International Groundwater Resources Assessment Centre

World-wide inventory on groundwater monitoring

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Utrecht
October 2004

International Hydrological Programme

United Nations Educational, Scientific and Cultural Organization

World Meteorological Organization

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1 Introduction

About two-third of the world's population depends for its water supply on groundwater resources. With a gradually increasing population many of the available groundwater systems in the world are ever more under stress of exploitation and contamination. Widely observed effects are dropping groundwater tables, depletion of groundwater reserves, deterioration of groundwater quality, degradation of nature reserves and ecosystems, and in many coastal zones seawater intrusion and land subsidence. With these problems growing, the awareness of the need for sustainable management of the groundwater resources has also increased. Moreover, it is recognised that successful management needs to be based on sufficient and sound data regarding the groundwater resources and their environment, and the stresses upon these systems.

IGRAC's inventory on existing monitoring practice is meant to reveal the state of groundwater monitoring world-wide and to identify the needs of the international community for support with information and guidelines. The inventory serves as a basis for ideas on promotion of groundwater monitoring world-wide. In this respect IGRAC formulated proposals for improved monitoring. One of the ideas is to produce a guideline on "baseline groundwater monitoring" in support of development and management of groundwater resources in countries, where groundwater monitoring is not yet standard practice.

Only about 20 % of the 233 countries responded to IGRAC's questionnaire on groundwater monitoring. So information was also searched for through other channels, for instance by studying earlier inventories and by holding interviews with experts who have been involved in groundwater studies in developing countries. It may be clear that the inventory report, based on information from some 60 countries is still far from complete. Therefore, it is not possible to provide a detailed geographical picture of the situation on groundwater monitoring worldwide. Yet the information covers a variety of different conditions with respect to climate, hydrogeology, water availability and water needs, economical development and social conditions. So the available information provides a reasonable sample of different situations encountered and can be used as a basis for formulating ideas and proposals. Also it will be possible to verify, amend and complete the existing picture gradually through IGRAC's contacts in the near future.

Acknowledgement

Without mentioning names IGRAC would like to thank all persons who have contributed to this report by responding to the questionnaire on groundwater monitoring. Also we want to thank the professionals who in interviews supplied information on groundwater monitoring from countries where they have been involved in groundwater studies. Without this valuable information it would not have been possible to get a good overview. IGRAC will keep these persons informed about further developments. We may also need them to comment on our proposals for development or to participate in further activities initiated by IGRAC.

2 Set-up of the investigations

2.1 Objectives of the inventory

The world-wide inventory on groundwater monitoring was conducted by IGRAC according to its Workplan 2003-2006. The purpose of the questionnaire on groundwater monitoring was to assess the actual situation with respect to groundwater monitoring and to identify the needs for information and guidelines. Results of the investigations would be used by IGRAC for:

- Preparation of an inventory report on the actual state with respect to groundwater monitoring world-wide and the possible needs for information and support from IGRAC.
- Formulation of ideas for improved monitoring, such as a proposal for baseline monitoring in countries that have no significant monitoring practice.
- Planning of IGRAC activities, aimed at providing information or guidance in the field of monitoring.

2.2 Set-up of the investigations

In order to get a broad picture of the state and needs with respect to groundwater monitoring, the inventory of monitoring practice world-wide was conducted through a combination of activities. These are:

- Disseminate the IGRAC-questionnaire on groundwater monitoring to 233 countries and analyse the responses;
- Study the EEA-inventory on groundwater monitoring (Koreimann, 1996);
- Study reports of international organisations with respect to monitoring;
- Conduct Internet searches for documents on groundwater monitoring;
- Study conference proceedings, especially those on groundwater monitoring;
- Study reports on groundwater assessment;
- Interview experts who have been working in international water projects.

IGRAC's questionnaire:

IGRAC's questionnaire was developed in October 2003. The questionnaire was divided in four distinct subject areas, viz.

1) Groundwater situation in your country,
2) Monitoring groundwater quantity
3) Monitoring groundwater quality
4) Technical support required from IGRAC.

An original questionnaire is presented in appendix A.

The questionnaire was composed in the English language. However, it was made clear to the potential respondents that answering the questionnaire in other languages, viz. French, German, Russian or Spanish would not be a problem for IGRAC.
The questionnaire was set up as an Excel 97 based digital questionnaire and made available via the IGRAC web. The advantages of a digital version are quick dissemination and response possibilities by e-mail, as well as quick post-processing options. For people without access to Excel 97 the IGRAC web site provided the questionnaire as a Word 2.x file, available for almost every respondent.

The digital questionnaire was forwarded to representatives of the International Hydrological Program (IHP) of UNESCO and of the National Committees of the International Association of Hydrogeologists (IAH) by using the contacts (e-mail addresses) of these international organisations. These representatives are based in about 180 countries world wide (roughly about 75% of the world's 233 countries. E-mail addresses of the other countries, mostly minor ones, were not known.

The first questionnaires were e-mailed by the end of October 2003 and the inventory closed at the end of March 2004. During that period IGRAC also informed the professionals of the groundwater community about the inventory on the websites of IHP, IAH and Partners For Water (PVW) and through the newsletters of IAH and IGRAC.

By September 2004 the questionnaire had been answered by 44 persons from only 40 countries. A table showing the number of countries per continent is given below. A detailed description and overview of the answers given is presented in Appendix A.

- Africa 10
- Asia 9
- Europe 11
- North America 3
- South America 5
- Oceania 2

Limitations
Getting a useful response to the questionnaire proved to be a difficult and time-consuming process, for several reasons. To mention some:

- The questionnaire had to be focusing on the main subjects and could not be too lengthy and get into too much detail, because respondents cannot be expected to spend much time.
- A stepwise approach with a number of forms (such as in the European questionnaire) was not considered feasible within the limited timeframe.
- It obviously takes time before the questionnaires reach the right persons. The questionnaires were sent to national representatives of UNESCO and IAH in about 180 countries, who may have to forward it to experts in the field of monitoring.
- In larger countries, with a variety of catchments and aquifer systems, it may be difficult to find persons having a good overview of the groundwater systems, the problems, and the needs for monitoring willing to answer the questionnaire.

From the relatively limited response to the questionnaire it is difficult to tell how representative the answers are. Statistics may be somewhat different in reality.

EC-inventory on groundwater monitoring

In 1996 the European Topic Centre on Inland Waters published a report with the title "Groundwater monitoring in Europe". The objective of the report was *"to give an overview of the current groundwater quality an quantity networks and monitoring procedures within the European Environmental Agency (EEA) area"*. The questionnaire contains four parts: (1) general description of monitoring activities at the country level; (2) surface water quantity monitoring; (3) groundwater quality; and, (4) groundwater quantity monitoring.
The major part of the report (40 pages) describes the aspects of groundwater monitoring for almost all countries in the EEA area. It contains a large amount of facts and figures about the national networks, including the type of databases used.

Study of reports from international organisations

Study of the global situation on groundwater and groundwater related programmes on the basis of international publications like World Water Development Report (UN/WWAP 2003), Global Environmental Outlook 3 (UNEP 2002) and others. These reports provide valuable background information about the water situation in the various countries and about international programmes related to the subject. However, it proved to be difficult to correlate the information to the results of the worldwide inventory on groundwater monitoring, at least for the time being.

Conference proceedings

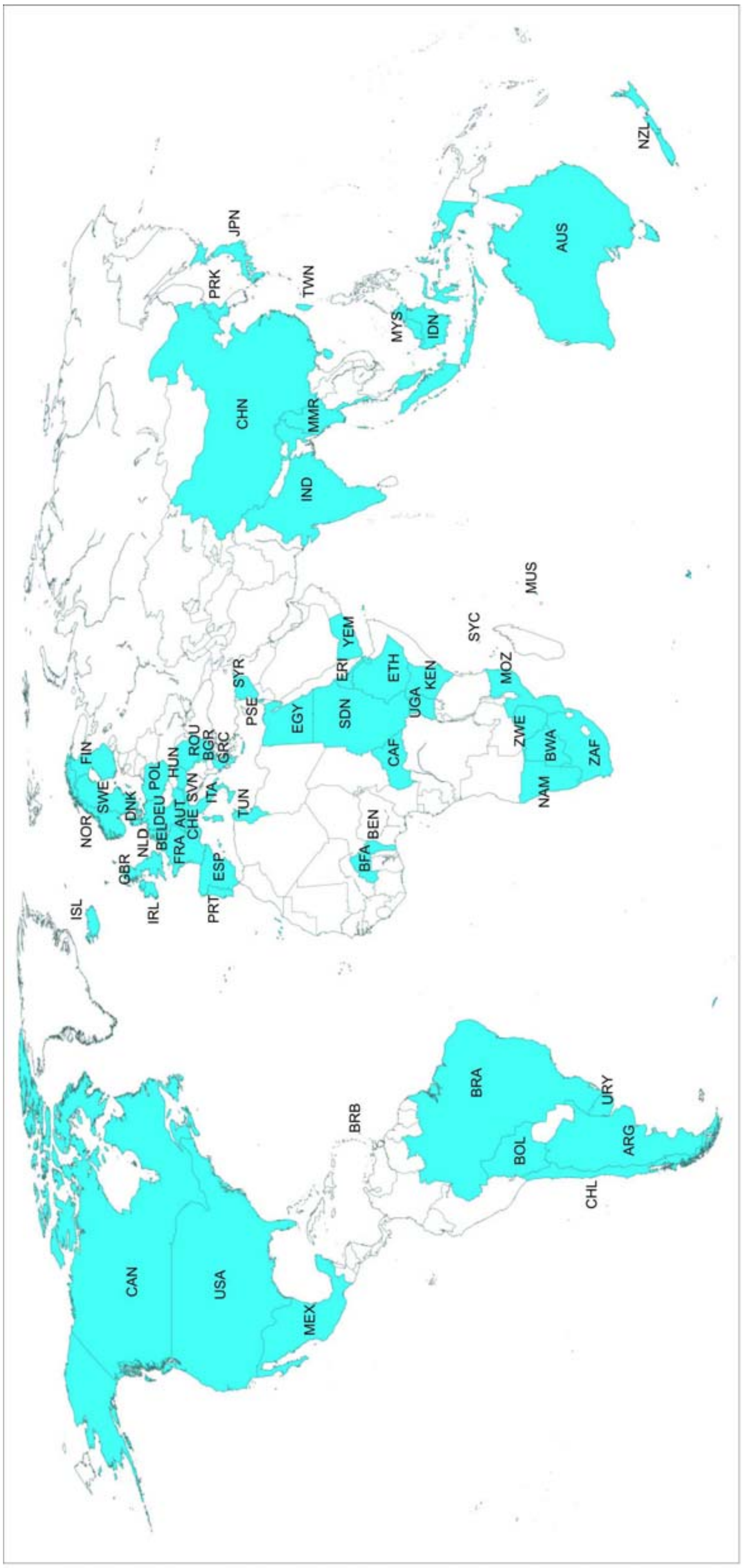
IGRAC staff also analysed the proceedings of some conferences on monitoring. These conference proceedings yielded only scarce information on groundwater monitoring activities worldwide. Even conferences especially dedicated to the subject of monitoring, such as "Monitoring Tailor-made" did not have many papers on field studies. Many papers contribute theoretical aspects and ideas about groundwater monitoring, but very few papers show practical results in relation to the properties of monitoring networks. A good exception is the proceedings of the second conference on Monitoring Tailor-made, with contributions on monitoring in Germany, Italy, Russia and Spain.

Results

Table 2.1 gives a concise overview of the information inventoried. All in all IGRAC collected information on groundwater monitoring from some 60 countries, with a reasonable worldwide coverage. Figure 2 give the global overview of these 60 countries.

Table 2.1: Overview of information sources

	Source of information	**Monitoring info** (number of countries)	**Specific info** (from websites, etc.)
1	IGRAC-Questionnaire	40	
2	EG-European inventory	16	
3	International organisations		Reports
4	Internet		Reports & papers
5	Conference proceedings		Papers
6	Reports		Methodology
7	Interviews	17	
Monitoring info (excluding country overlaps): About 60			



ARG	Argentina
AUS	Australia
AUT	Austria
BEL	Belgium
BEN	Benin
BFA	Burkina Faso
BGR	Bulgaria
BOL	Bolivia
BRA	Brazil
BRB	Barbados
BWA	Botswana
CAF	Central African Republic
CAN	Canada
CHE	Switzerland
CHL	Chile
CHN	China
DEU	Germany
DJI	Djibouti
DNK	Denmark
EGY	Egypt
ERI	Eritrea
ESP	Spain
ETH	Ethiopia
FIN	Finland
FRA	France
GBR	United Kingdom
GRC	Greece
HUN	Hungary
IDN	Indonesia
IND	India
IRL	Ireland
ISL	Iceland
ITA	Italy
JPN	Japan
KEN	Kenya
LVA	Latvia
MEX	Mexico
MMR	Myanmar
MOZ	Mozambique
MUS	Mauritius
MYS	Malaysia
NAM	Namibia
NLD	Netherlands
NOR	Norway
NZL	New Zealand
POL	Poland
PRK	South Korea
PRT	Portugal
PSE	Palestine
ROU	Romania
SCG	Serbia and Montenegro
SDN	Sudan
SVN	Slovenia
SWE	Sweden
SYC	Seychelles
SYR	Syrian Arab Republic
TUN	Tunisia
TWN	Taiwan
UGA	Uganda
URY	Uruguay
USA	United States of America
YEM	Yemen
ZAF	South Africa
ZWE	Zimbabwe

Figure 2.1: Overview of countries of which information on groundwater monitoring is available

3 Historical development of groundwater monitoring

3.1 Some historical facts

As far as known the first network for monitoring groundwater levels was set up in England/Wales around 1845. Other European countries followed in the twentieth century. Systematic monitoring in Europe started in the period 1950-1980. Many records of groundwater level data have now a length of 20 - 30 years.
France set up the first groundwater quality network in Europe in 1902. However, systematic groundwater quality monitoring in most countries started not earlier than 1980.

First groundwater monitoring in the USA dates from the beginning of the twentieth century, as may be illustrated by the report "Water Fact Sheet, History of Water Resources Activities of the USGS" (USGS, 1985). To meet new and stronger demands for information on the availability and efficient use of ground water, recording groundwater levels in observation wells began in New Jersey by 1923 and in Pennsylvania by 1925. The first know national compilation of a groundwater map titled "Ground-Water Provinces in the US" was presented by Meinzer in 1923 according to the USGS (Meinzer, 1923). The ground-water observation well network had been extended nationwide by the end of 1960.

In many developing countries the start of international projects on groundwater assessment or on urban water supply from groundwater marks the first steps in monitoring. Unfortunately many of these projects have led to only short-term records that stopped not long after the end of the project.

Development and status of groundwater monitoring networks depend on many factors. On the one hand monitoring networks are adjusted to the development of groundwater resources exploitation and the increasing impacts on the environment. Monitoring networks may evolve from very incoherent collections of wells in the reconnaissance stage of groundwater resources assessment to multifunctional networks for complex situations of groundwater exploitation. On the other hand local factors such as climate, topography and hydrogeology as well as population density, economy, etc. are of great influence on the actual state of the networks. In next paragraph some aspects of monitoring network development will be discussed.

3.2 Development of monitoring networks

From temporary to permanent groundwater monitoring

Groundwater monitoring generally starts with local problems, for instance, when groundwater levels drop because of groundwater withdrawal or when the quality of pumped water is deteriorating. In such cases monitoring will be conducted on a local scale, whenever possible by making use of available wells. In this stage investments made for observation of water levels or sampling and analysis of groundwater quality are often kept to a minimum.
Such local networks may never develop into more permanent ones if the reason for their existence vanishes after some time, for instance, when the investigations end. This is the fate of many local monitoring networks, created for the purpose of temporary studies. Also many networks installed for national or international groundwater resources development projects have ended up like that. These situations can be found in practically any country of the world where groundwater is important for development.
Conditions change, for instance, where and when water supply requires data on a more permanent operational basis, or where conflicting interests are constantly demanding attention. In such cases

the local groundwater situation needs to be observed more permanently. Many local networks employed around well fields for water supply of big cities are having such a permanent status.

From local to regional groundwater monitoring networks

There are a number of conditions that may require operating large regional networks.
1. The scale of the aquifers exceeds the local scale. Regional monitoring networks are not needed where groundwater pockets are of local size and isolated from each other, for instance in basement areas;
2. The impact of interventions exceeds the local scale, interfering with one another. These situations cannot be treated as isolated local problems. For instance, the drawdown effect from one well field interferes with that of other well fields at considerable distance.
3. Pro-active planning of water resources development in large size aquifers often requires a reference network exceeding the local scale of effected area. The reference network is used to provide the data for quantifying the expected impacts and to provide reference values from unaffected areas for comparison.

From use of available wells to specially drilled monitoring wells

In the initial stage of water resources development in an area, when the characteristics of an aquifer are not known well, groundwater level measurements are usually taken in any type of suitable existing well. In that stage networks may be far form ideal with considerable gaps.
Usually, as time proceeds and the potential of the aquifer for water supply becomes better known and is being exploited more intensively, also the need for data will become more urgent. As soon as the interest increases it will become easier to find funds for analysis of relevant processes and for monitoring. In that phase the monitoring network can be improved with extra observation wells. Finally, when conflicts of interest increase and groundwater management is in need of more detailed data, the monitoring network may even be adjusted more precisely to the needs of information with the help optimisation techniques.

3.3 Variation in stage of groundwater monitoring

The table below shows the stage of groundwater monitoring in different countries, according to the information from the questionnaire and the interviews.

Table 3.1: Groundwater monitoring stage - variation among countries (examples)

	Category	***Countries (examples)***
1	As far as known, no significant and systematic groundwater monitoring going on. Only scattered and temporal groundwater monitoring activities, mostly problem driven.	Africa: Burkina Faso, Eritrea, Kenya, Mozambique, Sudan, Zimbabwe; Asia: Myamar; C- & S-America: Bolivia, Paraguay, and Uruguay.
2	Local groundwater monitoring networks running for several years already, with regular frequency (e.g. networks around well fields)	Africa: Benin, Central African Republic (?),Ethiopia, Namibia, South-Africa; Asia: Djibouti, Indonesia; Palestine, Syria, Yemen; N-America: Canada;
3	National or regional reference groundwater monitoring networks operational in combination with local groundwater monitoring networks	Africa: Botswana, Egypt, Mauritius, Seychelles, Tunisia; Asia: China, India, Japan, Korea, Malaysia; Australia; New Zealand; Europe: Austria, Belgium, Bulgaria, Denmark, Finland, Germany, Hungary, Italy, Moldova, Netherlands, Poland, Romania, Slovenia, Switzerland; N-America: USA, Mexico; C- & S-America: Barbados, Brazil, Chile;

Comments:

Based on the available data three stages of groundwater monitoring have been considered:
1. *No significant and systematic groundwater monitoring going on* or only project-wise or problem-driven. This is a situation often found in countries, where groundwater development is in an early stage. Data on groundwater levels or groundwater quality are monitored within the framework of local and temporal projects.
2. *Local groundwater monitoring networks monitored with regular frequency for several years.* This situation exists in countries, where systematic groundwater development and monitoring have become important. However, the situation may also be found in countries where no need for large regional or national groundwater monitoring networks exists.
3. *National or large regional reference groundwater monitoring networks in combination with local networks.* Many countries are planning their groundwater development with the help of a national monitoring network or large regional groundwater monitoring networks. The networks are used to investigate the properties of regional groundwater systems and their potential and suitability for water supply. Provision of licenses for withdrawal may be made dependent from these estimates (for instance in India and Moldova).
   A combination of a national or large regional and local networks offers the advantages of flexibility (a general overview and a detailed picture wherever necessary). Many countries use such combinations for their groundwater management.

Information drawn from the questionnaire and the interviews (Table 3.1) shows the following:
- A number of the countries for various reasons do not have permanent groundwater monitoring networks (Category 1).
- A significant number of the countries have permanent local networks for monitoring (Category 2).
- The largest part of the countries has at least one (or more) regional groundwater monitoring networks in combination with local ones.

The classification is based on the information provided by respondents to the questionnaire and consulted professionals.

