MONITORING OF GROUNDWATER QUALITY: EXPERIENCES FROM THE NETHERLANDS AND EGYPT

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Introduction

Groundwater management and groundwater monitoring are two activities, which are not only closely related, but in fact are inseparable. Without proper groundwater monitoring, effective groundwater management is not possible. This chapter discusses groundwater monitoring within the context of groundwater management. It will do so by looking at the cases of the Netherlands and Egypt.

The examples and experiences discussed in this chapter are derived from years of direct involvement of IWACO in groundwater monitoring and management. Involvement in the case of the Netherlands includes advising provincial and central governments, drinking water companies, and industries with an interest in groundwater. At the request of these parties, groundwater monitoring systems are designed and set up, assistance is provided to interpret data, and existing monitoring systems are optimised. The experiences in Egypt are mainly derived from the 15-year co-operation between the Research Institute for Groundwater (RIGW) and IWACO within the framework of the Dutch-Egyptian co-operation program. The joint activities during this period included the preparation of hydro-geological maps, the inventory of aquifers and their potentials, and since four years now, the design and implementation of a groundwater quality monitoring network.

This chapter has four sections. In section one, the question is discussed why monitoring is necessary, which role monitoring plays in groundwater management, and which data have to be collected in groundwater monitoring. The following deals with experiences from the Netherlands. Two examples of groundwater monitoring, and how monitoring data contribute to the formulation of groundwater management policies, are presented. The subsequent section deals with the establishment of a groundwater monitoring network in Egypt. The focus is on critical decisions in the design of a national monitoring network. The concluding section presents a set of principles for effective groundwater monitoring. These principles are based on Dutch experiences in operating a network and the more recent experiences of establishing a network in an arid country like Egypt.

Monitoring

Groundwater resources are not static; they change under influence of natural processes, the actions of groundwater users, and management decisions. Changes can be either planned or uncontrolled. As long as active management does not take place, all changes are
uncontrolled by definition. Changes occur with respect to both volume and quality of water bodies. Trends in groundwater resources can be either unfavourable or favourable.

As groundwater is the invisible part of the hydrological cycle, monitoring is a prerequisite to detect and understand changes in quality and quantity of groundwater bodies. Groundwater monitoring involves data collection. Unlike collecting data for the sake of some academic research purpose, data collecting for groundwater monitoring is focused on providing necessary information for management decisions. At all times it should be avoided to collect data for the sake of collecting only, as this results in excessive amounts of data that will never be used. The danger of 'data grave yards' should be avoided.

Data are meant to be fed into the management process. They should be interpreted and used to support management decisions. Management decisions in turn have an impact on a groundwater resource. Monitoring will pick up the changes in the resource that result from these decisions. This new information is brought to the attention of decision makers again, who may be prompted to take new decisions. In other words, groundwater management is cyclic and groundwater monitoring is an essential stage in this process.

It could also be said in other words. Groundwater monitoring means having your eyes in the ground. Its purpose is to understand groundwater resources, and to detect changes and trends in groundwater resources.

Figure 1. The cyclic nature of groundwater monitoring

Figure 1 depicts the cyclic nature of groundwater management and the role of monitoring. In the Netherlands groundwater quality has been managed since decades, the various steps of the cycle have been taken several times. In Egypt, groundwater quality management is relatively new; only the first steps of the cycle have been taken. In Egypt groundwater quality monitoring started some three years ago. The first step was to design a national monitoring network. Subsequently, monitoring wells were installed; the physical network was completed only recently. Collection of water samples will start at the beginning of 1998. The experiences gained in the Netherlands with setting up groundwater quality monitoring systems were a useful input in the design phase of the Egyptian network.
Water quality monitoring in the Netherlands

Data on water quality in the Netherlands are collected and analysed on national level at four years intervals. The data are collected by the National Institute of Public Health and Environmental Protection (Rijks Instituut voor Volkshygiëne en Milieu, RIVM), which for this purpose operates a network of some 340 wells. These wells have screens at about 10 and 25 metres below ground level. The RIVM is also responsible for data interpretation and assimilation. The data serve practical purposes: they are released to the general public and to specialised organisations, such as RIZA and KIWA.

