition of acidifying substances<br>agricultural methods | pH, $SO_4$, $NO_3$ in precipitation | effect on ecosystem<br>vegetation change | cost of air pollution reduction programmes |
| salinization | discharge to water<br>type of crop<br>agricultural use (irrigation)<br>industrial water use<br>domestic water use<br>water management<br>climate<br>plant cover | water quality (salt)<br>concentration Cl | loss of yield<br>impairment of drinking water quality | artificial recharge<br>cost of drinking water<br>control abstraction<br>more efficient water use<br>water treaties |
| dispersion of heavy metals | | concentration of heavy metals | Pb levels in blood | |
| hydrological change/ desiccation | desiccation | length of dry season<br>water temperature<br>salt content<br>amount ($m^3$) water in shallow aquifers | impairment/loss of wet ecosystems | increase in cost of drinking water |
| waste | production of:<br>domestic waste<br>industrial waste<br>nuclear waste<br>other hazardous waste | number of dump sites<br>amount of waste | leakage to groundwater | measures to decrease waste production<br>taxes on waste recycling |
| dispersion of other hazardous substances | production/transport/ use/storage of hazardous substances | concentration of hazardous substances | number of water-borne diseases<br>number of cases exceeding drinking water standards | % of drinking water sources with protection programmes |