4 Groundwater level monitoring

4.1 Monitoring objectives

General

A clear specification of monitoring objectives and required information is critical information for design of a monitoring network that is meant to provide the necessary data for water management. From experience it turns out that a significant share of the costs of monitoring may be saved if the objectives are well defined and specified.

Monitoring objectives can be defined from different perspectives. At least two "levels" of objectives can be distinguished:

- *The management level of objectives.* Management objectives are for instance: a) developing groundwater resources for drinking water supply, optimisation of crop production, protection of nature conservation areas, restoration of wetlands, dealing with claims concerning damage, etc.
- *The technical level of objectives.* Technical objectives are for example: to determine the directions of groundwater flow, to establish the areas of infiltration and seepage, to quantify the relation between groundwater and surface water, to feed the groundwater models, etc.

The objectives will first have to be translated into clear technical specifications to relate them to the monitoring network (see Appendix C for more information on this subject). Both types of objectives have been inventoried (see Appendices A and B).

Groundwater level monitoring for water supply and groundwater management

With respect to the main focus of groundwater level monitoring in different countries, roughly four categories can be distinguished, see table 4.1.

Table 4.1: Groundwater level monitoring focus - variation among countries (examples)

Stage	***Main focus***	***Objectives***	***Regions and Countries (examples)***
1	Assessment	Reconnaissance of groundwater systems (including spatial patterns and temporal trends) and assessment of the potential for water supply.	Africa: Botswana, Djibouti, Ethiopia, Seychelles, South Africa, Tunisia Asia: China, India, Japan, Korea, Myanmar, Palestine, Yemen Europe: Belgium, Bulgaria, Denmark, Hungary, Italy, Poland, Moldova, Netherlands, Romania, Slovenia N-America: Canada (Quebec), USA Oceania: Australia, New Zealand C- & S-America: Argentina, Barbados, Brazil, Chile, Uruguay
2	Optimized Development	Groundwater levels monitored for optimisation of groundwater withdrawal.	Africa: Benin, Central African Republic; Asia: China, Japan, S-Korea, Malaysia, New Zealand, Palestine; Europe: Belgium (F+W), Denmark, Finland, Moldova, Slovenia; N-America: Canada (Quebec); C- & S-America: Argentina, Barbados;
3	Integrated Management	Integrated water management and control of groundwater resources (pro-active).	Asia: India Australia; N-America: USA; Europe: Netherlands, Germany, Hungary

Comments
Regarding the purpose of groundwater monitoring, different stages have been distinguished. The focus of groundwater monitoring may be mainly on (1) groundwater assessment, (2) optimized development of groundwater resources, or (3) integrated water management.

The need for groundwater monitoring depends on the presence of groundwater resources, the need and possibilities to develop these resources and the conflicts of interest that may arise. In addition technical, economic and other factors determine the stage of groundwater monitoring.
In many countries there is a gradual transition from stage 1 to stages 2 or 3, marking the different stages of groundwater resources development. When the effects of development get more complex (different users and interests), regional networks are usually needed.
Stages 2 or 3 usually also require local networks. However, there is not always a need to reach the stages 2 or 3. For instance, when the need or possibilities to develop the groundwater resources are absent (no need for stage 2) or when conflicts of interest are no important issue (no need for stage 3). The position of countries in the table is mainly based on the response to the questionnaire.

Monitoring in relation to landsubsidence

Land subsidence is caused by compaction of clay and peat layers, usually when groundwater levels are drawn down by groundwater abstraction or increased drainage. Especially coastal zones with thick alluvial aquifer systems and high rates of groundwater abstraction are vulnerable areas for land subsidence. Many countries with coastal zones have such problems and are monitoring groundwater levels to control the situation, as can be noticed in Table 4.2.

Table 4.2: Groundwater level monitoring objectives - Land subsidence

	Category	***Countries (examples)***
	Land subsidence	Africa: South Africa Asia: Djibouti, China, India, Korea, Indonesia, Japan, Myanmar, Thailand; Europe: Belgium, Italy, Slovenia; N-America: USA, C- & S-America: Argentina, Brazil, Uruguay

4.2 Network types and configuration

On the basis of scale and objectives two types of groundwater monitoring networks can be considered:
a) large scale “primary networks” for overall studies of the groundwater system and for background and reference values;
b) locally oriented “secondary networks” installed for specific purposes.

Primary groundwater monitoring networks.
Primary networks for groundwater level monitoring (also called reference networks or background networks) are large-scale monitoring networks, usually covering aquifers of large regional size. They serve to provide data about groundwater system behaviour and overall impacts on the groundwater situation caused by groundwater exploitation and other interventions. They also serve as reference networks for specific local studies.
They may cover an entire country (e.g. Netherlands) or only the plains and valley fills. Primary networks have their observation wells in the major aquifers, mainly in the fresh water zones.
The selected wells are usually at relatively large distances, sufficiently close to provide an overall picture of the groundwater situation. In Europe for instance, the coverage of observation wells may range from 1 per 250 km^2 (Norway) to more than 5 on one square kilometre for special networks. The density of wells in confined aquifers can be much less than that in unconfined aquifers, which are more open to meteorological and human influences.

Secondary groundwater monitoring networks
Secondary groundwater monitoring networks are composed to serve specific purposes, such as monitoring water table decline around pumping well fields, monitoring effects of irrigation schemes, monitoring the groundwater levels in nature conservation areas, etc. These networks are usually local networks, adjusted to the specific situation they are meant for. Their configuration depends on the subject studied and the aquifer situation involved.

Combination of primary and secondary groundwater monitoring networks
Primary and secondary networks are often combined to a wide-spaced regional network with denser-spaced parts in areas of particular interest. The terminology of primary and secondary networks can be used to link these networks to respectively “overall objectives”, valid for large regions and “specific objectives”, used to focus on particular aspects and, usually, local conditions. The classification of primary and secondary networks may also be used to divide the responsibility for monitoring (and its expenses) between governmental organisations, responsible for overall water management, and organisations with specific tasks or interest.
Table 4.3 shows how a primary network can be combined with secondary networks to cover the objectives described in paragraph 4.1.

Table 4.3: Relation between “groundwater level monitoring objectives” and network types needed

Purpose	Description	Type of monitoring network	
		Primary monitoring network	Secondary monitoring networks
1	Investigation of aquifer characteristics and parameters;	X	
2	Characterisation of the groundwater system;	X	
3	Quantifying effects of groundwater abstraction;	X	X
4	Quantifying effects of surface water management;	X	
5	Quantifying effects of groundwater management measures	X	
6	Monitoring transboundary effects	X	
7	Protection of nature conservation areas	X	X

Use of networks world-wide – variation among countries

Stage of groundwater monitoring – Table 3.1

Table 3.1 (chapter 3) shows the type of monitoring networks used in a number of countries. The type of networks used is closely related to the stage of groundwater monitoring. A considerable part of the countries (13 out of 40) do not have permanent monitoring networks. It is quite difficult to conclude from the answers of the questionnaire, whether large permanent monitoring networks would be needed. However, many of these countries are arid or semi-arid countries and it can be safely assumed that they would benefit from reliable data on their groundwater resources.

Density of groundwater monitoring networks - Table 4.4

Asked about their opinion with respect to the density of the groundwater monitoring networks in their countries, the respondents answered as shown in table 4.4.
Most European respondents think the density of the observation wells in their country is either good or fair. A significant number of countries in Africa, according to the experts consulted, are not having sufficiently dense monitoring networks. Also the respondents of big countries like China, India and USA are of the opinion that their networks can still be improved.

Table 4.4: Opinions of respondents on density of observation wells – from different countries

	Opinion	***Countries (examples)***
1	*Good*	Africa: Mauritius Asia: Korea Europe: Bulgaria, Finland, Netherlands, Romania, Slovenia N-America: Canada Oceania: Australia C- & S-America: Barbados
2	*Fair*	Africa: Botswana, Seychelles Asia: Japan, Malaysia, Palestine Europe: Belgium, Denmark, Hungary, Switzerland Oceania: New Zealand C- & S-America: Uruguay
3	*Insufficient*	Africa: Benin, Djibouti, Ethiopia, South Africa, Tunisia Asia: China, India, Myanmar, Yemen Europe: Belgium N-America: Canada, USA C- & S-America: Argentina, Brazil, Chile, Mexico
4	*Negligible*	Africa: Central African Republic

4.3 Monitoring wells and equipment

To keep the questionnaire within reasonable limits, no questions were asked about the type of monitoring wells used in the various countries. These questions would probably have yielded similar answers without many surprising facts. For the sake of completeness the subject will be discussed on the basis of impressions obtained during participation in international projects by IGRAC staff.

Monitoring wells

Various types of wells can be used to observe groundwater levels in the initial phase of groundwater resources assessment, ranging from dug wells, abandoned or used production wells, to specially drilled monitoring wells.
After the potential of the groundwater system for water supply has been proven and development is on its way, the monitoring network may be improved by installing extra monitoring wells at critical locations and replacing available wells that do not fit the criteria.

Criteria for installation of monitoring wells can be found in internationally available handbooks. Newly installed monitoring wells will often be used for water level observation and for groundwater quality sampling as well. Therefore, installation of the well may need to satisfy both sets of criteria.

The following definition and sets of criteria comes from the US-EPA (Aller 1990):

> The primary objective of a monitoring well is to provide an access point for measuring ground-water levels and to permit the procurement of ground-water samples that accurately represent in-situ ground-water conditions at the specific point of sampling. To achieve this objective, it is necessary to fulfil the following criteria:
> - construct the well with minimum disturbance to the formation;
> - construct the well of materials that are compatible with the anticipated geochemical and chemical environment
> - properly complete the well in the desired zone;
> - adequately seal the well with materials that will not interfere with the collection of representative water-quality samples; and
> - sufficiently develop the well to remove any additives associated with drilling and provide unobstructed flow through the well.
>
> In addition to appropriate construction details, the monitoring well must be designed in concert with the overall goals of the monitoring program. Key factors that must be considered include:
> - intended purpose of the well;
> - placement of the well to achieve accurate water levels and/or representative water-quality samples;
> - adequate well diameter to accommodate appropriate tools for well development, aquifer testing equipment and water-quality sampling devices; and
> - surface protection to assure no alteration of the structure or impairment of the data collected from the well.

If two or more aquifers are found, separated by less permeable layers, monitoring or observation wells may have to be installed in each aquifer. If conditions are favourable, constructing one large diameter well with several piezometers, isolated from one another, can also do this.

Because of limitations of the questionnaire discussed in chapter 2, no details have been asked about the use of different types of monitoring wells. Therefore, it is not possible to provide statistics on this subject.

Water level measuring devices

Equipment for groundwater level measurement ranges from very simple measuring tapes for manual measurement (1 and 2) to sophisticated recorders (3 through 6) for continuous registration (Aller 1990):

1. *A measuring tape*. The basic water-level measuring device is a steel tape typically coated with ordinary carpenter's chalk. This is the simplest water-level measuring device considered accurate at moderate depths;
2. *A tape with electric sensor.* Electric sensors are suspended on the end of a marked cable. When the sensor encounters conductive fluid, the circuit is completed and an audible or visual signal is displayed at the surface;
3. *Float type devices* rest on the water surface and may provide a continuous record of water levels on drum pen recorders or data loggers. Float sizes range from 1.6 inches to 6.0 inches in diameter, but are only recommended for wells greater than 4 inches in diameter, due to loss of sensitivity in smaller diameter bore holes;
4. *Pressure transducers* are suspended in the well on a cable and measure height of water above the transducer centre. Transducers are available in diameters as small as 0.75 inches;
5. *Acoustic well probes* use the reflective properties of sound waves to calculate the distance from the probe at the wellhead to the water surface. Acoustic probes are designed for well diameters as small as 4 inches and are limited to water depths greater than 25 feet (Ritchey, 1986);
6. *Air lines* are installed at a known depth beneath the water and by measuring the pressure of air necessary to discharge water from the tube, the height of the water column above the discharge point can be determined.

The choice between manual observation and use of automatic recording depends on:

- Information needs (e.g. the need for frequent data or high level of accuracy);
- Institutional and financial conditions (designation of tasks and budgets, availability of trained staff, availability of cheap labour, etc.);
- Logistic and other conditions (distance to the wells, availability of transport, accessibility of the spot, permits, etc.).

Methods of water level recording world-wide

Based on documentation and the interviews it appears that manual recording of groundwater levels is still a widely used method. Automatic level-recording in most countries is restricted to rapidly changing values, such as surface water levels, and to places that are difficult to access. Many analogue recorders are still being used.
However, in industrialised countries, where wages are high and in many situations where reliability of data is valued highly, automatic groundwater level recording is increasing rapidly. Most countries make use of recently developed small size groundwater level probes with digital memory and connections for data transition. This is true for Europe, North America and Australia. Also India has made a considerable shift towards automatic recording.
It should be stressed that the absence of automatic water level recorders is not necessarily a constraint for effective and technically sound monitoring.

Table 4.5: Method of groundwater level recording - variation among countries (examples)

	Method of recording	***Countries (examples)***
1	Monitoring, predominantly by "manual" measurement and analogue recorders	The usual method in large parts of the world
2	Monitoring, increasingly using digital memory recorders	India Australia France, Germany, Hungary, Netherlands USA

4.4 Observation procedure

As a general rule, monitoring has to be adjusted to the dynamics of the groundwater system behaviour as well as to the monitoring objectives and required accuracy.

Initial stage of monitoring
In the initial stage of groundwater resources assessment the behaviour of the system is not known very well and one may have to resort to best estimates. However, in that situation the main objective for monitoring will be to identify the properties of the groundwater system, which does not require a very high degree of accuracy. In a later stage of groundwater resources development, when the systems' behaviour is known better, the frequency of observation can be adjusted more exactly to the systems' response.

Monitoring in production wells
A mix of wells can be used for monitoring groundwater levels, ranging from open dugwells, to tubewells, either abandoned or still producing, and specially installed observation wells. Monitoring in active production wells may be needed, if these are the only wells in the area of interest. However, active production wells are far from ideal, because of their influence on the groundwater table. If no other option is available, measuring the water level can be done in production wells on condition that pumping can be stopped for the period of recovery of the groundwater level. Measurements should be taken a few times during the period of recovery, till a stable situation is reached close enough. Only the level belonging to the final stage of recovery should be put in the records.

Frequency of observation
The frequency of observation will have to be adjusted to the highest level of relevant fluctuations. In natural conditions relevant fluctuations are often the seasonal fluctuations. If the frequency of observation is high enough to assess these seasonal fluctuations (for instance monthly fluctuations), they are usually also sufficient for variations with a longer period. Variations with a longer period may be variations caused by dry and wet years or long term trends. If seasonal fluctuations are of minor importance, the frequency of observation can usually be limited to one or two measurements per year.
The best strategy of observation is to start with a frequency high enough to observe seasonal fluctuations, if these are expected to be relevant. This period of frequent observation should preferably last for some years (3 to 5). After quantifying the magnitude of seasonal fluctuation, the frequency of monitoring can be adjusted to the minimum accuracy requirements, for instance aimed at identifying long term trends.

Table 4.6 shows the opinion of respondents of the questionnaire about the frequency of observation in their country. The required frequency of observation is narrowly related to the variation of the groundwater levels and the accuracy needed for different objectives.
A relatively small category of respondents regards the frequency of monitoring insufficient for their purposes. The majority of them classifies the frequency as good or fair.

Table 4.6: Opinions on frequency of observation – in different countries

	Opinion	***Countries (examples)***
1	*Good*	Africa: Botswana, Mauritius, Seychelles Asia: Korea Europe: Belgium, Bulgaria, Denmark, Finland, Romania, Switzerland N-America: Canada, USA Oceania: Australia C- & S-America: Barbados
2	*Fair*	Africa: Central African Republic, Djibouti, Tunisia Asia: China, India, Japan, Malaysia, Palestine Europe: Belgium, Hungary, Slovenia Oceania: New Zealand C- & S-America: Uruguay
3	*Insufficient*	Africa: Benin, Ethiopia, South Africa Asia: Myanmar, Yemen C- & S-America: Argentina, Brazil, Chile, Mexico

4.5 Processing and storage of data

After being measured and registered manually or automatically, groundwater data is collected and stored. This part of the process can be critical for the final quality of the data. In order to guarantee a certain quality measured series must be checked. This process should also be registered so that the editing is traceable, especially if changes are involved. The process of editing is not without danger, because it may easily lead to unrealistic or even wrong results. For instance, if outlyers are removed from a time series, by inexperienced persons valuable information may be lost.

Question 2.5 of the questionnaire asks for the opinion on the state of the art with respect to use and quality of groundwater monitoring data. The results are presented in table 4.7 and 4.8. Respondents selected one out of four categories to give their opinion.

Table 4.7: Opinion on quality of groundwater level data – in different countries

	Opinion	***Countries (examples)***
1	*Good*	Africa: Mauritius, Seychelles, Tunisia Asia: Korea Europe: Belgium, Bulgaria, Denmark, Netherlands, Romania, Slovenia, Switzerland N-America: Canada, USA Oceania: Australia, New Zealand C- & S-America: Barbados
2	*Fair*	Africa: Djibouti, Ethiopia Asia: Malaysia, Myanmar, Palestine Europe: Belgium, Finland, Hungary C- & S-America: Argentina, Uruguay
3	*Incomplete or insufficient*	Africa: Benin, Botswana, Central African Republic, South Africa Asia: China, India, Japan, Yemen C- & S-America: Brazil, Chile, Mexico
4	*Negligible*	C- & S-America: Argentina

It is remarkable to see that just a few respondents regard their data of good quality. Combining different processing steps (checks and statistical analyses) could significantly increase the data quality.

From the IGRAC questionnaire we see that respondents who regard the quality of their data insufficient are also interested in support by IGRAC with guidelines and protocols (see Appendix A).

Table 4.8: Opinion on use of groundwater level data – in different countries

	Opinion	***Countries (examples)***
1	*Good*	Africa: Djibouti, Mauritius Asia: India, Korea Europe: Romania N-America: USA Oceania: Australia, New Zealand
2	*Fair*	Africa: Botswana, Central African Republic, Ethiopia, Seychelles, Tunisia Asia: Myanmar Europe: Belgium, Bulgaria, Denmark, Hungary, Slovenia, Switzerland N-America: Canada C- & S-America: Barbados, Chile, Uruguay
3	*Incomplete or insufficient*	Africa: Benin, South Africa Asia: China, Japan, Malaysia, Palestine Europe: Belgium_1, Finland N- America: Canada_2 S- America: Argentina, Brazil, Mexico
4	*Negligible*)	Asia: Yemen S. America: Argentina

The availability of groundwater data does not necessarily correspond with significant use of them. Accessibility of the data proves to be an critical aspect in this regard. Use of digital databases has boosted the use for groundwater data in studies, reports and bulletins.
In many industrialised countries responsible organisations provide access to their data through Internet. An other group of countries has started to bring their data in digital format. For instance, China (opinion: incomplete or insufficient) recently started a project to set up a database for groundwater data. Unfortunately an unknown number of countries still rely on paper archives. In such cases processing of those data is cumbersome and data may be lost easily.