The design of the data collection network, thereby the system of wells, is based on two criteria: soil type and land use. Three soil types are used in the design process for water quality monitoring in the Netherlands: sandy soils, clay soils and peat soils. Four different land uses are distinguished: agriculture, nature, industry and urban. On the basis of these criteria, homogeneous areas with respect to soil type and land use are identified. An example would be an industrial area on sandy soils near town A. Town A, on the same sandy soils complex, would be a separate homogenous area (same soil type, but different land use). The result is a large number of homogenous areas. The wells are distributed at random in these areas. The location of the wells were determined mainly according to statistical principles.

Groundwater quality monitoring implies in general the monitoring of four processes. These are (i) nitrification of groundwater, (ii) acidification, (iii) migration of contaminants, and (iv) salinisation. Nitrification of groundwater is caused by contamination with manure and fertiliser (nitrate problem). Acidification occurs as a result of pollution by industries and transport. Information on the migration of contaminants is particularly relevant in the case of large industrial zones, such as the Rotterdam harbour. Salinization is due to intrusion and upsurge of salt and brackish water; it is a potential risk in the western part of the Netherlands along the North Sea coast.

Initially, the Dutch monitoring network did not provide sufficient information on changes in water quality. This was partly because the network was designed purely on the basis of statistical criteria. An extension of the network was required. Over and above the 340 wells used for water quality monitoring, another set of wells of roughly the same number have been installed by the provinces. Doubling of the number of wells was required in order to gain sufficient information to support groundwater management at a more regional scale (provincial level). In the Netherlands groundwater management is the responsibility of the provinces: ultimately the provinces decide where groundwater can be used or should be protected, how much can be extracted, etc. (see also the contributions by Pellenbarg, Arnold, and Romijn, this volume.)

An example will explain the water quality monitoring system in the Netherlands. The example also shows how monitoring data have directly influenced groundwater management decisions.

Walcheren

Figure 2 shows the region of Walcheren. Walcheren is one of the former islands of the province of Zeeland, which is the Dutch province with the longest coast line. The figure is a typical example of an output map for visualisation of groundwater quality conditions. The map looks simple, but the amount of data needed to prepare such a map is substantial. The dots (consisting of several coloured rings each) on the map represent monitoring wells. Each
well has three filters, which are situated at different depths. The rings on the map represent these filters; smaller rings stand for deeper filters. The colours of the rings indicate trends in relative changes of chloride values. A negative trend in chloride means that water is becoming more brackish. This is indicated by the colour of red. A positive trend, that is a decrease in the value of chloride, is indicated by the colour of green. The condition that chloride values remain unchanged (neutral) is indicated by the colour of blue.

drained their land by using a very effective subsurface drainage system. In fact, the drainage system was so effective that too much fresh water was drained off. Salt water replaced fresh water; the At location B on Figure 2, farmers blue ring became red. The monitoring system provided the data to observe this trend. Data analyses and interpretation led to the explanation.

Figure 2. Groundwater monitoring Zeeland, The Netherlands
A water management decision, involving both provincial authorities and farmers, was taken. It was mutually agreed to avoid excessive drainage. This would probably stop and even reverse the intrusion of brackish water. The understanding of what exactly was going on underground was correct. As a result of the management decision the brackish water near the surface turned fresh again after a few years.

Both of the above mentioned examples illustrate the relation between groundwater quality monitoring on the one hand and active groundwater management on the other.

**Groundwater quality management in Egypt**

The national Research Institute for Groundwater (RIGW) was established in the 1950's. One of the first activities of the institute was the establishment of a monitoring network with wells all over the country. Until recently the wells were used almost exclusively for the measurement of water levels. The quantitative aspects and not the quality aspects were the aspects that policy makers were interested in. Water levels were measured regularly, at monthly intervals. Altogether some 800 wells were installed.

Water quality management became an issue only in the early nineties. The RIGW published three studies that assessed contamination of groundwater by waste products from the agricultural and industrial sectors and from households. The assessments were based on a preliminary monitoring campaign (RIGW/IWACO 1990). The study of the RIGW showed that agricultural pollution occurs at least locally. Farmers all over the country, but in particular in the irrigated Nile basin (Nile valley and delta), apply high levels of fertiliser. Contamination of groundwater with nitrates is most serious along the fringes of the Nile basin. Here, soils are more sandy, highly permeable and thus more vulnerable to pollution. Immediately adjacent to the Nile and in the Nile basin itself, the aquifer is less vulnerable to pollution. A thick layer of clay (upto12 metres) protects the underlying groundwater, which is of relatively good quality.

Industrial waste is another source of contamination. Groundwater quality monitoring in the industrial areas around Cairo and new industrial cities, like Sadat City and Tenth of Ramadan, aims at detecting if groundwater is polluted with industrial waste products (heavy metals, industrial solvents, dyeing agents, etc.). Pollution is expected due to a general lack of adequate treatment and environmental care systems. In some cases industrial waste water is transported to oxidation ponds and discharged afterwards into infiltration areas. During this process contaminated water could infiltrate directly into the subsoil and mix with good quality groundwater.

A third source of contamination of groundwater in Egypt are open drains that are used as sewers. Water from these open drains is often contaminated with bacteria from domestic sources. It infiltrates into the subsoil and reaches groundwater bearing layers down to a depth of 15 m below surface. This contamination is a direct threat to public health, especially in areas where shallow hand pumps are used.

Groundwater is becoming a more important source for water supply (domestic, industrial and agricultural purposes) and groundwater quality problems require actions at the central level. To accommodate these requirements, a national groundwater quality monitoring network was established. Based on Dutch experiences, a network was designed applying a process-based approach. This implies a relatively long design period of about three years. The process-based approach includes a thorough inventory and interpretation of the various geological, hydro-geological and hydro-chemical data and processes.
Special care is warranted during the early stages of designing a monitoring network. The problem is that each monitoring system produces its own set of data. Once a system is in place, it is difficult, and often impossible, to produce other data than the system was designed to produce. In the case of Egypt, designers started at the end of the process and moved backwards. They first made an overview of the immediate and mid-term data requirements among clients (Ministry of Public Works, drinking water companies). Subsequently, a monitoring system was designed which would produce these data. This in turn determined the location of the wells, well depths and screen depths.

The objectives of the national groundwater quality monitoring network are:
- to quantify changes in groundwater quality, either caused by pollution or by salinisation;
- to describe the overall current groundwater quality status on a national or regional scale.

The process-based design procedure is summarised in Table 1.

<table>
<thead>
<tr>
<th>Step</th>
<th>Activity</th>
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<tbody>
<tr>
<td>1</td>
<td>Identification of regions and aquifers</td>
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<tr>
<td>2</td>
<td>Identification of hydro-chemical units</td>
</tr>
<tr>
<td>3</td>
<td>Identification of priority sub-areas</td>
</tr>
<tr>
<td>4</td>
<td>Selection of areas for monitoring salinisation</td>
</tr>
<tr>
<td>5</td>
<td>Identification of homogeneous pollution units</td>
</tr>
<tr>
<td>6</td>
<td>Selection of monitoring areas and final distribution of wells</td>
</tr>
<tr>
<td>7</td>
<td>Detailed design</td>
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<tr>
<td>8</td>
<td>Construction of wells</td>
</tr>
<tr>
<td>9</td>
<td>Sampling, analyses and data reporting</td>
</tr>
<tr>
<td>10</td>
<td>Evaluation of data, reporting and optimization</td>
</tr>
</tbody>
</table>

_source: RIGW/IWACO 1994_

Data collection and inventory is carried out in step 1 to 5. In step 6 priority areas are identified. These are areas where relative are rapid changes in water quality are expected. The total number of wells that could be installed is estimated on the basis of available budgets and other resources. The distribution of wells over the priority areas is based on the size and potential threats (salinisation, pollution). Detailed design (step 7) starts with a general determination of well locations and well depths. In order to decide exact locations, conceptual hydro-geological models are produced for each priority area. In such models the information produced in step 1 to 5 is included. This includes data on main aquifers, groundwater flow directions, possible sources of pollution, and areas of salt water intrusion. On the basis of these models, the detailed network of monitoring wells is determined.

Figure 3 shows the priority areas for groundwater quality monitoring in Egypt. The main aquifer in Egypt is the Nile aquifer. This aquifer underlies the Nile valley and the Nile delta. Other aquifers are more local in nature, like the aquifers near the Mediterranean and Red Sea coast, which exist in wadi deposits, fractured rock or limestone. The proposed priority areas are all examples of aquifers in which rapid changes in either volume (because of large scale groundwater abstraction) or quality are expected. In these areas a relative larger numbers of
wells will be installed. In areas where changes in groundwater quality are not expected to be acute, a less dense network is designed (remaining part of the Nile basin). The emphasis in the latter areas is on reference wells. Sampling, that is, data collection, will take place with a frequency of once a year in the priority areas, where rapid changes are expected, and once every five years in areas where changes will not occur as rapidly.