5 Groundwater quality monitoring

5.1 Monitoring objectives

In international documents on groundwater monitoring a variety of objectives can be found for groundwater quality monitoring. The general need for information has much in common, but the monitoring objectives differ somewhat per country, depending on the typical situation, needs and priorities. A list of common objectives on groundwater quality monitoring, mentioned in international documentation, is the following:

1. Characterisation of groundwater quality in the region observed;
2. Establishing groundwater suitability for various types of use;
3. Establishing background values as reference for contamination studies;
4. Establishing effects on groundwater quality by diffuse sources of pollution (agriculture: fertilisers, herbicides, pesticides; gardening; industrial sites);
5. Establishing effects on groundwater quality by line and point sources of pollution (industrial end municipal disposal sites, oil stores, etc.).
6. Establishing effects of remedial measures

5.2 Examples of groundwater quality aspects monitored world-wide

Table 5.1: Parameters presently being monitored, according to available information

Aspect	*Countries*
TDS, EC and macro parameters	Africa: Botswana, Central African Republic, Djibouti, Mauritius, South Africa Asia: China, India, Japan, Korea, Malaysia, Myanmar; Europe: Belgium, Denmark, Finland, Hungary, Romania, Slovenia, Switzerland; North America: Canada, USA; Oceania: Australia, New Zealand; Central and South-America: Argentina, Argentina_2, Barbados, Chile, Uruguay.
Pollution by Domestic sewage (e.g. nitrate, bacteria, etc.) and Industry (e.g. heavy metals, DNAPL, etc.)	Africa: Benin, Central African Republic, Djibouti, Mauritius, Seychelles, South Africa, Tunisia; Asia: China, India, Japan, Malaysia, Myanmar; Europe: Belgium, Denmark, Finland, Hungary, Moldova, Romania, Slovenia, Switzerland; N-America: Canada, USA; Oceania: Australia, New Zealand; C- & S-America: Argentina, Barbados, Brazil, Chile, Uruguay.
Pollution by Agriculture (e.g. fertilizers, pesticides)	Africa: Mauritius, South Africa, Tunisia; Asia: China, India, Japan, Malaysia, Myanmar; Europe: Belgium, Denmark, Finland, Hungary, Moldova, Netherlands, Romania, Slovenia, Switzerland; N-America: Canada, USA; Oceania: Australia, New Zealand; C- & S-America: Argentina, Barbados, Chile, Uruguay.
Specific natural constituents limiting groundwater use (e.g. arsenic, boron, etc.)	Africa: Benin, Botswana, South Africa; Asia: India, Japan, Malaysia, Myanmar; Europe: Belgium, Denmark, Finland, Hungary, Moldova, Slovenia, Switzerland; North America: Canada, USA; Oceania: Australia, New Zealand; South America: Argentina, Chile, Uruguay.

Table 5.1 shows which quality aspects are presently being monitored in countries that responded to the questionnaire.

From the table it can be concluded that most countries are monitoring similar, more or less standard sets of groundwater quality parameters. It is expected that most countries monitor basic quality parameters.
The amount of quality data cannot be derived from this table but it will differ a lot.
Primary quality networks are not widespread. A number of countries, for instance Ethiopia and Uruguay are only monitoring groundwater quality data in wells of public water supply. The respondent from Québec (Canada) mentions that they have only data from ad-hoc studies.
A group of countries are monitoring specific constituents that limit groundwater use, such as arsenic, boron, etc. It is not possible to distinguish between countries on the basis of these statistics.
Although many countries are sampling and analysing groundwater quality parameters, the data often stick in databases. From experience we know that use of data for characterising the groundwater system and in depth analyses of the relation between groundwater quality, land use, soil quality and groundwater flow is still no routine practice in many countries.

5.3 Network types and configuration

Different types of groundwater quality monitoring networks

For monitoring groundwater quality, three types of monitoring networks can be distinguished:
1. A baseline network for initial characterisation of groundwater quality and for general studies of groundwater suitability and natural trends;
2. Specific networks for monitoring effects on groundwater quality caused by diffuse sources of pollution;
3. Specific networks for monitoring effects on groundwater quality of point and line sources of pollution.

The classes distinguished here may be termed different in (inter) national documents on groundwater monitoring. Baseline networks are also called “primary” or “background” networks, while specific networks (types 2 and 3) are also termed “secondary” and “tertiary” networks.
For more information on the methodology of groundwater quality monitoring, see Appendix D.

The following impression is based on interviews with experts, rather than on actual data from the countries themselves.

Table 5.2: Groundwater quality monitoring networks - variation among countries (examples)

	Category	***Countries (examples)***
1	As far as known, no significant or only scattered groundwater quality monitoring	Many countries in Africa (e.g. Eritrea, Kenia, Tanzania), some countries in the Middle East (e.g. Yemen) and some in South America (e.g. Bolivia)
2	Background monitoring network for groundwater quality characterisation in large regional aquifers	Practically all countries in Europe, many countries in Asia, large parts of North America, coastal regions of Australia, New Zealand.
3	Specific groundwater monitoring networks for diffuse groundwater pollution problems (Nitrates, phosphate, herbicides, pesticides, etc.)	This type of monitoring is coming-up in lowlands with shallow water tables. Examples: the Netherlands, Belgium (Flandres), Germany.
4	Specific groundwater monitoring networks for point sources pollution control	Local groundwater monitoring networks around pollution sites are wide spread. These networks exist in countries with environmental protection laws and regulations.

The oldest records on groundwater quality exist for a long time (e.g. France since 1902), but background monitoring of groundwater quality on a large (regional) scale is from a much more recent period. In many countries groundwater quality is sampled in all types of available wells. The water quality parameters can then be used in a regional picture of background values. However, for trend observation in relation to land use networks of medium deep monitoring wells are needed. In Europe special networks for diffuse pollution were only installed since about 1990.

5.4 Monitoring wells and equipment

Monitoring wells

Various types of wells can be used to sample groundwater quality for initial or general characterisation in the initial phase of groundwater resources assessment, ranging from dug wells to abandoned or used production wells. For monitoring the effects on the groundwater by diffuse sources of pollution, the number of available wells with the right screen depth may be small. Then extra monitoring wells will be needed on selected locations, to be installed in the critical zones of the groundwater system. In order to enable sampling the water at different depths, these wells may have more than one piezometer with a screen in a predefined depth range.

Criteria for installation of monitoring wells can be found in internationally available handbooks. Newly installed monitoring well will often be used for water level observation and for groundwater quality sampling as well. Therefore, installation of the well may need to satisfy both sets of criteria.

The following definition and sets of criteria comes from the US-EPA (Aller 1990) (For convenience they are repeated here).

> The primary objective of a monitoring well is to provide an access point for measuring ground-water levels and to permit the procurement of ground-water samples that accurately represent in-situ ground-water conditions at the specific point of sampling. To achieve this objective, it is necessary to fulfil the following criteria:
> - construct the well with minimum disturbance to the formation;
> - construct the well of materials that are compatible with the anticipated geochemical and chemical environment
> - properly complete the well in the desired zone;
> - adequately seal the well with materials that will not interfere with the collection of representative water-quality samples; and
> - sufficiently develop the well to remove any additives associated with drilling and provide unobstructed flow through the well.
>
> In addition to appropriate construction details, the monitoring well must be designed in concert with the overall goals of the monitoring program. Key factors that must be considered include:
> - intended purpose of the well;
> - placement of the well to achieve accurate water levels and/or representative water-quality samples;
> - adequate well diameter to accommodate appropriate tools for well development, aquifer testing equipment and water-quality sampling devices; and
> - surface protection to assure no alteration of the structure or impairment of the data collected from the well.

5.5 Sampling procedures and sample conservation

Methods for sampling and conservation of samples and laboratory analysis are described extensively in the guidelines produced by the *International Organization for Standardization (ISO)* and the *American Society for Testing and Materials (ASTM International).* These international organisations have produced collections of guidelines on sampling methods, sample conservation and physical, chemical and biological testing methods. The guidelines can be found on their respective websites.
For determining water quality in the field, special field kits have been developed, which produce good results for a quick first impression. However, these field kits are limited with respect to the number of parameters and less accurate than methods of analysis in the lab. Therefore, they can be considered a valuable add to the lab methods, useful for pilot studies and quick assessment of the groundwater quality situation.

6 Monitoring groundwater discharge and abstraction

Groundwater is discharged by rivers and springs and abstracted through wells and galleries. Data on the amount of groundwater discharged from the groundwater system through these different manners is indispensable information for groundwater resources assessment and in particular for estimates of the potential of the system for water supply.

The present state of monitoring groundwater discharge and abstraction in different countries, according to the questionnaire, is shown in paragraph 6.1. The answers of the questionnaire do not show detailed information. Therefore, the methods for monitoring and quantification of the volumes of groundwater discharged in various ways are discussed in more detail in next paragraphs (paragraphs 6.2 through 6.5).

6.1 Monitoring groundwater discharge and abstraction – results from questionnaire and interviews

Table 6.1 shows the results of the questionnaire with respect to the state of monitoring groundwater discharge (baseflow and spring flow) and groundwater abstraction. Countries monitoring their groundwater situation well, according to the opinion of the respondent, generally also monitor spring discharge and collect information on groundwater abstraction. Apparently these countries have a rather complete programme of monitoring quantitative groundwater aspects.
The answers to the questionnaire do not provide details about the methods followed and the accuracy achieved, because the questionnaire did not focus on such details. Hence additional information would be needed to judge about the integral aspects of monitoring. For instance, information on the location of discharge measurement stations (in relation to the groundwater bodies observed), the methods applied, the quality of data, etc. Such detailed questions were beyond the possibilities of this questionnaire.

Table 6.1: Groundwater discharge and abstraction presently monitored

	Component	**Countries (examples)**
1	Base flow of streams	Africa: Ethiopia, Mauritius, Seychelles, South Africa; Asia: China, Japan, Myanmar; Europe: Belgium, Bulgaria, Denmark, Hungary, Italy; N-America: Canada, USA, Mexico; Oceania: New Zealand; C- & S-America: Argentina, Chile, Uruguay.
2	Spring discharge	Africa: Ethiopia, Mauritius, South Africa, Tunisia; Asia: China, Japan, Korea, Myanmar, Palestine; Europe: Belgium, Bulgaria, Finland, Hungary, Italy, Romania, Slovenia, Switzerland; N-America: USA; C- & S-America: Barbados, Chile, Uruguay.
3	Groundwater abstraction through wells	Africa: Benin, Botswana, Central African Republic, Djibouti, Ethiopia; Mauritius, Seychelles, South Africa, Tunisia; Asia: China, India, Japan, Korea, Malaysia, Myanmar, Palestine, Yemen; Europe: Belgium, Denmark, Finland, Hungary, Netherlands, Romania; N-America: Canada, USA; Oceania: Australia, New Zealand; C- & S-America: Argentina, Barbados, Chile, Uruguay.

6.2 Groundwater discharged into rivers - Baseflow

About baseflow

Baseflow is the "groundwater component" of stream flow, drained from the adjacent aquifers.
In *semi-arid* or *arid* areas baseflow is often an easy distinguishable part of the total stream flow. In dry periods it is the only runoff component (if present), whereas during wet periods it still is a traceable part. It can be estimated quite well from the runoff record.
In *humid* climates it is less easy to distinguish between direct runoff and baseflow, and one may have to fit a mathematical model to the discharge data, for separation of both components.

Composing a baseflow record

The method of composing a baseflow record consists of four steps, presented in next box:

1. *Water level measurements*
   Water levels are recorded, either manually or by means of a water level recorder. Using a recorder allows for constant recording or at small time intervals. In streams with a fast changing discharge, this is by far the most efficient and accurate method.

2. *Constructing the Q-h graph*
   The Q-h graph of the relation between discharge and water level is constructed on the basis discharge measurements and water level data of the stream concerned. The data points of the Q-h graph represent discharge-level combinations for a range of discharges from low to high. Next the graph fitted through the data points can be used to calculate discharge for any water level recorded, within the normal ranges of the Q-h graph.

3. *Composing the Discharge record*
   A time series of discharge data is now composed by calculating the amount of discharge for each measured point of the water level record.

4. *Composing the Baseflow record*
   The baseflow record is deduced from the discharge record by separating the baseflow component from the total discharge (see following text).

A baseflow record is deduced from the discharge record of a stream by separating the baseflow component from the total discharge. There are various techniques for estimating the baseflow, from simple graphical estimation methods to filter and modelling techniques. Descriptions can be found in literature.
Although the process of assessing baseflow may be rather indirect, the baseflow component is often considered one of the strongest components in the groundwater balance.

Preferred location for baseflow measurement

In order to estimate the amount of groundwater discharged as baseflow from a catchment area the discharge measurement station should be preferably located near the downstream end of the catchment area. In that way the discharge-record automatically provides the data of total runoff from the catchment. In turn the baseflow record deduced from the discharge-record will also be representative for the catchment area, enclosed by its water divides and by the discharge measurement station, controlling the outlet.

6.3 Groundwater discharged by springs

About springs

Definition of a spring: Place where water flows naturally from a rock or soil onto land or into a body of surface water (International Glossary of Hydrology van UNESCO/IHP).

There are various types of springs, as listed below:
- *Contact Spring:* A spring that usually occurs where a mass of permeable rock or unconsolidated materials overlie a mass of impermeable material.
- *Depression Spring:* A spring that occurs where the topography of the Earth's surface dips below the water table, thus forming marshes or small ponds.
- *Fault Spring:* A spring that originates where there is a fault in the rock layer.

(Definitions from Ohio State University - Ground- and Surface-Water Terminology)

Measuring spring discharge

Since springs discharge groundwater from the earth they often mark the start of a stream by which the water flows to topographically lower areas. Spring-discharge is usually measured in these streams. The method of measuring spring discharge depends on the volume of water released by the spring.
- If the discharge of the spring is relatively small (e.g. less than 0.1 m^3/ second), the discharge can be measured with a bucket, barrel or other vessel. By recording the volume of the vessel and the time needed to fill it, the discharge can be expressed in m3 per unit of time. For measuring small spring discharges one can also make use of devices such as metal flumes, of which the Q-h graph is provided by the manufacturer.
- If the discharge of the spring is larger (e.g. more than 0.1 m^3/ second), one has to resort to methods for measuring larger stream flow, such as the method listed in paragraph 6.1. In such case, installing a permanent discharge measurement station, equipped with a weir or a flume and a water level recorder, can also be considered.

As spring discharge is often fairly stable in time, records of spring discharge tend to be quite smooth. In that case the frequency of discharge measurements does not need to be very high.

Preferred location for spring discharge measurement

The location of the spring discharge measurement station should be representative for the discharge of the spring, while losses of stream flow should be avoided. Therefore, the location should be as close as possible to the spring, if possible within the first 20 m.

6.4 Groundwater abstracted through wells

About groundwater abstraction

Abstraction of groundwater, by pumping or lifting water from wells, often constitutes an important discharge component. This is illustrated by the fact that public water supply and irrigation schemes may take a considerable percentage of the annual recharge of groundwater.
Although it is generally recognised that data on groundwater abstraction are indispensable information for groundwater resources assessment studies, collection of these data remains a very weak point. As long as monitoring is not done in a systematic way, only rough estimates will be possible.

Different ways of quantifying groundwater abstraction from wells

The volume of water withdrawn from a groundwater body by pumping wells can be quantified with direct and indirect methods:

- *Direct methods.*
  In a direct way groundwater abstraction is measured with a "flow meter" in the conduct or tube, connecting the pumping well(s) with the water distribution system. When more than one pumping well is involved, the measuring device is often installed in the collecting tube.
- *Indirect methods.*
  The amount of water withdrawn from the aquifer can also be estimated by recording the time of pumping and by multiplying it with the estimated net capacity of the pumps. This method may provides "fair estimate" of groundwater withdrawal from the aquifer(s), if it is conducted in a critical way.
  Another indirect method is based on estimates of water consumption. The volume of groundwater withdrawn from the groundwater system is calculated by multiplying, for instance, the number of persons and animals depending on the water supply, by their estimated daily consumption or use. Because of the uncertainty in the data, this method will provide only a "very rough estimate" of the groundwater provided by the supply system.

It may be clear from the above a that use of direct methods will generally provide a much better accuracy. However using these methods may require substantial investments, which is not always feasible. Indirect methods may then be used to get a better insight in abstraction.

Quantification of groundwater abstraction

World wide groundwater is used in a variety of different ways, depending on the demand for water, the availability of groundwater and surface water, accessibility of these resources, financial and social aspects, etc. Depending on these conditions groundwater supply and use may differ significantly between urban and rural areas.
As a consequence also the methods for quantifying groundwater abstraction may have to be adjusted to the situation in these areas, as can be illustrated by the following example from Moldova (East Europe):

- In the rural areas of Moldova the population depends for their water supply mainly on dugwells in shallow aquifers. Estimates of the number of these open wells in Moldova range from 200000 to many more. For quantifying the total amount of groundwater withdrawn by these wells from the shallow aquifers a direct method is no option and, therefore estimates are based on indirect methods.
- Many of the collective farms and rural hospitals pump groundwater from tubewells installed in deep aquifers. In the absence of measuring devices, estimates of their annual production were made on the basis of well capacity and average period of operation.
- In some of the larger towns of Moldova water is supplied from tubewells installed in deep groundwater aquifers. The amount of groundwater withdrawn by these wells is quantified by measuring the total production of the well fields in the supply system.

6.5 Groundwater abstracted through galleries

About galleries

In many areas of the Middle East, North Africa and parts of Asia groundwater is abstracted from drainage galleries, known by various names, such as qanat, falaj, ghayl foggara or karez.
These galleries are more or less horizontal tunnels cut into the rocks and collecting groundwater drained from water bearing zones. Where the galleries surface, the water is transported by open or covered canal systems, which lend themselves well for discharge measurements.

Discharge measurements

Measurement of the groundwater discharge from galleries can be conducted in a similar way as that of springs. The channel system of these galleries is suited well for discharge measurements. A suitable location is near the opening before water is diverted or lost.
The volume of water discharged from the rocks is representative for the rocks drained. However it may not be easy to correlate the discharge data with groundwater level data from these rocks or to extrapolate this information to other areas.

7 Monitoring seawater intrusion

Seawater intrusion occurs when natural discharge and abstraction of groundwater in a coastal zone exceed average groundwater recharge and inflow.
In coastal aquifer zones fresh groundwater under land surface meets saline groundwater under sea surface. As fresh groundwater is lighter than saline water, fresh water will tend to stay on top of saline water, which leads to a wedge-shaped interface between both types of water in a coastal zone. The position of the interface depends on the balance between recharge of groundwater from the surface and from the back land, and discharge of groundwater through wells or groundwater flow into the sea.
The balance between recharge and discharge can be disturbed by excessive abstraction of groundwater from the coastal zones. The interface will then move landinward, reducing the fresh groundwater reserves of the coastal area and threatening the well fields.

Because of limitations of the questionnaire, IGRAC has chosen to inquire about the occurrence of the problem without asking too many questions about it at this stage. Table 3.1 shows the list of countries controlling the fresh-saline groundwater interface in their coastal aquifers by means of monitoring.

Table 7.1: Countries monitoring sea water intrusion, according to questionnaire

Water quality aspect	***Countries (examples)***
Seawater intrusion	Africa: Benin, Djibouti, Mauritius, Seychelles, Tunisia; Asia: China, Japan, Korea, Malaysia, Myanmar; Europe: Belgium, Denmark, Netherlands; North America: Canada, USA; Oceania: Australia, New Zealand; South America: Argentina, Barbados, Brazil, Chile, Uruguay.

As can be concluded from the table seawater intrusion is a wide spread problem occurring in many countries with coastal areas (roughly 50% of the responding countries have this problem). These countries are aware of the problems and are monitoring the situation. Many of the respondents opted for technical support by IGRAC. The need for further support with guidelines or information will have to be investigated in more detail.

8 Towards world-wide recommendations

8.1 The present situation on groundwater monitoring - conclusions

Response to the questionnaire has been very limited so far. Out of 180 countries approached with a questionnaire, answers were received from only 40. In addition IGRAC collected information on other countries from reports and through interviews, and has now information on over 60 countries world-wide. This sample about monitoring under different conditions is considered sufficiently representative to draw rough conclusions.

With respect to the stage of groundwater monitoring, observed by IGRAC in 2004, roughly three categories of countries can be distinguished.

Table 8.1: Countries in different stages of monitoring

Group	Use of groundwater monitoring	Monitoring networks
Group 1	No significant groundwater monitoring programme going on.	No permanent monitoring networks.
Group 2	Systematic groundwater monitoring programmes for groundwater resources assessment and water supply	Primary and/or secondary monitoring networks, fixed frequency of observation
Group 3	Groundwater monitoring integrated in water resources management and environmental protection	Well designed or optimised primary monitoring networks, well fixed monitoring frequency

In the *countries of group 1* no significant monitoring is going on, which means that quantitative analysis of the groundwater resources in these countries cannot be conducted. Because of lack of systematic monitoring historical data sets are not being established. Because of lack of data groundwater management cannot evolve to a more professional level. Respondents from group 1 seem to be rather frustrated about their possibilities (see Appendix A) and ask for guidelines and available information about all subjects indicated by IGRAC.

In the *countries of group 2*, groundwater monitoring has become a standard practice in relevant parts of the country. In this situation quantitative groundwater assessment based on data and with the help of modern techniques is becoming possible. Groundwater management can be developed, on the basis of those results. The respondents of the questionnaire often find the density of monitoring networks in these countries and/or the frequency of monitoring unsatisfactory. Use of groundwater data is often far from optimal, according to professionals interviewed. This applies especially to groundwater quality data from the networks. The interest of the respondents of the IGRAC questionnaire concerns guidelines and information on optimisation techniques and data processing methods (see table 8.2).

The *countries of group 3* are well equipped with groundwater monitoring networks. These countries use their primary or background monitoring networks for planning and control in pro-active (ground) water management. Data from the networks can often freely be obtained from national, provincial or district databases. Improvements in the networks may be still possible, as some respondents of the questionnaire state, but they have found ways to serve themselves with the latest news. A number of these respondents do not think that IGRAC can play a role for them.

Some remarks

- It should be stressed that the situation of countries of group 1 is clearly unsatisfying. Each country needs to have a basic idea of its groundwater resources and the potential of their development. Groundwater assessment and monitoring at a baseline level for reconnaissance of the groundwater situation in a country is regarded a minimum requirement for development of water management policy.
- Group 3 does not necessarily represent the optimal level of groundwater monitoring that should be reached in all countries. This level of monitoring is mainly desirable in situations where conflicts of interest play a major role in groundwater management. In situations with little interaction between users and no harm to nature, simple groundwater networks may suffice.

8.2 How to improve the present situation – limiting factors

The development of network(s) and programmes for groundwater monitoring in a country depend on a series of conditions. Basic critical factors are:

- Groundwater of good quality has to be available in reasonable quantities;
- The country has to be in need of good quality groundwater;
- Authorities have to be willing to invest in groundwater resources development;
- Relevant institutions and organisations have to be in place and have to have mandates;
- Politics have to be in favour of development or have to be no disturbing factor.

Without these conditions being satisfied, the monitoring networks will probably not be developed òr be much less efficient.

1. Groundwater has to be available in reasonable quantities

If a country or a region possesses no groundwater systems of any significance, there is no reason for monitoring network to be developed. This is the case in areas with old crystalline rocks with no or only thin weathered zones and local groundwater pockets (for instance basement areas in Africa and granite areas in Scandinavia). Also brackish or saline groundwater systems are often of no interest, though specific networks may be needed to control the interface with fresh groundwater zones (intrusion or upconing of saline groundwater).

2. The country has to be in need of good quality groundwater

If a country, or parts of it, does not need the groundwater, because of low population density or availability of easy accessible and good quality sources of surface water, there will be no reason to develop groundwater monitoring networks. Sparsely populated areas in humid climate zones may fit in this category.

3. Authorities have to be willing to invest in groundwater resources development

If a country does not have the financial means to invest in groundwater resources, or is reluctant in doing so, groundwater-monitoring networks will not be developed. Many developing countries with faltering economies have difficulties in directing investments towards groundwater resources development. This applies even more to investments in monitoring, which is often considered luxury. This attitude may change if the importance of groundwater resources for development of these countries can be proven.

4. Relevant institutions and organisations have to be in place and have mandates

Development of groundwater resources depends to a large extent on institutions and organisations responsible for development of these resources. When there are no governmental organisations responsible for groundwater management, or when these organisations do not have the proper mandates and budgets for their tasks, groundwater development will not come into being. On a lower level responsible technical institutions must be given tasks and be equipped with trained staff to conduct assessment studies and deal with technical problems. Also these institutions will have to be given directives for their tasks.

5. *Politics have to be in favour of development or be no disturbing factor.*
It hardly needs explanation that politics must be supportive for groundwater development and management. If, for instance, interests of local groups dominate regional or national politics regional groundwater development will become very cumbersome or be deemed to fail. Also the political situation in a wider sense may disturb developments in a country.

Examples of positive development

Within the above context "Hydrology Project" in India can be cited as an example of positive development. Groundwater exploitation is essential for this country with rising water needs of its large population. Therefore, high investments were directed towards developing the groundwater resources. Authorities are convinced on what should be done and mandates were given to the institutions involved.
Provision of licenses for groundwater abstraction in districts was made dependent on the groundwater situation. That way groundwater data are a critical element in groundwater management. In turn the need for groundwater data makes sure that groundwater-monitoring programmes will be conducted.

Another example of a positive development can be found in Europe, where the policy with respect to protection of surface and groundwater is harmonised for all EU member states in the "Water Framework Directive" (WFD), implemented in 2000. An important aspect of the WFD is that all member states have to apply the WFD to national legislation regarding their own particular surface and groundwater situations. A minimum requirement for groundwater monitoring in the member states is to provide the data for verification of goals described in the WFD, not only on a national scale but primarily on watershed scale.

From the above it can be concluded that groundwater monitoring programmes will only be useful if conditions 1 and 2 are met. To be successful also the conditions 3 trough 5 will have to be fulfilled.

8.3 What can IGRAC do to improve the situation

This question has been asked to the groundwater community through the IGRAC questionnaire. A summary of the interests is given in next table.

Table 8.2: Interest of countries for support by IGRAC

Guidelines or protocols on:	
Design of monitoring networks	Africa: Benin, Botswana, Central African Republic, Djibouti, Ethiopia, Seychelles, South Africa, Tunisia; Asia: China, India, Japan, Korea, Malaysia, Myanmar, Palestine, Yemen; Europe: Belgium, Bulgaria, Hungary, Italy, Romania, Slovenia; N. America: Canada; C & S. America: Argentina,, Barbados, Brazil, Mexico, Uruguay.
Drilling and installation of observation wells	Africa: Benin, Central African Republic, Djibouti, Ethiopia, South Africa; Asia: China, India, Japan, Korea, Malaysia, Myanmar, Palestine, Yemen; Europe: Belgium, Hungary; C & S. America: Argentina, Barbados, Chile, Mexico.
Data collecting, processing and analyses	Africa: Benin, Botswana, Central African Republic, Djibouti, Ethiopia, Mauritius, Seychelles, South Africa, Tunisia; Asia: China, India, Japan, Korea, Malaysia, Myanmar, Palestine, Yemen; Europe: Belgium, Finland, Italy, Romania, Slovenia; N. America: Canada; C & S. America: Argentina, Barbados, Brazil, Chile, Mexico, Uruguay.

Information on:	
Case studies, instrumentation and software	Africa: Benin, Botswana, Central African Republic, Djibouti, Ethiopia, Mauritius, Seychelles, South Africa, Tunisia; Asia: China, India, Japan, Korea, Malaysia, Myanmar, Palestine, Yemen; Europe: Belgium, Finland, Hungary, Italy, Romania, Slovenia; N. America: Canada; Oceania: New Zealand; C & S. America: Argentina, Barbados, Brazil, Chile, Mexico, Uruguay.

From the above table it may be clear that a large group of respondents is interested in support by IGRAC.
Considering the criteria listed in paragraph 8.2, IGRAC can only be supportive to a limited extent in alleviating technical constraints, by providing guidance and information. Concerning priorities, assistance should be directed towards the groups of countries most needing it.

- First priority should be to assist countries of group 1, viz. countries that have no systematic groundwater monitoring programmes going on, in finding ways to start groundwater monitoring. For improving the situation in these countries with respect to groundwater monitoring we have formulated ideas for baseline monitoring (see paragraph 8.4).
- Second priority should be given to countries of group 2, viz. countries having embarked on systematic groundwater monitoring programmes of their water resources. These countries may be assisted with information and guidelines regarding evaluation and optimisation of their monitoring networks. From experience we know that many of the networks are producing data that are only weekly related to the requirements. A programme for critical evaluation of monitoring networks with respect to objectives and data requirements could possibly help to improve the efficiency of their monitoring programmes.
- The third group of countries hardly needs support. These countries do not need any support from IGRAC, as stated in the response to the questionnaire. However their knowledge and experience can be used in sharing it with less advanced countries (see IGRAC's mission).

8.4 Ideas for baseline monitoring

Baseline monitoring. Baseline groundwater monitoring is aimed at obtaining useful results for groundwater development and management against a sensible level of investments.

From the information available about groundwater monitoring world-wide it is clear that a category of countries (group 1) have not yet reached the point of systematically monitoring the groundwater resources. The lack of sufficient data causes a considerable risk of deterioration of the groundwater situation, both quantity and quality, without sufficient warning. Also a solid quantitative analysis of the groundwater resources cannot be made and as a consequence groundwater management cannot evolve to a more professional level.

Baseline groundwater monitoring will have to be stimulated with priority in these countries. Since the reason(s) for arrearage in these countries may vary – one or more of the conditions discussed in paragraph 8.2 are not fulfilled – baseline monitoring will have to be adjusted to their actual situation. The process will thus have to be rather flexible.

To get things going, baseline monitoring will have to provide useful results for groundwater managers in a relative short period of time (e.g. 1 or 2 years). In order to ensure financing of the monitoring programme the results will also have to be of local, regional, national or even international interest.

Some conditions for success:

- Monitoring must obviously be adjusted to the local conditions in the country observed;
- Gradual growth of the monitoring network from low profile to the right level of groundwater monitoring, always adjusted to the needs.
- Clear management and technical objectives in every stage of the process of gradual growth;
- Initial use of all available means (available wells, cheap observers, etc.)
- Fast results, showing the character of the groundwater system at hand and (after some time) its potentials for water supply or other forms of use (e.g. nature conservation) and possible negative trends;
- Results presented in such a way that they can be used for programs of groundwater development, if the situation proves to be promising.
- Use of the data in reports and overviews of international organisations may be a stimulating factor.

Technical ideas:

- *Representative stations.* It is proposed that baseline monitoring networks be set up to cover the water systems at hand with a minimum of representative monitoring stations. Representative units will be selected on the basis of hydrogeological, hydrological and other properties of the area. Each station will be representative for a selected unit. For instance, if the hydrogeological situation of an area can be divided into a number of different classes on the basis of its properties, these classes or parts of them could be taken as units. Combinations with hydrologic and land use features are possible. Such a classification system will have to be developed.
- *Criteria for selection of suitable locations.* Selection of suitable location for a baseline station will need to take into account the properties of its unit as well as the local conditions. Relevant criteria are its representative function and the local conditions of accessibility, ownership of the area, protective measures, etc. A set of criteria for representative localities will also have to be developed.
- *Combined use of the monitoring equipment.* It will be advantageous if the monitoring of relevant hydrological variables can be combined at some stations. That way the resulting records can be analysed in relation to each other, which will improve the usefulness of stations and broaden the results. Examples are combinations of a groundwater monitoring well with a rain gauge. Other combinations can be considered as well.
- *Results serving management objectives.* Before planning and installation of the monitoring stations the objectives of monitoring should be carefully analysed. Results are essential for the continuity of the monitoring programme. So the authorities should be approached with questions about their wishes. These wishes should be considered critically and held against the technical possibilities of the programme. It should be made clear what is possible and what is not. Also requests for information by international organisations may be considered.
- *Results being presented in attractive ways.* Technical staff in the local institutions will have to work on the presentation of the results. In order to make the results attractive and easy to be incorporated in reports or bulletins, they should be facilitated with guidelines and information on standard ways of presentation and simple software programmes. An inventory of such simple software for graphs and tables will be necessary.

9 References

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A. IGRAC's questionnaire

A1. Set-up of the questionnaire

The questionnaire comprises four categories of questions. They concern:
- Table 1: the groundwater situation and the major groundwater problems;
- Table 2: state of the art on groundwater quantity monitoring;
- Table 3: state of the art on groundwater quality monitoring;
- Table 4: needs for guidance and information that could be fulfilled by IGRAC.

In addition respondents were requested to provide some data about their present employer and position.

1 Groundwater situation in your country

1.1 Categories of groundwater use

Please, specify the categories of groundwater use in your country by putting marks in the table. Please make distinction between major groundwater use categories (M) and minor ones (S). If possible, also specify which type of aquifers are mainly involved.

Use of groundwater:	In general *(major use: M)* *(minor use: S)*	By aquifer types involved	
		Major aquifers of large extent	Local aquifers
• Domestic water supply			
• Public water supply			
• Industrial use			
• Irrigation			

Please, add comments if you regard these useful for the interpretation

1 Groundwater situation in your country

1.2 Specification of problems related to groundwater

Please specify by marking them which groundwater problems are encountered in your country. If possible indicate whether they present themselves in large aquifers, in small ones or in both.

Groundwater problems:	In general	By aquifer types involved	
		Major aquifers of large extent	Local aquifers
• Groundwater table decline			
• Pollution			
• See water intrusion			
• Land subsidence			
• Other: <text>			

Please, add comments if you regard these useful for the interpretation

2 Monitoring groundwater quantity

2.1 What is presently being monitored

Please, specify what variables are presently being monitored in relation to groundwater and related purposes. If possible, also mark the type of aquifer involved in monitoring the specified variable.

Variables monitored:	Being monitored?	For the following purpose(s) (see below)*	Aquifer types involved	
			Major aquifers of large extent	Local aquifers
• Groundwater levels	☐	e.g. 1,4,5	☑	☑
• Groundwater abstraction from wells	☐	e.g. 1,4,5	☑	☑
• Springs discharge	☐	e.g. 1,4,5	☑	☑
• Base flow of streams	☐	-----	☑	☑
• Land subsidence	☐	-----	☑	☑
• Other: <text>	☐	-----	☑	☑

Purpose	*Description*
1	Groundwater flow analysis
2	Control of groundwater table
3	Groundwater balance calculation
4	Optimisation of groundwater withdrawal
5	Control of land subsidence
6	*<type your description>**
7	*<type your description>**
8	*<type your description>**

** add your own discription to use in column 3*

2 Monitoring groundwater quantity

2.2 Characteristics of monitoring networks for groundwater quantity

How would you describe the characteristics of monitoring networks in your country? Please indicate whether the following types of networks are present. Please, also give a rough indication of the total numbers of wells involved and the usual number of observations made per year.

Scale of networks:	Description	Network present? (yes/no)	Total number of observation wells (see below)*	Frequency of observations: every … (see below)*
Primary networks (A)	Monitoring networks to observe water levels over the total extent of regional aquifers	☐	-----	-----
Secondary networks (B)				
1. Around pumping stations	Special observation wells for control of local drawdown	☐	-----	-----
2. In nature conservation areas	Special observation wells for control of groundwater levels	☐	-----	-----
3. Other <text>	<text>	☐	-----	-----

Nr. of observation wells	*Frequency of observations*
< 100	day
100 - 1000	week
1000 - 10000	month
> 10000	year
*<type your number>**	*<type your frequency>**

** make selection or type your own value*

2 Monitoring groundwater quantity

2.3 Monitoring groundwater abstraction

Please, indicate whether groundwater abstraction is being monitored and by which organisation(s).
Please, also provide Internet-sites and e-mail addresses.

Groundwater abstraction for:	Yes/No	main organisation(s) performing monitoring	e-mail address(es) internet-sites
...public water supply	☐	-----	-----
...irrigation schemes	☐	-----	-----
...industrial purposes	☐	-----	-----
Other <text>	☐	-----	-----

Please, add comments if you regard these useful for the interpretation

<comment 2.3>

2 Monitoring groundwater quantity

2.4 Organisations responsible for monitoring groundwater quantity

Please, indicate the main organisation(s) responsible for groundwater quantity monitoring. Please, also provide Internet-sites and e-mail addresses.

	Networks	main responsible organisation(s)	e-mail address(es) internet-sites
	Primary networks (A)		
A	For basin-wide control	<text>	@ and/or www.
	Secondary networks (B)		
B1	Around well fields	<text>	@ and/or www.
B2	In nature conservation areas	<text>	@ and/or www.
B3	In over-exploited zones	<text>	@ and/or www.
B4	Other <text>	<text>	@ and/or www.

Please, add comments if you regard these useful for the interpretation

<comment 2.4>

2 Monitoring groundwater quantity

2.5 State of the art with respect to monitoring groundwater levels

Please specify how you would evaluate the situation in your country with respect to monitoring groundwater levels, the quality and use of data. If possible specify by aquifer type.

Characteristics of monitoring	In general	Major aquifers of large extent	Local aquifers
• Density of observation wells		-----	-----
• Frequency of observation		-----	-----
• Quality of the groundwater level data			
• Use of groundwater level data			

Your judgement
3: Good
2: Fair
1: Incomplete or insufficient
0: Negligible

Please, add comments if you regard these useful for the interpretation

<comment 2.5>

3 Groundwater quality monitoring

3.1 What is presently being monitored

Please, specify whether groundwater quality monitoring is being applied in relation to the purposes given in the table. If possible, also indicate what type of monitoring network is being used.

	Monitoring purpose	Being monitored?	Primary network(s)	Secondary or special networks
	Baseline quality			
A1	• Only TDS and/or EC	☐	☑	☑
A2	• Detailed set of macro parameters	☐	☑	☑
	Pollution by			
B1	• Domestic sewage (e.g. nitrate, bacteria, etc.)	☐	☑	☑
B2	• Industry (e.g. heavy metals, DNAPL, etc.)	☐	☑	☑
B3	• Agriculture (e.g. fertilisers, pesticides)	☐	☑	☑
C	**Specific natural constituents limiting groundwater use** (e.g. arsenic, boron)	☐	☑	☑
D	**Saline water intrusion**	☐	☑	☑
E	**Other, please specify:**			
	<text>	☐	☑	☑
	<text>	☐	☑	☑

Please, add comments if you regard these useful for the interpretation

<comment 3.1>

3 Groundwater quality monitoring

3.2 Organisations responsible for monitoring groundwater quality

Please, indicate the main organisation(s) responsible for groundwater quality monitoring. Please, also provide *Internet-sites* and *e-mail addresses*.

	Networks	main responsible organisation(s)	e-mail address(es) internet-sites
	Primary networks (A)		
A	For general groundwater quality control	<text>	@ and/or www.
	Secondary networks (B)		
B1	Domestic sewage	<text>	@ and/or www.
B2	Industry	<text>	@ and/or www.
B3	Agriculture	<text>	@ and/or www.
C	Specific natural constituents	<text>	@ and/or www.
D	Saline water intrusion	<text>	@ and/or www.
E	Other, please specify: <text>	<text>	@ and/or www.

Please, add comments if you regard these useful for the interpretation

<comment 3.2>

4 Support from IGRAC

IGRAC has been established to promote sustainable groundwater development through transfer of groundwater related information and knowledge. Among others, IGRAC is stimulating the use of guidelines and protocols for groundwater assessment and monitoring. Regarding monitoring, IGRAC may be of help by providing guidance and information or by creating a platform for discussions between professionals. We like to know whether there is demand for such support and what are the priorities.

Please, specify in which fields of monitoring you like IGRAC to give support to the groundwater community in your country:

Our country would profit from the following:	Yes/No	Please describe your information needs in more detail:
Guidelines or protocols on:		
Design of primary networks for groundwater level monitoring	☐	-------
Design of monitoring networks for groundwater abstraction	☐	-------
Design of monitoring networks for groundwater quality	☐	-------
Drilling and installation of observation wells	☐	-------
Data collection methods	☐	-------
Data processing, storage and screening methods	☐	-------
Data analysis methods	☐	-------
Other: <text>	☐	-------
Information on:		
Case studies as examples of good practice	☐	-------
Instrumentation for monitoring	☐	-------
Software for data analysis, storage and presentation	☐	-------
Other: <text>	☐	-------

A2. Reactions to the questionnaire

The table below gives an overview of the home organisations of the respondents.