Figure 3. Priority areas for monitoring

Concluding remarks and recommendations

This chapter is concluded with a number of comments and recommendations on groundwater management and the design and establishment of monitoring systems. Some of these recommendations have a more general character and have been suggested also by other contributors to this book.

Integration of groundwater and surface water in day to day management

Groundwater and surface water bodies are physically interlinked; and need to be managed in an integrated way. Egypt is in the favourable situation that both surface and groundwater are
under the responsibility of the Ministry of Public Works and Water Resources (MPWWR). The institutional integration of surface and groundwater management in Egypt is therefore not an issue.

Initially, groundwater and surface water management/monitoring in the Netherlands was carried out by different institutions. During the last decade the concept of integrated water management has been introduced.

**Participation of (ground)water users in the management of their resource**
The MPWWR has made a start with involving various users (industries, tourist companies, drinking water companies, and of course, farmers) in decision making. As an example can be mentioned an integrated water management project involving users, which will soon start in the Aswan region.

**Both quality and quantity aspects need to be considered in water management**
Practically this means that research institutes, like the RIGW, but also the Drainage Research Institute and the Nile Research Institute, will be actively involved in water management. This results in, for example, exchange of information and comparison of data sets. This will help in getting a consistent overall picture of the (ground)water resources in Egypt.

Also in the Netherlands further integration of the monitoring agencies is required.

**Data needs of clients determine the design of monitoring networks.**
The data needs of clients, the actual users of data, determine the design of a monitoring network. A first step is the formulation of relevant questions. Relevant hydro-geological processes and expected trends in groundwater quality should be investigated prior to network construction. A process-based design procedure, which takes into account available data and existing hydro-geological knowledge, will provide fit-for-purpose networks.

Related is the need to be consistent in the operation of the groundwater quality network. Sampling approaches, analytical techniques in laboratory, etc. should not be changed (without warning) during the monitoring process, as this results in data and conclusions that can not be explained.

Improvement of data collection systems is required from time to time. Monitoring systems provide specific data, namely the data that the systems are designed to produce. Information needs may change over time. Changed information needs in turn necessitate adjustments in the data collection system.

In the Netherlands optimisation resulted in an extension of the monitoring network. Experience made clear that a statistical design approach has its limitations and that a process-based design procedure results in a more fit-for-purpose network.

**Water users need to be made aware of the potentials and the limitations of the resource they are using.**
Water users and water managers, including decision making authorities, need more adequate information. Decisions to allow users to extract groundwater are sometimes based on limited information. In Egypt tailor-made maps are used that show both quantity and quality aspects of groundwater resources. These maps are easy to use by the responsible authorities and include sufficient information. The maps provide the basis for various (ground)water management plans. The existing licensing system could be optimised so as to serve as an effective management tool.
(Ground)water management will benefit from decentralisation.
In Egypt, decentralisation of (ground)water management has a special meaning, as water is considered a strategic resource. The country is almost entirely dependent on the Nile for its water. Without the Nile, there would not be Egypt. Notwithstanding this importance of water to the national economy and stability, decentralisation of groundwater management is still believed to be required. The main reason is that the distance from the central government to users is unpractically long. Lower level governments have a better view of conditions that affect water use and can react more rapidly to undesirable developments.

In the Netherlands authority to make water management decisions has also gradually shifted from national to regional level.

This paper is concluded with a final observation. In all countries groundwater monitoring can be further improved. Ultimately a more complete picture is possible, showing in detail both quantitative and qualitative aspects of groundwater. However, a groundwater resource is a very variable medium (in space, time and composition). In particular the quality of groundwater is difficult to predict, as it changes constantly under influence of all kind of hydro-chemical processes. Processes that we may never be able to fully understand, or even measure.

References


RIGW/IWACO. 1990. Development and management of groundwater resources in the Nile valley and delta project: assessment of groundwater pollution from domestic, agricultural and industrial activities. Internal project report RIGW/IWACO, Cairo.