	Africa	
1	Benin	office of consulting engineer "SETEM-BENIN Ingénieurs Conseils"
2	Botswana	Wellfield Consulting Services Pty Ltd. / Groundwater Association of Botswana
3	Central African Republic	Ministiere de la Modernisation et de developpement de l'agricultureCentral African Republic
4	Djibouti	United Nations High Commissioner for Refugees
5	Ethiopia	Ministry of Water Resources, Basin development studies and Water utilisation control department
6	Mauritius	Ministry of Public Utilities/ Water Resources Unit
7	Seychelles	Public Utilities Corporation (Water and Sewerage Division)
8	South Africa	GEOSS (Geohydrological and Spatial Solutions)
9	Tunisia	Ecole Nationale d'Ingénieurs de Sfax: ENIS
10	Uganda	Water Resources Management Department, Directorate of Water Development

	Asia	
11	China	China Institute for Geo-Environment Monitoring
12	India	Regional Research Laboratory, (CSIR), Bhopal
13	Japan	Institute of Environmental Systems, Graduate School of Engineering, Kyushu University
14	Korea	Hydrological Institute. HMA
15	Malaysia	Minerals and Geoscience Department Malaysia
16	Myanmar	Dept. of Meteorology & Hydrology
17	Palestine	RWTH Aachen University/Germany
18	Yemen	Independent Hydrogeologist
19	Taiwan	Department of Earth Sciences, National Cheng Kung University (Water Problems Enterprise Information & Incubation Center)

	Europa	
20	Belgium	Flanders: Flemish Community, section Water
21	Belgium	Wallonia: Direction générale des Ressources naturelles et de l'Environnement (DGRNE)
22	Bulgaria	Geological Institute at Bulgarian Academy of Sciences, Department of Hydrogeology
23	Denmark	Geological Survey of Denmark and Greenland
24	Finland	Central Finland Regional Environment Centre
25	Hungary	VITUKI Water Resources Research centre Plc.
26	Italy	CNR-IRPI
27	Latvia	University of Latvia, Faculty of Geography and Earth Sciences
28	Romania	Ministry of Agriculture, Forests, Water and Environmental
29	Serbia and Montenegro	Head of the Department for Groundwater Station Network
30	Slovenia	Environmental Agency of the Republic of Slovenia
31	Switzerland	Federal Office for Water and Geology

	North America	
32	Canada	Dept. of Environment and Energy, Provincial government of Prince Edward Island
33	Canada	Nova Scotia Environment and Labour
34	Canada	Ministère de l'Environnement du Québec
35	USA	US Geological Survey
36	Mexico	Comision Nacional del Agua – Gerencia de Aguas Subterráneas

	Oceania	
37	Australia	International Association of Hydrogeologists
38	New Zealand	Sinclair Knight Merz NZ Ltd

	Central and South America	
39	Argentina	Instituto de Hidrología de Llanuras (IHLLA)
40	Argentina	Universidad Nacional de Mar del Plata
41	Barbados	Ministry of Agriculture and Rural Development
42	Brazil	Dep. Geologia - Universidade Federal do Rio de Janeiro
43	Chile	Universidad de Concepcion
44	Uruguay	OSE (Administración de las Obras Sanitarias del Estado)

A3. Overview of answers

The following tables show an overview of the answers given to the IGRAC questionnaire by all 42 respondents. Countries as sorted alphabetically by continent.

1 Groundwater situation in your country

1.1 Categories of groundwater use

	• Domestic water supply			• Public water supply			• Industrial use			• Irrigation			comment:
	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	
Africa													
Botswana	M	Yes	Yes	M	Yes	Yes	S	No	Yes	M	No	Yes	
Djibouti	M	No	Yes	M	No	Yes	S	No	Yes	S	No	Yes	
Ethiopia	M	No	Yes	M	Yes	Yes	M	No	Yes	S	Yes	No	<: Most aquifers are local fractured consolidated rocks. There are some unconsolidated aquifers covering large area in valleys. >
Mauritius	M	Yes	Yes				M	Yes	Yes	S	Yes	Yes	*1: Groundwater accounts for 75% of our domestic water supply *2: as compared to surfacewater Mauritius is of volcanic origin. The aquifers are of multilayer type constituted by the superposition and the juxta(?)position of basaltic flows Groundwaters are compartmentalized in aquifers by structures of ancient volcanic fomations. these are five principal aquifers in Mauritius (located in the recent and intermediate volcanis formations) but they are exploited differently. Presently, these are 360 boreholes in use. These are classified as below. <type> <no of boreholes> < groundwater utilitation (m3(?)> Domestic water supply - 112 - 114 Industrial - 115 - 10 Agriculture 133 - 24 total 360 - 148
Benin	M	Yes	Yes	M	Yes	Yes	S	Yes	No		No	No	80% of the country live in a zone of cristalline rock, where approvisionnement by groundwater is difficult. For the 20% remainder the principal aquifers are those of the Cretaceous and the Continental Terminal.
Seychelles				S	No	Yes				S	No	Yes	
Central African Republic	M	Yes	Yes	M	Yes	No	S	No	Yes	S	No	Yes	Many wells are installed to meed the need for rural and agricultural hydrology, usually in cristaline geological formation.
South Africa	M	Yes	No	M	Yes	No	M	Yes	No	M	Yes	No	
Tunisia	S	Yes	Yes	S	Yes	Yes	S	Yes	Yes	M	Yes	Yes	
Asia													
China	M*	Yes	Yes	M*	Yes	Yes	M*	Yes	Yes	M*	Yes	Yes	*M (north) -S (south
India	M	Yes	Yes	M	No	Yes	M	Yes	Yes	M	No	Yes	
Japan	S	Yes	Yes	S	Yes	Yes	S	Yes	Yes	S	Yes	Yes	Due to the complex geological formation in Japan, it is not easy to classify the types of aquifers. The large aquifer develops in the interlayered alluvial plains in Ishikari, Kanto, Nohbi, Osaka, and Chigo areas located in the norther, mid and southern islands. On the other hand, volcanic areas form the porous aquifer and much efficient groundwater is yielded. However, most of the Japanese aquifers would be classified as local compared with those in the continents. Only above plains are regarded as the major aquifers where the groundwater is used for any water uses.
D.P.R. of Korea	M	Yes	Yes	M	Yes	Yes	M	Yes	No	S	Yes	No	1. alluvium - fissure aquifer 2. alluvium - fissure aquifer 3. alluvium - .... 4. alluvium/karst - ....
Malaysia	M	No	Yes	S	No	Yes	S	No	Yes	S	No	Yes	There is one State in Peninsular Malaysia which uses groundwater extensively for public water supply system
Myanmar	M	No	Yes	S	No	Yes	S	No	Yes	S	No	Yes	
Palestine	M	Yes	Yes	S	Yes	Yes	S	Yes	Yes	M	Yes	Yes	* In Palestine the Public water supply and Industrial use are normally measured as part of the Dometsic water supply, there is no seperate measurements for these two sectors.
Yemen	M	Yes	Yes	M	Yes	Yes	M	Yes	Yes	M	No	Yes	
Europe													
Belgium_1	S	No	Yes	M	Yes	Yes	M	Yes	No	S	Yes	No	The use for farm breeding is shared between domestic and public water supply. Irrigation is very marginal in Wallonia.
Belgium_2	S	No	Yes	M	Yes	No	M	Yes	No	S	Yes	Yes	
Bulgaria	M	Yes	Yes	M	Yes	No	M	Yes	No	M	Yes	No	
Denmark	S	No	Yes	M	Yes	No	M	Yes	No	M	Yes	Yes	
Finland	S	No	Yes	M	No	Yes	S,M		Yes	S*		Yes	*if any
Hungary	S	Yes	Yes	M	Yes	Yes	M	Yes	Yes	S	Yes	Yes	
Italy	M	Yes	Yes	M	Yes	Yes	S	Yes	Yes	M	Yes	Yes	
Latvia	M	No	Yes	M	Yes	No	M	Yes	No	S	Yes	No	<comment 1.1>
Romania	M	Yes	Yes	M	Yes	No	M	Yes	No	S	No	Yes	Majority of irrigation systems are supplied with surface water. Some of them have as alternative source wells to the shallow aquifers. The use for irrigation is considered minor regarding the quantities of water used, but a lot of people (farmers) are using domestic wells inside villages to irrigate vegetable gardens.
Serbia and Montenegro	M	No	Yes	M	Yes	No	M/S	Yes	Yes	S	Yes	Yes	Categories marked in the Table are given in general and differ from case to case. Table shown (in completed questionnaire) gives water quantities that can be obtained theoretically from certain aquifers where the primary purpose of such waters is domestic and public water supply.
Slovenia	S	Yes	Yes	M	Yes	No	M	Yes	No	S	Yes	Yes	
Switzerland	M	No	Yes	M	Yes	Yes	M	Yes	Yes	M	Yes	No	Public water supply in Switzerland originates from 40% groundwater in valley gravel aquifers, 40% groundwater from springs and 20% lake water.
North America													
Canada_2	M	Yes	No	M	Yes	No	M	Yes	No	S	Yes	No	Use of groundwater for irrigation could become major in the future.
Canada_1	M	Yes	Yes	M	Yes	No	S	Yes	Yes	S	Yes	Yes	These answers apply to Nova Scotia only, not other provinces within Canada. The answers provided here are based on professional judgement, rather than a detailed search of water resource databases.
Canada_3	M	No	Yes	M	Yes	Yes	S	No	Yes	S	No	Yes	Generally speaking, groundwater is the main source of water for domestic use (and public) for about 20% of the population. This is a major use for us because this 20% of population is spread on about 80% of the populated province area. We don't know much about where groundwater is pumped for domestic uses and how much water is pumped, so we don't know which aquifers are sollicitated and how much they are.
USA	M	No	Yes	M	Yes	Yes	M	Yes	Yes	M	Yes	Yes	
Oceania													
Australia	S	Yes	Yes	S	Yes	Yes	M	Yes	Yes	M	Yes	Yes	Australian figures for 2000 - Irrigation 2003 GL, Urban/industrial 1370 GL, Rural 788 GL.
New Zealand	M	Yes	Yes	M	Yes	Yes	S	Yes	Yes	M	Yes	Yes	
South America													
Argentina_1	M	Yes	Yes	M	Yes	Yes	S	Yes	Yes	S	Yes	Yes	The use of groundwater for irrigation and industrial purposes is unevenly distributed on the country. Major cities (Buenos Aires, La Plata, Córdoba) concentrate most of the industries; hence, the use of groundwater is quite relevant. Irrigation is important in Mendoza Province, as well as in many places of Buenos Aires Province.
Argentina_2	M - S	Yes	No	M	Yes	No	M - S	Yes	No	M	Yes	No	Aquifers localised in sedimentary basins, permeability: fair to good, behaviuor: free to semiconfined

	● Domestic water supply			● Public water supply			● Industrial use			● Irrigation			comment:
	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	
Barbados	M	Yes	Yes	M	Yes	Yes	M	Yes	Yes	M	Yes	Yes	Public water supply is also used for irrigation
Brasil	M	No	Yes	S	Yes	No	M	Yes	Yes	S	No	Yes	The country has a large territory and simplifications or generalizations are sometimes not possible.
Chile	M	Yes	Yes	M	Yes	Yes	M	Yes	Yes	M	Yes	Yes	In Chile, groundwater use is predominant from Santiago to the north. South of Santiago the use of groundwater is less important than superficial water, however it will increase systematically in the future. Because of the particular geography of Chile, the aquifers are nor really large comparing with others countries.
Uruguay	S	No	Yes	M	Yes	Yes	S	No	Yes	S	No	Yes	<comment IGRAC: 'S' in 1 and 4 were not given in the original questionnaire but 'local aquifers' however were selected!> The Guarani Aquifer is the only aquifer of large extent in Uruguay, it is a transboundary aquifer shared by Argentina, Brasil, Paraguay and Uruguay. Here it is exploited only for public water supply and for thermal spas. It is of minor use
Mexico	S	Yes	No	M	Yes	No	S	No	Yes	M	Yes	No	Groundwater pumping in México is around 28,000 Millions of m3 (Mm3) per year. 71% is used for agriculture, 20% for Water Supply, 6% for Industrial, and 3% for other activities .
number of 'M'	**26**			**30**			**20**			**17**			
number of 'Yes'		**26**	**35**		**33**	**27**		**29**	**28**		**26**	**30**	

	1 Groundwater situation in your country																
	1.2 Specification of problems related to groundwater																
	Groundwater problems:																
	• Groundwater table decline			• Pollution			• See water intrusion			• Land subsidence			• Other:				comment
	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	specify	in general	Major aquifers	Local aquifers	
Africa																	
Botswana	Yes	Yes	Yes	Yes	No	Yes	No			No			Natural inherent salinity in deep basins	Yes	Yes	No	
Djibouti	Yes	No	Yes	No	No	No	Yes	No	Yes	No	No	No		No	No	No	
Ethiopia	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No		No	No	No	<: Most pollutions observed in the rift valley and lowlands of Fthiopia are the result of natural environment (fluoride,calcium, sulphate etc.). There is also polution coming from industrial effluent and human waste disposal in cities and towns. There is little concern and awareness to monitor unless and otherwise the effect of pollution is reflected on humans or animals. In Ethiopia there is no concern for sea water intrusion. On the contrary,it is observed that there is salinity coming from the formation, agricultural activty and to some extent from saline lakes. Land subscidence due to pumping of groundwater is an important aspect that need to be observed. there has not been any attempt to monitor this due to little awareness and concern.>
Mauritius	No			Yes	Yes	Yes	Yes	Yes	Yes	No				No			** Groundwater table decline: Groundwater recharge occurs annually especially during summer ** See water intrusion: under control
Benin	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No		No	No	No	
Seychelles	No			Yes	No	Yes	Yes	No	Yes	No				No			
Central African Republic	No			Yes	Yes	Yes	No			No				No			Chemical (industry and agriculture) and biological (urban) contaminants
South Africa	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes		No			
Tunisia	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No				No			
Asia																	
China	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No		No			
India	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes		No	No	No	
Japan	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No			Any type of the groundwater problems can be found in Japan as it can be seen in the attached file which was sent by the writer in the previous mail (W:\a5\j3\p53021\IGRAC\D.guidelines,protocols,monitoring-networks\monitoring\additional data\Groundwater in Japan Jinno et al.PDF). Recently, the industries and real estates are more concerned with the soil and groundwater pollution and the remediation.
D.P.R. of Korea	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes		Yes	Yes	Yes	
Malaysia	No			Yes	Yes	Yes	Yes	Yes	Yes	No			To encourage the use of groundwater as supplementary/alternative sources of water supply	No			
Myanmar	Yes	No	Yes	Yes	No	Yes	Yes		Yes	Yes		Yes		Yes		Yes	No regular monitoring system.
Palestine	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No			* Salt water upconing from deep salty aquifers. * Scarce groundwater resources due to the usage of most of them by the Israelis as well as due to the arid-semi arid climate of Palestine.	Yes	Yes	Yes	* There are no measurements for land subsidence, but there are indications and expectations that this problem exists.
Yemen	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No				No			
Europe																	
Belgium_1	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No		No	No	No	Tempory level problems for local aquifers are linked to climate (rain). In limestones competition may arise between the abstraction for water supply and abstraction for quarrying, that may have consequences at a regional scale
Belgium_2	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	No	No	No		No	No	No	
Bulgaria	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No				No			
Denmark	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	No			DRAINING OF SURFACE WATERS	Yes	Yes	Yes	Draining of surface waters is a problem in regions of Denmark in seasons with low precipitation
Finland	No			Yes	No	Yes	No			No				No			
Hungary	Yes	Yes	Yes	Yes	Yes	Yes	No			No			Decrease of springs discharge	Yes	Yes	Yes	The origina chemical components (As, ammonia, Fe, Mn) of the deep groundwater causes problems.l
Italy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes		No			
Latvia	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No			<text>	No			<comment 1.2>
Romania	Yes	Yes		Yes	Yes	Yes	No			No				No			Groudwater table declines significantly only in the Upper Pliocene (Romanian) - Low Pleistocene major aquifer from the Southern Romania, the most affected zone being that of Bucharest. Pollution problems affect a lot of sites, mainly concerning shallow aquifers, but knowledge about them is far from being complete.
Serbia and Montenegro	Yes	Yes	No	Yes	Yes	No	No			No			<text>	Yes	Yes	Yes	General decrease of the groundwater level occurs in several aquifers of the large extent area of Vojvodina (northern part of Serbia), but the problem exists only in the water supply resources. Pollution problem occurs in alluvial aquifers that supply majority of public. Breakthrough of saline water from deeper aguifers occurs due to the over conumption. Depressing of the soil due to the aguifer overconsumption has not been recorded yet. Insuficiently developed observation netvork that does not cover all the aquifers on the total teritory of Serbia can be considered a major problem.
Slovenia	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	No		No	No	No	
Switzerland	No		Yes	Yes	Yes	Yes	No			No			Climate change and groundwater ressources evolution	Yes	Yes	Yes	Groundwater table decline: seasonal in local aquifers
North America																	
Canada_2	No			Yes	Yes	Yes	Yes	Yes	Yes	No			baseflow reduction/impacts on aquatic habitat	Yes	Yes	Yes	
Canada_1	Yes	No	Yes	Yes	No	Yes	No			No			Naturally occuring contaminants: As, U, Pb-210	Yes	Yes	Yes	Same as comments in Section 1.1
Canada_3	No			Yes	No	Yes	Yes	No	Yes	No				No			Groundwater pollution at Ville-Mercier, a well-known major problem, and see water intrusion at Îles-de-la-Madeleine, two sites for which we have special regulations, are the main cases of groundwater problems. Agricultural contamination (nitrates and bacteria) is also a big concern for the population and the autorities but there are still few sites with evidences of groundwater contamination.
USA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No			

	• Groundwater table decline			• Pollution			• See water intrusion			• Land subsidence			• Other:				comment
	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	in general	Major aquifers	Local aquifers	specify	in general	Major aquifers	Local aquifers	
Oceania																	
Australia	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No	Salinisation	Yes	Yes	No	These problems occur locally despite "In general" tick. They have not reached catastrophic levels and no resource has been rendered unusable because of them.
New Zealand	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes		No			Some aquifers are experiencing groundwater level rise due to the effects of defforestation of plantation forests and also irrigation return water.
South America																	
Argentina_1	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Salt-water upconing	No	Yes	Yes	All problems above mentioned are quite restricted geographically. The only exception is pollution, which affects large areas in the central portion of the country (mostly related to nitrate contamination from human activities).
Argentina_2	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	No				No			Groundwater table decline, only in localised urban and suburban areas and in rural areas. Recovery of piezometric levels due to the stop of exploitation wells. Pollution due to lack of sewerage, inefficient construction of wells, agriculture, urban wastes,etc. Sea water intrusion unicamente in Mar del Plata and La Plata (River Plate)
Barbados	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No				No			Sea water intrusion is in the aquifer system in coastal areas. No known land subsidence as a result of water abstraction
Brasil	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes		No			The groundwater resources are in general well preserved but in restricted areas (in and around large cities, industrial areas, etc.) there are all the problems listed above.
Chile	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	No				No			<Groundwater table decline is found in some aquifers like Casablanca Valley. A comun problem in the coastal area is sea water intrusion (ej. Quintero)
Uruguay	No			Yes	No	Yes	Yes	No	Yes	No				No			Main problems are high nitrates rates
Mexico	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes		No			At the present 100 aquifers are classified like overexploitated, 15% of the total aquifers (650). They pump around 5,400 Mm3/year and are located at the central and north part of the country in the main cities: Mexico City, Queretaro, Aguascalientes,Hermosillo,Toluca,etc. More than 17 aquifers are affected by saline intrusion, and 60 have been affected by some kind of anthropogenic or industrial, agriculture or anthropogenic pollution.
number of 'Yes'	**29**	23	23	**39**	22	36	**30**	13	25	**13**	6	10		**10**	10	9	

2 Monitoring groundwater quantity

2.1 What is presently being monitored

Variables monitored:

	• Groundwater levels				• Groundwater abstraction from wells				• Springs discharge				• Base flow of streams				• Land subsidence				• Other:					comment
	monitored?	purpose(s)	Major aquifers	Local aquifers	monitored?	purpose(s)	Major aquifers	Local aquifers	monitored?	purpose(s)	Major aquifers	Local aquifers	monitored?	purpose(s)	Major aquifers	Local aquifers	monitored?	purpose(s)	Major aquifers	Local aquifers	specify	monitored?	purpose(s)	Major aquifers	Local aquifers	
Africa																										
Botswana	Yes	1,2,3,4	Yes	Yes	Yes	1,2,3,4	Yes	Yes	No				No				No					No				
Djibouti	Yes		No	Yes	Yes		No	Yes	No		No	No	No		No	No	No		No	No		No		No	No	
Ethiopia	Yes	2,3,4	Yes	Yes	Yes	1,2,3,4	Yes	Yes	Yes	4	No	Yes	Yes	1,3,6,7	Yes	Yes	No					No				<:Monitoring of ground water is not yet accustomed in Ethiopia. This is primarily due to the cost of drilling and construction of monitoring wells, lack of awareness of the use of monitoring wells,good will and lack of knowledge. Abstraction and water level is monitored evey three months or once a year at some big towns and cities as suited. It is not done on appropiate monitoring wells (abstraction wells drilled for public use or other purposes]. springs are also monitored may be twice a year if they are used for the supply of drinking water.Therefore, it is not possible to mention the presence of real groundwater monitoring network. Baseflows and peak flows are monitored daily,monthly on intermitent rivers for whatever use it might be.It has a lot of river guaging stations allover the country.>
Mauritius	Yes	1,2,4	Yes	Yes	Yes	2,3,4	Yes	Yes	Yes	1,3	Yes	Yes	Yes	3,4	Yes	Yes	No					No				** Land subsidence: not a major issue in Mauritius
Benin	Yes	1,4	Yes	Yes	Yes	1,4	Yes	Yes	No		No	No	No		No	No	No		No	No		No		No	No	
Seychelles	Yes	1,2,3	No	Yes	Yes	2	No	Yes	No				Yes	3	No	Yes	No					No				
Central African Republic	Yes	2	Yes	Yes	Yes	2	Yes	Yes	No				No				No					No				Around 20 monitoring filters are places in different parts of the country for monitoring the inter seasonal groundwater fluctuations in order to be able to set/adjust the depth of the groundwater abstraction pumps.
South Africa	Yes		Yes	No	Yes		Yes	No	Yes		Yes	No	Yes		Yes	No	Yes		Yes	No		No				
Tunisia	Yes	1,2	No	Yes	Yes	1,2	Yes	No	Yes	1,2	Yes	Yes	No				No					No				
Asia																										
China	Yes	1,2,3,4	Yes	No	Yes	1,2,3,4	No	Yes	Yes	1,2,3	No	Yes	Yes	3	No	Yes	Yes	4,5	Yes	No		No				
India	Yes	1,2,3	Yes	Yes	Yes	1,2,3	Yes	Yes	No		No	No	No		No	No	No		No	No		No		No	No	
Japan	Yes	1,2,3,4,5	Yes	No	Yes	1,2,3,4,5	Yes	No	Yes	3,6	Yes	Yes	Yes	1,2,3	Yes	No	Yes	1,2,3,4,5	Yes	No		No				Even though every Japanese aquifer in Japan is not sufficiently surveyed in terms of environmental conservation, the local inhabitants are aware of the water quality protection in general. Accordingly, the counteractions are taken quickly by the local and central governments.
D.P.R. of Korea	Yes	1,2,3,4	Yes	Yes	Yes	1,3,4	Yes	Yes	Yes	3	No	Yes	No				No					No				
Malaysia	Yes	1,2,4	Yes	No	Yes	3,4	Yes	Yes	No				No				Yes	5	Yes	No		No				
Myanmar	Yes			Yes	Yes			Yes	Yes			Yes	Yes			Yes	Yes			Yes		No				WRUD-> No regular monitoring system.However groundwater abstraction from wells in Monywa groundwater Irrigation Project can be extrapolated based on crop patterns and irrigated area.
Palestine	Yes	1, 2, 3, 4	Yes	Yes	Yes	1, 2, 3, 4, 6	Yes	Yes	Yes	1, 2, 3, 4	Yes	Yes	No				No					No				* Interpretation of point 6: The Israelis have given each Palestinian well in Palestine a certain pumping quota, which it shall not exceed. They also prevent the drilling of new Palestinian wells. These limitations and restrictions by the Israelis are because of political reasons: The Israelis use most of the groundwater in Palestine, therefore they want to minimize the usage of the Palestinians in order to continue using that water for themselves.
Yemen	Yes	6	Yes	No	Yes	6	Yes	Yes	No				No				No					No				
Europe																										
Belgium_1	Yes	2,4,1,6	Yes	No	Yes	4,3	Yes	Yes	Yes	1,3	No	Yes	Yes	3,4	No	No	Yes	7	No	No		No		No	No	
Belgium_2	Yes	2	Yes	No	Yes	2, 4	Yes	Yes	No		No	No	No		No	No	No		No	No	*	Yes	**	Yes	Yes	*nitrate in phreatic aquifers; **2, quality
Bulgaria	Yes	1, 2, 6	Yes	Yes	No				Yes	3, 6	No	Yes	Yes	1, 3, 6	Yes	Yes	No					No				
Denmark	Yes	1; 2; 3; 4;	Yes	No	Yes	1; 2; 3; 4;	Yes	No	No				Yes	1; 3; 6;	Yes	No	No					No				
Finland	Yes	2,4	No	Yes	Yes	2,3,4	No	Yes	Yes	4	No	Yes	No				No					No				
Hungary	Yes	1,2,3,4	Yes	No	Yes	1,3,4	Yes	Yes	Yes	1,3	Yes	Yes	Yes	1,3	Yes	Yes	No					No				The monitoring of sprins discharge and base flow of streams is insufficient.

	• Groundwater levels				• Groundwater abstraction from wells				• Springs discharge				• Base flow of streams				• Land subsidence				• Other:					comment
	monitored?	purpose(s)	Major aquifers	Local aquifers	monitored?	purpose(s)	Major aquifers	Local aquifers	monitored?	purpose(s)	Major aquifers	Local aquifers	monitored?	purpose(s)	Major aquifers	Local aquifers	monitored?	purpose(s)	Major aquifers	Local aquifers	specify	monitored?	purpose(s)	Major aquifers	Local aquifers	
Italy	Yes		Yes	No	No				Yes		Yes	Yes	Yes		Yes	No	No		No	No		No				Italian local authorities basically manage the groundwater monitoring. The number and type of parameters, the density, the frequency and the purpose of monitoring are so extremely variable in the country.
Latvia	Yes	1,2,4,6	Yes	Yes	Yes	4	Yes	Yes	No				No				No					No				0
Romania	Yes	2, 3	Yes	Yes	Yes	3, 6	Yes	Yes	Yes	3, 6	No	Yes	No				No					No				For Groundwater levels see also the For gw abstraction from wells and spring discharges, see also the
Serbia and Monteneg	Yes	2	Yes	No	No				Yes	6	Yes	No	No				No					No				Republic Hydrometeorological Institute of Serbia performs systematic measuring of the changes in the level and temperature of the first fratic aquifer where the network covers almost all the aquifers of this category. The Institute carries out sporadic mesauring of water quantity outflow on certain major karst springs.
Slovenia	Yes	2,1	Yes	No	No		No	No	Yes	2,1	Yes	No	No		No	No	No		No	No		No		No	No	
Switzerland	Yes	1,2,4,6,7,8	Yes	Yes	No				Yes	1,2,7,8	No	Yes	No				No					No				
North America																										
Canada_2	Yes	1,3	Yes	Yes	No				No				Yes		Yes	Yes	No					Yes		Yes	Yes	
Canada_1	Yes	1, 3, 4	Yes	Yes	Yes	3, 4	Yes	No	No				No				No					No				See comments in Section 1.1
Canada_3	Yes	1, 6	No	Yes	No				No				No				No					No				6 : Groundwater contamination progression (pathway).
USA	Yes	1,2,5	Yes	Yes	Yes	1,2,5	Yes	Yes	Yes	1,2,5	Yes	Yes	Yes	1,2,5	Yes	Yes	Yes	1,2,5	Yes	Yes		No				
Oceania																										
Australia	Yes	1,2,3,4,6,7	Yes	Yes	Yes	3,4,7	Yes	Yes	No		No	No	No		No	No	Yes	5	Yes	No		No		No	No	
New Zealand	Yes	1,3,4	Yes	Yes	Yes	4	Yes	Yes	No				Yes	6	Yes	Yes	Yes	7	No	Yes		No				
South America																										
Argentina_1	Yes	1	No	Yes	Yes	6	No	Yes	No		No	No	Yes	3	No	Yes	No		No	No		No		No	No	There is not an official monitoring programme. Although the federal as well as provincial governments may do some monitoring, mostly such activities depend on research activities carried out by universities.
Argentina_2	Yes	2,3,4	Yes	Yes	Yes	2,3,4	Yes	Yes	No				Yes	3	Yes	Yes	No					No				There is a great heterogeneity in the monitoring of the variables in the country. Regions with low income have a poor monitoring.
Barbados	Yes	1 2 3 4	Yes	Yes	Yes	1 2 3 4	Yes	Yes	Yes	1 2 3 4	Yes	Yes	No				No					No				
Brasil	Yes	2	Yes	Yes	No				No				No				No				*	Yes		Yes	No	* Water quality; There are very few zones currently being monitored.
Chile	Yes	1,2,3,	Yes	Yes	Yes	1,3	Yes	Yes	Yes		Yes	Yes	Yes	1,3	Yes	Yes	No					No				<At a national levelt monitoring toring is carry out by the Dirección General de Aguas (www.dga.cl). Local monitoring is carry out by agencies like universities and othes reseach centers>
Uruguay	Yes	1,2,3	No	Yes	No				No				Yes		No	No	No					No				
Mexico	Yes	1,2,3,4,6,7,8	Yes	No	Yes	1,2,3,4,7,8	Yes	No	Yes	1,2,3,4	No	Yes	Yes		Yes	No	Yes	5	Yes	No		Yes	6	Yes	Yes	
number of 'Yes'	**40**		32	28	**32**		26	26	**21**		11	19	**20**		14	13	**10**		7	3		**4**		4	3	
purposes:																										***purposes:***
	1	28				15				11				7				2					0			*1. Groundwater flow analysis*
	2	29				17				8				2				2					1			*2. Control of groundwater table*
	3	20				20				11				12				1					0			*3. Groundwater balance calculation*
	4	20				20				5				2				2					0			*4. Optimisation of groundwater withdrawal*
	5	2				2				1				1				5					0			*5. Control of land subsidence*
	6	7				4				3				4				0					0			*6. Variable*
	7	3				2				1				1				2					0			*7. Variable*

	2 Monitoring groundwater quantity													
	2.2 Characteristics of monitoring networks for groundwater quantity													
	Scale of networks:			Secondary networks (B)										
	● Primary networks (A)			1. Around pumping stations			2. In nature conservation areas			3. Other				comment:
	Network?	no.obs. wells	Frequency	Network?	no.obs. wells	Frequency	Network?	no.obs. wells	Frequency	specify	description	no.obs. wells	Frequency	
Africa														
Botswana	Yes	100 - 1000	month	Yes	< 100	day	No			Groundwater drawdov	Special observat	< 100	month	We can not really answer to secondary networks (B) reliably. In Botswana the Geological Survey monitors about 150 observation boreholes on a monthly basis. Monitoring around pumping stations is regularly done by the Department of Water Affairs (DWA)and we don't have detailed information of this networks. Please directly contact DWA for accurate information, if not already done so. For information on the mines contact DEBSWANA, Botswanas national diamond company.
Djibouti	No	*	*	Yes	< 100	week	No							
Ethiopia	No			Yes	<the abstraction	<towice a year	No							<: As I mentioned above it can not be said that there is a monitoring network in general. I know one case at Addis Ababa water supply where monitoring wells were drilled for Modelling purpose around the pumping station.>
Mauritius	Yes	230	month	Yes	100 - 1000	fortnightly/mon	Yes	20	month	sea water intrusion		30	2 month	4. Water quality monitoring in sensitive zones - 50 - 2 month basis 5. Automatic groundwater level recorder - 20 - continues
Benin	Yes	< 100	month	Yes	< 100	month	Yes	< 100	month					For nature conservation area, the network of obsevation is on the coast and is intended for the observation of the intrusion of marine water in the surface aquifers
Seychelles	Yes	< 100	52	Yes	< 100	52	No							
Central African Republic	Yes	< 100	< 100 ??	Yes	100 - 1000	< 100 ??	No							Groundwater levels are usually determined when installing a new filter (?) or during situations with special problems.
South Africa	Yes			Yes			Yes							
Tunisia	Yes	100 - 1000	biannual	No			No							<The frequency of observation are manly two times per year>
Asia														
China	Yes	1000 - 10000	5 days	Yes	1000 - 10000	day	Yes	> 10000	10 day					
India	Yes	1000 - 10000	month	No			No							
Japan	Yes	1000 - 10000	day	Yes	< 100	day	No	< 100	day					The Japanese government and local prefecture government equip the monitoring wells appropriate for the type of the groundwater problems. However, probable number monitoring wells in Japan may not be systematically registered. This fact may come from that monitoring wells are not systematically well defined. Besides, the number of the monitoring wells tend to increase because of the new law for soil and groundwater protection enacted in 2002.
D.P.R. of Korea	Yes	100 - 1000	100-1000	Yes	100 - 1000	< 100	Yes	< 100	< 100					
Malaysia	Yes	< 100	month	Yes	< 100	month	No							
Myanmar	No			Yes			No							WRUD-> Currently special observation wells for checking water level changes in Monywa Groundwater Irrigation Project defunct.
Palestine	Yes	100 - 1000	Once every two r	No			No							* These are not real observation wells, they are normal pumping wells in which the measurements are done.
Yemen	Yes	100 - 1000	variable	No			No							
Europe														
Belgium_1	Yes	300	month	No			No							From the 300, 40 observation wells are equiped with continuous measurement.
Belgium_2	Yes	100 - 1000	month	Yes	100 - 1000	month	Yes	100 - 1000	month	agricultural areas	phreatic network	2100	seasonal	
Bulgaria	Yes	290	month	Yes			No							6% of the observational wells (A) are equiped with water level recorders, and 5% are measured from 2 to 6 times per month. Besides this monitoring network, monthly discharges from 31 artesian wells and 97 karstic springs are available (35 springs from them are with daily data).
Denmark	Yes	< 100	day	Yes	1000 - 10000	month	No							
Finland	Yes	< 100	week/month	Yes	< 100	week	No							
Hungary	Yes	1000 - 10000	week	Yes	1000 - 10000	month	Yes	100 - 1000	week					
Italy	Yes			Yes			No							See note to paragraph 2.1
Latvia	Yes	100 - 1000	2-3 times per mo	Yes	100 - 1000	week	No			In the area of dams of	Special observat	100 - 1000	week	0
Romania	Yes	1000 - 10000	week	Yes	< 100	week	No							Concerning Primary Network(A) : Quantity National Monitoring Network extents all over the country, but it concerns only shallow aquifers. The total number of quantity monitoring stations is 4582 and the frequency of level measurements is every 3 days.
Serbia and Montenegro	Yes	100 - 1000	week	No			No							0
Slovenia	Yes	100 - 1000	day	No			No					1000 - 100	1	
Switzerland	Yes	850	continuous	No			No							National network (NABESS) with 43 stations. - Networks of several cantons (total about 800 stations: mostly piezometres and pumping wells, only a few springs.
North America														
Canada_2	Yes	< 100	day	No			No							
Canada_1	Yes	< 100	hourly	Yes	< 100	various	No							See comments in Section 1.1
Canada_3	No			No			Yes	<20	day	At and around the are	Monitoring netw	< 100	day	Most observation wells have been installed for recent specific area studies, so the information is unevenly distributed.

	● Primary networks (A)			1. Around pumping stations			2. In nature conservation areas			3. Other				comment:
	Network?	no.obs. wells	Frequency	Network?	no.obs. wells	Frequency	Network?	no.obs. wells	Frequency	specify	description	no.obs. wells	Frequency	
USA	Yes	100 - 1000	quarterly - contin	No			No							We have only one national GW network funded in cooperation with state and local governments. The federal funding is minimal for a national network. State and local governments may have both primary and secondary networks as described above. I do not know #'s of wells for these.
Oceania														
Australia	Yes	> 10000	all of above	Yes	100 - 1000	all of above	Yes	100 - 1000	all of above					
New Zealand	Yes	< 100	month	Yes			No							
South America														
Argentina_1	Yes	< 100	month	No			No							Most provinces do not have groundwater level monitoring networks. The one I pointed out above corresponds to Buenos Aires Province, which used to be very well-operated, although nowadays funds for such activity have been cut off or reduced.
Argentina_2	Yes	1000 - 10000	year	Yes	1000 - 10000	year	No							ANA --> San Juan prov. Mandoza prov. INTA --> 8 regional offices (areas of 10,000-20,000 km2) responsible agencies B.1. water supply companies
Barbados	Yes	< 100	month	Yes	< 100	day	Yes		month					
Brasil	Yes	100 - 1000	semester	No			No							Restricted to more poppulated and developed regions of the southeastern region.
Chile	Yes	100 - 1000	month	No			No			<Local monitoring>	<Proyecto Unive	< 100	month	<The project that I mention in Other correspond to a systematic study that we are carry out in the area of Peumo, Lat 34 S>
Uruguay	Yes	< 100	b	Yes		a	No							Water levels are measured around some explotation areas or in some aquifers which are the object of specific projects
Mexico	Yes	1000 - 10000	2	Yes		1	Yes	< 100	1					At the present there are more than 5,000 observation wells located into 150 principal aquifers from 650 classified . The 150 are monitored regularly by CAN and they pump around the 80% of the total volume of GW used in the country.
Yes/Major	**36**			**27**			**11**							

2.5 State of the art with respect to monitoring groundwater levels

Characteristics of monitoring

	• Density of observation wells			• Frequency of observation			• Quality of the data	• Use of groundwater level data	comment
	In general	Major aquifers	Local aquifers	In general	Major aquifers	Local aquifers	In general	in general	
Africa									
Botswana	2	1	3	3	3	3	1	2	
Djibouti	1	...	1	2	...	2	2	3	
Ethiopia	1	1	1	1	1	1	2	2	<: Monitoring is not done frequently in every aquifer unless some problem such as level decline and qualty is observed. there has to be sufficient awareness. >
Mauritius	3			3			3	3	
Benin	1	1	1	1	1	1	1	1	
Seychelles	2	...	2	3	...	3	3	2	
Central African Republic	negl.	negl.	negl.	2	2	2	1	2	The number of monitoring filters is insufficient and with a bad distribution over the country. Moreover, the sample frequency is to low because a lack of financial means. The data is usualy not processed!
South Africa	1	1	1	1	1	1	1	1	
Tunisia	1	2	1	2	2	2	3	2	
Asia									
China	1	1	2	2	2	2	1	1	
India	1	negl.	2	2	2	2	1	3	
Japan	2	2	2	2	2	2	1	1	Due to the histories of the land subsidence, saltwater contamination, heavy metal contamination, and recently the NAPLS contamination, Japan will take similar counteractions as Europe and United States. Accordingly, the number of monitoring wells will increase in the near future. On the other hand, however, the engineers who can be systematically involved in the problems and who can educate the inhabitants and local governments as well as central government are limited. From the view point of installation of the systematic monitoring schemes in Japanese society, more external approach might be significant.
D.P.R. of Korea	3	3	2	3	3	2	3	3	
Malaysia	2	2	1	2	2	1	2	1	
Myanmar	1	...	...	1	...	...	2	2	
Palestine	2	2	2	2	2	2	2	1	* The density of observation wells is fair, but their distribution is not enough, there are several "large" areas which are left without any monitoring.
Yemen	1	1	negl.	1	1	negl.	1	negl.	
Europe									
Belgium_1	1	1	1	2	3	1	2	1	network is potentially good but it is not homogeneous enough and is not designed in a sufficiently well- defined purpose
Belgium_2	2	2	2	3	3	3	3	2	need for methodology, manpower for interpretation
Bulgaria	3	3	1	3	3	...	3	2	The density and frequency of observations is good for general overview of the major aquifers. They are insufficient for special purposes/tasks, especially in local aquifers. Taking into consideration very complicated geological structure of the territory of Bulgaria, high diversity of hydrogeological conditions is typical for our country. There are also many karstic massives drained by springs.
Denmark	2	2	1	3	3	1	3	2	
Finland	3	...	3	3	...	3	2	1	
Hungary	2	2	1	2	2	1	2	2	
Italy									
Latvia	3	3	2	3	3	3	3	2	
Romania	3	3	3	3	3	3	3	3	The national monitoring system is very developed concerning the monitoring of shallow aquifers, but it must be completed with a program of observations in the confined aquifers (see also)
Serbia and Montenegro	2	2	negl.	2	2	negl.	2	1	Observation network encomasses only the first freatic aquifer (shallow aquifers) of the large extent area.
Slovenia	3	3	1	2	2	negl.	3	2	
Switzerland	2	2	negl.	3	3	negl.	3	2	
North America									
Canada_2	3	3	1	3	3	1	3	2	
Canada_1	1	2	1	3	3	3	3	1	See comments in Section 1.1
Canada_3	1	1	1	3	...	...	3	2	The few data we have are taken and processed by us (provincial government).
USA	1	1	1	3	3	3	3	3	
Oceania									

	• Density of observation wells			• Frequency of observation			• Quality of the data	• Use of groundwater level data	comment
	In general	Major aquifers	Local aquifers	In general	Major aquifers	Local aquifers	In general	in general	
Australia	3	3	3	3	3	3	3	3	Monitoring can be improved in some areas. Good moniroing under threat in some areas due to cutbacks in Govt spending.
New Zealand	2	2	1	2	2	1	3	3	
South America									
Argentina_1	1	1	2	1	1	2	negl	negl.	
Argentina_2	1	1	...	1	1	...	2	1	
Barbados	3	3	3	3	3	3	3	2	
Brasil	1	negl.	1	1	negl.	1	1	1	
Chile	1	1	1	1	1	1	1	2	
Uruguay	1		1	1		1	1	1	
Mexico	2	2	1	2	2	1	2	2	At the present there are more than 5,000 observation wells located into 150 principal aquifers with a monitoring density of around average 4 wells /100 km2., covering around 130,00 km2. The frequency depends on the several local hydrogeological conditions, but in general is two times per year. In some cases due the occurrence of extraordinary precipitations (Hurricane occurrences) or severe drought, in several aquifers are instaled automatic data logger which are registering the levels every 12 hr. We have around 100 data logger installed on 10 aquifers. The position of the monitoring wells and the piezometric data are storage at a GIS system using arc view software. This allows to display and process the information by digital format.
3: Good	**9**	**7**	**5**	**16**	**13**	**9**	**17**	**8**	
2: Fair	**11**	**11**	**8**	**13**	**11**	**9**	**10**	**17**	
1: Incomplete or insufficier	**18**	**12**	**20**	**10**	**7**	**13**	**11**	**12**	
0: Negligible	**1**	**3**	**3**	**0**	**1**	**3**	**1**	**2**	
	0	**4**	**2**	**0**	**5**	**4**	**0**	**0**	
	8	**10**	**9**	**8**	**10**	**9**	**8**	**8**	

	3 Groundwater quality monitoring																													
	3.1 What is presently being monitored																													
	Baseline quality						Pollution by																							
	● Only TDS and/or EC			● Detailed set of macro parameters			● Domestic sewage (e.g. nitrate, bacteria, etc.)			● Industry (e.g. heavy metals, DNAPL, etc.)			● Agriculture (e.g. fertilisers, pesticides)			Specific natural constituents limiting groundwater use			Saline water intrusion			Other, please specify:				Other, please specify:				comment:
	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	specify	Being monitored?	Primary network(s)	Secondary	specify	Being monitored?	Primary network(s)	Secondary	
Africa																														
Botswana	Yes	No	Yes	Yes	No	Yes	No			No			No			Yes	No	Yes	No				No				No			The DGS has ot regularly monitored hydrogeochemistry parameters. If this is done, then it relates to research programmes implemented with foreign institutes and organization (e.g. Nitrate Reasearch Project; contact env.geo@info.bw, att. Dr. Vogel or the Kalahari Research Project: contact: oobakeng@gov.bw or obakeng@itc.nl
Djibouti	No	No	No	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	*	No	No	No		No	No	No	*<Local monitoring of impact of refugees presence on the ground water>
Ethiopia	No			No			No			No			No			No			No				No				No			<: There is little monitoring of groundwater quality and level on abstraction wells there is no monitoring .pollution is also not monitored.>
Mauritius	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No			Yes	Yes	Yes		No				No			C: not applicable
Benin	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes		No	No	No		No	No	No	
Seychelles	Yes	Yes	Yes	No			Yes	Yes	Yes	No			No			No			Yes	Yes	Yes		No				No			
Central African Republic	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No			No			No			No				No				No			see example form in appendix
South Africa	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No				No				No			
Tunisia	Yes	Yes	No	No			Yes	No	Yes	No			Yes	No	Yes	No		No	Yes	No	Yes		No				No			
Asia																														
China	No			Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	No			Yes	No	Yes		No				No			
India	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No		No	No	No		No	No	No	
Japan	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No				No			Basically, the enacted law in 2002 leads the attention of the local and central governments to monitor the groundwater quality which covers the water standards similar to WHO. The nation wide monitoring system is not yet sufficiently established. However, very dense monitoring system is setup once serious problems are detected by the government. The local prefecture governments are likely urged to monitor the groundwater quality systematically due to the law.
D.P.R. of Korea	Yes	Yes	No	Yes	Yes	No	No			No			No			No			Yes	Yes	Yes		No				No			
Malaysia	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No				No			Department of Environment (DOE) is also involved in the monitoring the quality of groundwater in selected areas
Myanmar	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes		No				No			WRUD->Regarding detailed set of macroparameters,WRUD and DDA, in corporation with UNICEF monitered the drinking water sources, including groundwater,nationwide during 2000 and 2001, focusing on 10 parameters. Arsenic,Fe,Nitrate,E.C., Chloride, Fluorite, turbidity,pH,Total Colliform. However,the process of testing chemically injurious parameter of Arsenic,undertaken by DOH is still in progress. Y.C.D.C.-> Presently, YCDC monitored main water sources and distribution water in pipeline.Mentin detailed set of macro parameters are turbidity,pH,Iron,Chloride,Sulphate,Total Hardness,TDS,Total Colliform and Faecal Coliform.
Palestine	Yes	Yes	No	No			No			No			No			No			No				No				No			The monitored parameters are normally: EC, TDS, majors cations and anions, they are measured for the monitored wells and springs. There are almost no measurements on sewage water, industrial water, agricultural water, etc.
Yemen	Yes	Yes	No	No			No			No			No			No			No				No				No			Occasionally macro parameters are measured although usually associated with a specific study.
Europe																														
Belgium_1	No	No	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	*	Yes	No	Yes	Conta	Yes	No	Yes	*Landfills; B1, B2 and C can be dealt to some extent by the primary network.
Belgium_2	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes		No	No	No		No	No	No	
Bulgaria	No			No			No			No			No			No			No				No				No			Please contact organisations responsible for monitoring groundwater quality:MOEW; NIMH
Denmark	No			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No				No			C: Also local problems with nickel due to overexploitation
Finland	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No				No				No			
Hungary	No			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No			*	Yes	Yes	Yes		No			*Environmental isotope; Ad hoc in case B2, B3, E.
Italy	No			No			No			No			No			No			No				No				No			
Latvia	No			Yes	Yes	Yes	No	No	No	Yes	No	Yes	No		No	No			Yes	No	Yes		No				No			
Romania	No			Yes	Yes	Yes	Yes	Yes		Yes	Yes		Yes	Yes		No			No				No				No			A2: Potential polluters began to create specific automonitoring stations downstream on the groundwater flow direction, but this must be improved B. In the National Monitoring Network for groundwater, from the mentioned 4582 stations, 1268 are also monitored from qualitative point of view. Twenty six general physical and chemical parameters are analised two times a year: temperature, pH, hardness, conductivity, chemical oxygen demand, calcium, magnesium, sodium, potassium, chlorides, sulphates, nitrates, nitrites, TDS, ammonium, phenol compounds, petroleum compounds, detergents, iron, manganesse, nickel, chromium, lead, zinc, cadmium and cooper
Serbia and Montenegro	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	No			Yes	Yes	No	Yes	Yes	No	No				No				No			From certain objects of the primary network of groundwaters, samplea are taken once a year for the quality control.

	• Only TDS and/or EC			• Detailed set of macro parameters			• Domestic sewage (e.g. nitrate, bacteria, etc.)			• Industry (e.g. heavy metals, DNAPL, etc.)			• Agriculture (e.g. fertilisers, pesticides)			Specific natural constituents limiting groundwater use			Saline water intrusion			Other, please specify:				Other, please specify:				comment:
	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	Being monitored?	Primary network(s)	Secondary	specify	Being monitored?	Primary network(s)	Secondary	specify	Being monitored?	Primary network(s)	Secondary	
Slovenia	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	No	No	No		No	No	No		No	No	No	
Switzerland	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No				No				No			
North America																														
Canada_2	No			Yes	Yes	Yes	Yes	No	Yes	No			Yes	No	Yes	No			No				No				No			
Canada_1	No			No			No		No	No			Yes	No	Yes	Yes	No	Yes	No				No				No			See comments in Section 1.1. Special networks, primarily registered public drinking water supply wells (such as public school wells) and domestic water wells, are currently being used to monitor for nitrates in agricultural areas and Uranium and Lead-210. Historic monitoring projects have been completed for As and pesticides.
Canada_3	No			No			No			Yes	No	Yes	No			No			Yes	No	Yes		No				No			Except for the Ville-Mercier area, the few data we have come from ad-hoc studies. In the process of getting an autorisation for potentially contaminating activities, sometimes a follow-up is required around the area. In this case, the follow-up is assumed by the owner (promoter).
USA	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes		No				No			Federally funded program NWQA (National Water Quality Assessment) is the only national GW quality monitoring program. Many local and state governments have their own programs, often in cooperation with a District USGS office
Oceania																														
Australia	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes		No	No	No		No	No	No	
New Zealand	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes		No				No			
South America																														
Argentina_1	No	No	No	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	No	Yes	No	Yes	No	No	No		No	No	No		No	No	No	
Argentina_2	No			Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes		No				No			B2. Only in large cities or industrial areas. B3: Monitoring very deficient. C. especially Arcenic Fl (Fluoride) and Vanadium (?) D Mar del Plata
Barbados	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No			Yes	Yes	Yes		No				No			Limitations on salinity are being addressed by two desalination plants directly and for future cocktailing.
Brasil	No			No			Yes	Yes	No	Yes	Yes	No	No			No			Yes	Yes	No		No				No			
Chile	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes		No				No			
Uruguay	No			No			No			No			No			No			No				No				No			Groundwater is monitored only in wells of public supply by OSE
Mexico	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	*	Yes	Yes	Yes	Oils S	Yes	Yes	Yes	*Mining activities; -We have a National Groundwater Quality Map based on TDS. At the present, We are building several thematic maps such as: arsenic and flour National maps concentration. Special monitoring attention is given to the arsenic natural occurrence in several aquifers.
Yes	**22**	**19**	**14**	**28**	**24**	**21**	**29**	**22**	**23**	**24**	**14**	**19**	**25**	**16**	**20**	**21**	**12**	**19**	**21**	**11**	**18**		**3**	**2**	**3**		**2**	**1**	**2**	

	4 Support from IGRAC									Information on:				
	Design of primary networks for groundwater level monitoring	Design of monitoring networks for groundwater abstraction	Design of monitoring networks for groundwater quality	Drilling and installation of observation wells	Data collection methods	Data processing, storage and screening methods	Data analysis methods	specify		Case studies as examples of good practice	Instrumentation for monitoring	Software for data analysis, storage and presentation	specify	
Africa														
Botswana	Yes	Yes	Yes	No	Yes	Yes	No		No	Yes	Yes	Yes		No
Djibouti	Yes	No	No	Yes	No	Yes	No		No	No	No	Yes		No
Ethiopia	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Mauritius	No	No	No	No	No	Yes	Yes		No	Yes	Yes	Yes		No
Benin	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Seychelles	No	Yes	No	No	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Central African Republic	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
South Africa	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Tunisia	Yes	Yes	Yes	No	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Asia														
China	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
India	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Japan	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
D.P.R. of Korea	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	No	Yes	Yes		Yes
Malaysia	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Myanmar	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Palestine	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes	Others	Yes
Yemen	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Europe														
Belgium_1	No	No	Yes	No	No	No	Yes		No	Yes	No	No		No
Belgium_2	Yes	No	No	Yes	No	Yes	Yes		No	Yes	No	Yes		No
Bulgaria	Yes	No	No	No	No	No	No		No	No	No	No		No
Denmark	No	No	No	No	No	No	No	How to optimise number of monitoring points? At the moment this is very often designed on the background of economic limitations.	No	No	No	No		No
Finland	No	No	No	No	No	No	Yes		No	Yes	No	Yes		No
Hungary	Yes	No	Yes	Yes	No	No	No		No	Yes	Yes	Yes		No
Italy	No	No	Yes	No	Yes	Yes	Yes	Standardization methods and criteria	Yes	Yes	Yes	Yes	Stanandardization methods and crite	Yes
Latvia	No	No	No	No	Yes	No	Yes		No	Yes	Yes	Yes		No
Romania	No	No	Yes	No	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Serbia and Montenegro	Yes	Yes	No	No	No	No	Yes	education of our experts	Yes	Yes	Yes	Yes		No
Slovenia	Yes	Yes	Yes	No	No	No	Yes		No	Yes	No	Yes		No
Switzerland	No	No	No	No	No	No	No		No	No	No	No		No
North America														
Canada_2	No	No	No	No	No	No	No		No	No	No	Yes		No
Canada_1	Yes	Yes	Yes	No	No	Yes	Yes		No	Yes	Yes	Yes	See comments in Section 1.1	No
Canada_3	Yes	Yes	Yes	No	No	No	No		No	Yes	No	No		No
USA	No	No	No	No	No	No	No		No	No	No	No		No
Oceania														
Australia	No	No	No	No	No	No	No		No	No	No	No		No
New Zealand	No	No	No	No	No	No	No		No	Yes	Yes	Yes		No
South America														
Argentina_1	Yes	No	Yes	No	No	Yes	No		No	No	No	No		No
Argentina_2	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Barbados	No	No	Yes	Yes	Yes	Yes	Yes		No	No	Yes	Yes		No
Brasil	No	Yes	No	No	No	Yes	Yes		No	Yes	Yes	Yes		No
Chile	No	No	No	Yes	Yes	No	Yes		No	Yes	Yes	Yes		No
Uruguay	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes		No
Mexico	No	Yes	No	No	No	No	Yes		Yes	Yes	Yes	Yes		No
Yes	**24**	**22**	**25**	**19**	**21**	**26**	**28**		**2**	**30**	**27**	**32**		**3**

B. Results of Interviews

Simultaneously to the IGRAC questionnaire interviews have been held with groundwater experts on the monitoring situation in several countries. The table below shows a concise summary of the information provided on several types of interests.

	Country:	**Hongary**	**Poland**	**Moldavia**	**Burkina Faso**	**Eritrea**	**Egypt**	**Kenya**	**Mozambique**	**Namibia**	**South Africa**	**Sudan**	**China**	**Indonesia**	**Syria**	**Bolivia**	**Yemen**	**India**
A1	**Type of groundwater bodies**																	
	- Large basins	1	1	1	0	?	0	1	1	1	?	1	1	1	1	0	0	
	- Alluvial valley fills - large size	0	0	1	1	?	1	1	1	1	?	1	1	1	1	0	0	
	- Local aquifers (e.g. in basement)	0	0	0	1	?	0	1	1	1	?	1	1		0	1	1	
A2	**Categories of groundwater use**																	
	- Domestic water supply	?	1	1	1		1			1	1	1	1	1	1	1	1	1
	- Public water supply	1	0	1	1		1	1	1	1	1	1	1	1	1		1	1
	- Irrigation	1	0	1	0		1	1	0	1	1	1	1	0	1	1	1	1
	- Industy	1	0	1	0		0	0	1	1	0	0	1		1			
	- Other	1	0	0	0		0	0	0	0		0			1			
A3	**Groundwater problems encountered**																	
	- Groundwater tabel decline	1	0	1	1		0	1	1	1	1	1	1			1	1	
	- Pollution	1	0	1	0		1	1	0	0		1	1			1		
	- Salinisation	1	0	?	0		1	1	0	0		0	1	1		0		
	- Sea water intrusion		?		?	1	1	1	1		1		1	1				
	- Land subsidence	0	0	0	0		0	0	0	0		0	1	1				
B1	**Monitoring groundwater levels**																	
	- Primary networks - national or regional	1	1	1	0	0	1	0	0	0/1	0	0	1	0	0	0		1
	- Secundary networks - local	1	1	1	1	0	1	1	1	1	1	1	1	1	0/1	1	1	1
	- Combination of primary and secondary networks	1	1	0	0	0	0	0	0	0	0		1		0	0		1
B2	**Objective monitoring groundwater levels**																	
	- Reconnaisance of groundwater system	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
	- Solving groundwater problems	1	1	0	0	0	1	0	1	1	0	1	1	1	0	1	1	1
	- Planning / pro-active management	1	1	1	0	0	1	0	0	1	0	0	1	0	0	0	1	1

B3	**Techniques of observation**																	
	- Recorders (extensive use)	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	1
	- Manual recording	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
B4	**Frequency of observation**																	
	- Daily					0	1	1					1		1			
	- Weekly	1				0	1			1					1			
	- Monthly	1	1	1		0	1			1		1	1	1	1			
	- Twice a year					0	1				1		1	1	1	1		1
	- Yearly				1	0	1		0/1						1			
B5	**Storage and use of data**																	
	- Intensive use	1	1	1	0	0	1	?	0				1			0		0
	- Data stored digitally	?	?	?	?	0	?		1	1	1				1	0		0/1
	- Ad hoc use	0	0	0	0	0	0		0			1		1	1	1		1
B6	**Monitoring groundwater discharge components**																	
	- Abstraction	1	1	1	1	0	0/1	1	0	1	0	1	1	0/1	1	?		1
	- Baseflow - (River discharge)	1	1		0	0	0	1	1	1	1	0	1	1	1	?		
	- Springs	1	1	1	0	0	0	0	0	1	1	0	1	0/1	1	?		
C1	**Monitoring groundwater quality**																	
	- TDS, EC	0	0	1	0	0	1	0	1	1	1	0	1	0/1	1	1		1
	- Macro parameters	1	1	1	0	0	1	?	0	1	1	0	1	0/1	1	1		1
C2	**Monitoring diffuse pollution**																	
	- From agriculture	1	0	1	0	0	0		0	0		0	0	0/1	0	0		
	- From industry	1	1	1	0	0	0		0	0		0	0	0/1	0	0		
	- From domestic wastes	1	1	1	0	0	0		0	0		0	0	0/1	0	0		
C3	**Special networks for diffuse pollution**																	
	- Yes	1	0	0	0	0	0		0	0	0	0	1	0	0	0		
C4	**Storage and use of data**																	
	- Intensive use	0	0	1	0	0	0	?	?	?		0	0/1	0		0		0
	- Data stored digitally	0	0								1	0	1	0	0	0		0
	- Ad hoc use	0	0									0		0		1		

C. Use of primary and secondary networks in groundwater level monitoring

1. Objectives

Groundwater level monitoring is conducted for a variety of purposes that may differ per region because of geographic differences in aquifer characteristics, climatic conditions, land use and human interference. The intensity of monitoring also differs because of financial and institutional conditions, urgency and priorities.
Typical objectives for groundwater level monitoring are:

1. Investigation of aquifer characteristics and parameters;
2. Characterisation of the groundwater system, including recharge and discharge areas;
3. Quantification of effects of groundwater abstraction;
4. Quantification of effects of surface water management, (including influences of canals, reservoirs, irrigation schemes, etc.);
5. Quantification of effects of groundwater management;
6. Protection of the groundwater regime in vulnerable areas, such as nature conservation areas;
7. Assessment of transboundary effects;
8. Etc.

The first group of objectives (1 through 4) are mainly technical objectives, aimed at characterising the groundwater system (1 and 2) and its response to two types of human interference, viz. by way of the fluxes (3) or the levels (4).
The second group of objectives (5, 6 and 7) are of the management type. These objectives are the result of “management or political subjects”. Examples are quantification of effects of management measures, protection of the environment, damage control, prevention of transboundary conflicts, etc.
For each objective, it is necessary to know where and when it applies and what specific information is needed. Management objectives usually need to be translated into technical specifications before they can be linked to criteria for the groundwater monitoring network. Some subjects are briefly discussed below.

Investigation of aquifer characteristics and parameters

Groundwater levels can be used to investigate the hydrogeological concept of an area (sequence of aquifers, aquitards and aquicludes) and the state of confinement of the aquifers. For instance, relevant differences in groundwater levels of observation wells, installed at different depths, provide clear indications of the presence of separating layers. Although a single set of values may not prove much, statistical evidence of these differences of measured in a number of wells does can be used to define and characterise the hydrogeological model of the subsoil.
Aquifer parameters, such as “hydraulic conductivity” and “storage co-efficient”, are mainly studied with the help of well tests or pumping tests. If, for the purpose of pumping tests, observation wells are required, these are usually installed in a particular configuration. The number of wells for this purpose is limited and confined to a relatively small area around the pumping well. Because of their limited distances, the majority of wells are generally not of interest for further groundwater development. However one or two observation wells may be saved to serve as an observation point in larger scale monitoring network.

Characterisation of the groundwater system
Characterisation of the groundwater system, (including recharge and discharge) concerns different aspects of the groundwater system, viz.:

- Identification of the directions of groundwater flow, both horizontally and vertically

- Delineation of the groundwater flow systems (areas of recharge, transition and discharge, groundwater divides, etc.)
- Assessment of the dynamics of the groundwater system, e.g. fluctuations in groundwater levels as effected by climatic conditions and human interference.

For characterisation of the groundwater system as a whole, there is a need for a large-scale network of distributed observation wells, which covers the groundwater system studied.

Quantification of effects of groundwater abstraction
Quantification of effects of groundwater abstraction on groundwater levels is needed to control impacts on the environment and to protect groundwater from over-exploitation. In order to enable assessment of the net effects of groundwater abstraction, measurements will be needed within the effected zone around the well or well field as well as outside that zone (reference points). The reference points serve to enable elimination of meteorological and other influences from the records, so that net effects by abstraction remain. As a consequence the required observation network has to extend beyond the area influenced by the abstraction wells and the frequency of observation has to be high enough to be distinctive for the various processes mentioned.

Quantification of effects of surface water management
Surface waters such as brooks, rivers, canals, lakes and reservoirs interact with the groundwater system, either discharging the system or recharging it. Therefore most interference in the surface water system (construction of dams or sluices, fixing the level of canals, etc). has a direct impact on the groundwater system as well. This relation is widely used to manipulate the groundwater system. The effects of surface water management depend on the hydraulic characteristics of the aquifers and separating layers.
To enable assessment of the impact on the groundwater levels, the levels of both water bodies must be measured. For measurement of the groundwater levels, groundwater observation wells will be needed in the vicinity of the surface water concerned. Each observation point (station) must have piezometers in all aquifers where effects can be substantial. The frequency of observation will have to be adjusted to the expected variations in groundwater levels.

Quantification of effects of groundwater management measures
Management of groundwater resources concerns optimal and sustainable use of these resources and protection of their environment. In order to fulfil these tasks groundwater managers will have to intervene in the groundwater system. Groundwater level data will be needed to judge about the impact of these interventions. The groundwater-monitoring network required will have to cover the aquifer system(s) concerned. Usually a large-scale reference network is needed to provide the reference data, while denser local networks may be needed in the areas where dominant effects are expected.

Protection of groundwater levels in nature conservation areas
In nature conservation area the effects of abstraction or other types of intervention may change the water table and in turn effect the natural vegetation. Examples of such vulnerable areas are wetlands and dune valleys, where the groundwater table is very close to the land-surface. In order to control the state of nature in such areas, data on the groundwater table may need to be combined with data on the vegetation. For observation of the groundwater table, mainly shallow observation wells will be needed in the most vulnerable areas. (Deep observation wells may also be needed if there is interaction with such deep aquifers). The frequency of observation may be adjusted to the pattern of dry and wet seasons.

Establishing transboundary effects
World wide quite some aquifers are found on the borders between countries or states. Management of the groundwater situation in such aquifers not only requires a certain level of co-operation between the water managers in both countries, but also matching groundwater data. In this context the European Water Framework Directive, for instance, requires that monitoring provide sufficient groundwater level data to enable investigating cross-boundary groundwater flow and the impacts of

measures on both sides. **(check).** For that purpose some countries have agreed to line up rows of observation wells across the border to study cross-boundary impact in major aquifers.

2. *Use of different network types*

On the basis of scale and objectives two types of groundwater monitoring networks can be considered:

c) large scale "primary networks" for overall studies of the groundwater system and for background and reference values;
d) locally oriented "secondary networks" installed for specific purposes.

Primary groundwater monitoring networks.

Primary networks for groundwater level monitoring (also called reference networks or background networks) are large-scale monitoring networks, usually covering aquifers of regional size. They serve to provide data regarding groundwater system behaviour and overall impacts on the groundwater situation caused by groundwater exploitation and other interventions. They also serve as reference networks for specific local studies.
They may cover an entire country or only the main plains and valleys, if these are separated by mountain ridges. Primary networks have their observation wells in the major aquifers, mainly in the fresh water zones.
The selected sites are usually at relatively large distances, sufficient to provide an overall picture of the groundwater situation. In Europe, for instance, the coverage of observation wells may range from 1 per 250 km^2 (Norway) to more than 5 on one square kilometre for special networks. The density of wells in confined aquifers can be much less than that in unconfined aquifers, which are more open to use and human influences, and where the effects of meteorology are more dominant.

Secondary groundwater monitoring networks

Secondary groundwater monitoring networks are composed to serve specific purposes, such as monitoring water table drawdown around pumping well fields, monitoring effects of irrigation schemes, monitoring ecological impacts, etc. These networks are usually local networks, adjusted to the specific situation they are meant for. Their configuration depends on the subject studied and the aquifer situation involved. Some examples are:
To monitor the impact of groundwater abstraction by pumping wells, the best configuration of the network may be star-shaped. If more than one aquifer is involved, an observation point will consist of two or more observation wells, one in each aquifer where effects are to be expected.
In wetlands observation points may be installed in the most vulnerable valleys. Each observation point may consist of a shallow well in the upper aquifer.

Combination of primary and secondary groundwater monitoring networks

Primary and secondary networks are usually combined to a wide-spaced regional network with denser-spaced parts in areas of particular interest. The terminology of primary and secondary networks can be used to link these networks to respectively "overall objectives", valid for large regions and "specific objectives", used to focus on particular aspects and, usually, local conditions.
The classification of primary and secondary networks is not only useful for the technical design purposes. It may also be used to divide the responsibility for monitoring (and its expenses) between governmental organisations, responsible for overall water management, and organisations with specific tasks or interest, such public water supply companies, organisations with a task in protection of nature conservation areas, and others.

The table below shows how a primary network can be combined with secondary networks to cover the objectives described in paragraph 4.1.

Relation between "groundwater level monitoring objectives" and network types needed

Purpose	Description	Type of monitoring network	
		Primary monitoring network	Secondary monitoring networks
1	Investigation of aquifer characteristics and parameters;	X	X (very local)
2	Characterisation of the groundwater system;	X	
3	Quantifying effects of groundwater abstraction;	X	X
4	Quantifying effects of surface water management;	X	
5	Quantifying effects of groundwater management measures	X	
6	Monitoring transboundary effects	X	
7	Protection of nature conservation areas	X	X

3. Monitoring wells and equipment

Monitoring wells

Various types of wells can be used to observe groundwater levels in the initial phase of groundwater resources assessment, ranging from dug wells, abandoned or used production wells, to specially drilled monitoring wells.
After the potential of the groundwater system for water supply has been proven and development is on its way, the monitoring network may be improved by installing extra monitoring wells at critical locations and replacing available wells that do not fit the criteria.

Criteria for installation of monitoring wells can be found in internationally available handbooks. Newly installed monitoring well will often be used for water level observation and for groundwater quality sampling as well. Therefore, installation of the well may need to satisfy both sets of criteria. The following definition and sets of criteria comes from US-EPA (Aller 1990):

The primary objective of a monitoring well is to provide an access point for measuring ground-water levels and to permit the procurement of ground-water samples that accurately represent in-situ ground-water conditions at the specific point of sampling. To achieve this objective, it is necessary to fulfil the following criteria:
- construct the well with minimum disturbance to the formation;
- construct the well of materials that are compatible with the anticipated geochemical and chemical environment
- properly complete the well in the desired zone;
- adequately seal the well with materials that will not interfere with the collection of representative water-quality samples; and
- sufficiently develop the well to remove any additives associated with drilling and provide unobstructed flow through the well.

In addition to appropriate construction details, the monitoring well must be designed in concert with the overall goals of the monitoring program. Key factors that must be considered include:
- intended purpose of the well;
- placement of the well to achieve accurate water levels and/or representative water-quality samples;
- adequate well diameter to accommodate appropriate tools for well development, aquifer testing equipment and water-quality sampling devices; and
- surface protection to assure no alteration of the structure or impairment of the data collected from the well.

If two or more aquifers are found, separated by less permeable layers, monitoring or observation wells may have to be installed in each aquifer. If conditions are favourable, this can also be done by constructing one large diameter well with several piezometers, isolated from one another.

Water-level measuring devices

Equipment for groundwater level measurement ranges from very simple measuring tapes for manual measurement (1 and 2) to sophisticated recorders (3 through 6) for continuous registration:

1. *A measuring tape*. The basic water-level measuring device is a steel tape typically coated with ordinary carpenter's chalk. This is the simplest water-level measuring device considered accurate at moderate depths;
2. *A tape with electric sensor.* Electric sensors are suspended on the end of a marked cable. When the sensor encounters conductive fluid, the circuit is completed and an audible or visual signal is displayed at the surface;
3. *Float type devices* rest on the water surface and may provide a continuous record of water levels on drum pen recorders or data loggers. Float sizes range from 1.6 inches to 6.0 inches in diameter, but are only recommended for wells greater than 4 inches in diameter, due to loss of sensitivity in smaller diameter bore holes;
4. *Pressure transducers* are suspended in the well on a cable and measure height of water above the transducer centre. Transducers are available in diameters as small as 0.75 inches;
5. *Acoustic well probes* use the reflective properties of sound waves to calculate the distance from the probe at the wellhead to the water surface. Acoustic probes are designed for well diameters as small as 4 inches and are limited to water depths greater than 25 feet;
6. *Air lines* are installed at a known depth beneath the water and by measuring the pressure of air necessary to discharge water from the tube, the height of the water column above the discharge point can be determined.

[Source: "Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells" (Aller, 1989).]

The choice between manual observation and use of automatic recording depends on:

- Information needs (e.g. the need for frequent data or high level of accuracy);
- Institutional and financial conditions (designation of tasks and budgets, availability of trained staff, availability of cheap labour, etc.);
- Logistic and other conditions (distance to the wells, availability of transport, accessibility of the spot, permits, etc.).

However, the absence of water level recorders does not necessarily have to be a constraint for effective and technically sound monitoring.

D. Use of networks in groundwater quality monitoring

Monitoring objectives

Groundwater quality is the result of a chain of interacting processes. Starting from precipitation onto the surface, these are:
- The chemical property of precipitation before it reaches the Earth's surface.
- The physical and chemical properties of the soils and geological formations passed by the water on its way through the ground.
- The physical, chemical and biological property of contaminating liquids, infiltrating from the surface or passing through faults or holes and wells in the ground.

Modern monitoring programmes are designed to provide the information needed for characterisation of the groundwater quality and for quantification of the trends in development caused by pollution and remedial measures.

In international documents on groundwater monitoring a variety of objectives can be found for groundwater quality monitoring. The general need for information has much in common, but the monitoring objectives differ somewhat per country, depending on the typical situation, needs and priorities. A list of common objectives on groundwater quality monitoring is the following:

1) Characterisation of groundwater quality in the region observed;
2) Establishing groundwater suitability for various types of use;
3) Establishing background values as reference for contamination studies;
4) Establishing effects on groundwater quality by diffuse sources of pollution (agriculture: fertilisers, herbicides, pesticides; gardening; industrial sites);
5) Establishing effects on groundwater quality by line and point sources of pollution (industrial end municipal disposal sites, oil stores, etc.).
6) Establishing effects of remedial measures
7) Etc.

Characterisation of groundwater quality

The following parameters can be used to characterise the groundwater situation:

List of suggested parameters required for a groundwater quality monitoring network (Nixon, 1996)

Descriptive parameters:	Temperature, pH, DO, (EC)
Major ions:	Ca, Mg, Na, K, HCO3, Cl, SO4, PO4, NH4, NO3, NO2, Total organic carbon
Additional parameters:	Choice depends partly on local pollution source as indicated by land-use framework.
Heavy metals:	Hg, Cd, Pb, Zn, Cu, Cr. Choice depends partly on local pollution sources as indicated by land-use framework.
Organic substances:	Aromatic hydrocarbons, halogenated hydrocarbons, phenols, chlorophenols. Choice depend partly on local pollution sources as indicated by land-use framework.
Pesticides:	Choice depends in part on local usage, land-use framework and existing observed occurrences in groundwater.
Microbes:	Total coliforms, feacal coliforms

Network types and configuration

Different types of groundwater quality monitoring networks

For monitoring groundwater quality, three types of monitoring networks can be distinguished:
1) A baseline network for initial characterisation of groundwater quality and for general studies of groundwater suitability and natural trends;
2) Specific networks for monitoring effects on groundwater quality caused by diffuse sources of pollution;
3) Specific networks for monitoring effects on groundwater quality of point and line sources of pollution.

The classes distinguished here may be termed different in (inter)national documents on groundwater monitoring. Baseline networks are also called “primary” or “background” networks, while specific networks (types 2 and 3) are also termed “secondary” and “tertiary” networks.

1. Baseline network for initial characterisation of groundwater quality

A baseline network is used to characterise the groundwater quality and to establish the suitability of groundwater for various types of use. The network should cover all relevant shallow and deep aquifers with fresh groundwater bodies of interest. The network is often selected out of existing monitoring wells and active or abandoned production wells. For this purpose there is no essential limitation for use of available wells, as long as these are in a good condition (cleaning must be possible) and their details are known. Usually many, if not all, wells of the primary network for groundwater level observation are used for this purpose. The network is needed at least once for initial characterisation of the groundwater quality. However it can be decided to repeat groundwater quality control with a frequency of, for instance, every five or 10 years.

2. Specific networks for monitoring groundwater pollution by diffuse sources

Known sources of diffuse pollution covering relatively large areas are:
- Agricultural sources of pollution: use of fertilisers, herbicides and pesticides;
- Domestic sources of pollution, mainly in rural areas: nitrates, ………..
- Industrial sources of pollution: ………

For analysis of the effects of a particular diffuse pollution source on a groundwater system, both the location and properties of the pollution source and the vulnerability of the groundwater system will have to be considered. The vulnerability of the groundwater system, in turn, depends on the prevailing hydrological conditions and on the hydraulic and chemical properties of the aquifer and its covering layers (if present).

Hence, the basis for network design for diffuse sources of pollution is the available information on the source of pollution and the vulnerability of the groundwater system, viz.:
- Maps showing the surface elevations and the drainage basins;
- Maps of land use, showing agriculture areas, urban and industrial areas, nature, etc.
- Soil maps and hydrogeological maps of the upper aquifers;
- Groundwater maps showing infiltration and exfiltration zones of the upper aquifers;
- Climatic conditions (only relevant for large countries divided by different climatic zones).

On the basis of these maps, the zones with high, intermediate and low risks of groundwater pollution by diffuse sources can be indicated.

As soon as the risks of pollution of the groundwater system have been mapped, decisions are needed about the information required from the network. For each monitoring objective the information needed must be specified. The priorities will have to be given by the authorities responsible for the groundwater system. In the final stage of the process the network will be designed according to the risks revealed and the priorities. Usually more than one option is considered in that process, both technically and financially. The final choice will be the basis for network design.

From the above it can be concluded that the process of network design for specific sources of diffuse pollution is a rather complex process, requiring extensive basic information (maps) of a high quality. The configuration of these networks can be very irregular, depending on the zones with high risks and the priorities attached. A gradual set-up of these monitoring networks, starting with "high risks first", may be the best strategy when available budgets are limited.

3. Specific networks for monitoring groundwater pollution by point sources

Specific networks for monitoring groundwater pollution by point sources are especially installed in the aquifers under threat. The monitoring wells are located in and around the estimated pollution plume. The frequency of sampling and analysis is adapted to the expected changes in groundwater quality, which are related to the velocity of the plume and the process of cleaning. These networks are for local and temporary use.
In order to protect the groundwater system from pollution by all kinds of point sources, many countries have adopted a strategy of prevention, requiring protective measures for the most risky activities. However, in all cases of pollution sources being already present, monitoring and cleaning up may still be needed.
The configuration of the networks is different for each case and will not be further discussed.

Combined use of baseline and specific networks

The objectives listed in paragraph 5.2 can be covered with these network types, as shown in the following table.

	Objectives	Baseline network (large scale, permanent)	Specific networks Permanent	Specific network Temporary
1	Initial characterisation of groundwater quality	X		
2	Establishing groundwater suitability for various types of use	X		
3	Establishing background values for contamination studies		Selected locations	
4	Establishing effects of diffuse sources of pollution - observing trends		Selected locations	
5	Establishing effects of point sources of pollution - observing a plume			Local sites
6	Establishing effects of remedial measures		Selected locations (see 3 and 4)	Local sites (see 5)

Monitoring wells and equipment

Various types of wells can be used to sample groundwater quality for initial or general characterisation in the initial phase of groundwater resources assessment, ranging from dug wells to abandoned or used production wells. For monitoring the effects on the groundwater by diffuse sources of pollution, the number of available wells with the right screen depth may be small. Then extra monitoring wells will be needed on selected locations, to be installed in the critical zones of the groundwater system. In order to enable sampling the water at different depths, these wells may have more than one piezometer with a screen in a predefined depth range.

Criteria for installation of monitoring wells can be found in internationally available handbooks. Newly installed monitoring well will often be used for water level observation and for groundwater quality sampling as well. Therefore, installation of the well may need to satisfy both sets of criteria. The following definition and sets of criteria comes from US-EPA (Aller 1990):

(For convenience they are repeated here).

The primary objective of a monitoring well is to provide an access point for measuring ground-water levels and to permit the procurement of ground-water samples that accurately represent in-situ ground-water conditions at the specific point of sampling. To achieve this objective, it is necessary to fulfil the following criteria:

- construct the well with minimum disturbance to the formation;
- construct the well of materials that are compatible with the anticipated geochemical and chemical environment
- properly complete the well in the desired zone;
- adequately seal the well with materials that will not interfere with the collection of representative water-quality samples; and
- sufficiently develop the well to remove any additives associated with drilling and provide unobstructed flow through the well.

In addition to appropriate construction details, the monitoring well must be designed in concert with the overall goals of the monitoring program. Key factors that must be considered include:

- intended purpose of the well;
- placement of the well to achieve accurate water levels and/or representative water-quality samples;
- adequate well diameter to accommodate appropriate tools for well development, aquifer testing equipment and water-quality sampling devices; and
- surface protection to assure no alteration of the structure or impairment of the data collected from the well.

Sampling procedures and sample conservation

Methods for sampling and conservation of samples and laboratory analysis are described extensively in the guidelines produced by the *International Organization for Standardization (ISO)* and the *American Society for Testing and Materials (ASTM International).* These international organisations have produced collections of guidelines on sampling methods, sample conservation and physical, chemical and biological testing methods. The guidelines can be found on their respective websites.
For determining water quality in the field, special field kits have been developed, which produce good results for a quick first impression. However, these field kits are limited with respect to the number of parameters and less accurate than methods of analysis in the lab. Therefore, they can be considered a valuable add to the lab methods, useful for pilot studies and quick assessment of the groundwater quality situation.