- POSTERS -

MONITORING OF GROUNDWATER, ESSENTIAL AND VALUABLE NATURAL RESOURCE

Patrícia Terceiro[1], Rodica Elena Ceclan[2], Mihail Ceclan[2],
João Paulo Lobo Ferreira[1], Teresa Leitão[1]

[1] National Laboratory for Civil Engineering, Lisbon, Portugal

[2] "Politehnica" University of Bucharest, Romania

Abstract

Groundwater extraction provides an important source of water supply. However, human development has been causing major pressures over the aquifers, requiring the identification and monitoring of both water quantity and quality, in order to define management strategies directed to protect water resources.
The paper presents a general overview of groundwater monitoring techniques and a summary of sampling procedures.

1. Introduction

In the last decades, groundwater role and importance has increased, with the aquifers being more and more recognized as an essential and valuable natural resource. However, human development has been causing major pressures over the groundwater resources (increase of water demand, pollution problems), which need to be identified and monitored, in order to define management strategies directed to protect water quality and to guarantee that water is used in a sustainable way.
The need to protect groundwater has been highlighted in EU in the Water Framework Directive (2000/60/EC) and, more recently, in the Groundwater Directive (2006/118/EC) on the protection of groundwater against pollution and deterioration.
This paper presents a general overview of groundwater monitoring techniques and a summary of sampling procedures.

2. Results and discussions

2.1. Point Pollution or Non Point Pollution

Point-source pollution refers to contamination originating from a single tank, disposal site, or facility. Wastewater discharges, industrial waste disposal sites, accidental spills, leaking gasoline storage tanks, and dumps or landfills are examples of point sources.

Non Point pollution is characterized by the difficulty in finding specific discharge areas and for having a large and diffuse number of polluting points. This type of pollution is usually found spread throughout a large area. Some examples of non point pollution sources include runoff from agricultural and forestry land, storm water runoff from urban areas and discharges from on-site sewage disposal systems.
The identification of the pollution sources existing in a study area can be done using tools like land cover, land use and land occupation cartography. Geographic Information Systems (GIS) can also help to determine some characteristics of the case study area, and fieldwork provides an opportunity to validate and update the data contained in the cartography.

2.2. European Legal Framework

Water Framework Directive (WFD) introduces an integrated approach, focused on protection measurements and it requires governments to take a new holistic approach to managing their waters.
In this context, and for the first time, groundwater has become a part of an integrated water management system, as it is included in WFD's river basin management planning. Milestones considering delineation of groundwater bodies, economic analysis, characterization of pressures and impacts, monitoring and designing of programmes of measures are clearly defined, aiming to achieve good quantitative and chemical status for all groundwater bodies by the end of 2015. Monitoring is a tool to support decision making in the water resources management [3].
For groundwater, the programmes referred in WFD shall cover monitoring of the chemical and quantitative status. WFD specifies three types of monitoring [4]:

- Long term surveillance monitoring: provides a broad understanding of the health of water bodies and tracks slow changes in trends, such as those resulting from climate changes.
- Operational monitoring: focuses on water bodies which do not meet good status and on the main pressures they face. This type of monitoring allows tracking the effectiveness of investments and other measures taken to improve the status of water bodies.
- Investigative monitoring: when further information about surface water bodies is needed and that cannot be obtained via operational monitoring, including information on accidents.

The Directive 2006/188/EC on the protection of groundwater against pollution and deterioration (Groundwater Directive) establishes specific measures to prevent and control groundwater pollution and sets up criteria for the assessment of good groundwater chemical status and for the identification and reversal of significant and sustained upward trends, as well as for the definition of starting points for trend reversals. These criteria take into account local characteristics and allow further improvements to be made based on monitoring data and new scientific knowledge.

2.3. Guidelines to delineate a groundwater monitoring plan

2.3.1. General considerations

Groundwater is used for a variety of purposes, including irrigation, drinking water supply and manufacturing. To verify if groundwater is suited for its use, it is necessary to develop an assessment of its quality, by collecting samples for subsequent analysis. These samples should be collected according to a monitoring plan, in order to give an accurate overview of the system being monitored. Figure 1 shows a flow diagram with the typical sequence of groundwater monitoring activities.

It is recommended a step by step approach, as it helps to minimize errors and provides a clear and concise strategy to identify the goals, requirements, and limitations of the program. A comprehensive and effective groundwater monitoring plan should address each activity that will occur during sampling analysis, data interpretation and response actions to be taken based on the results of monitoring [2].

The preparation of a groundwater monitoring plan begins with the understanding of the hydrogeological/geochemical setting. This knowledge is an essential prerequisite to design an effective groundwater system. This first information can be attained from available data from site explorations, literature reviews and previous experience with similar sites.

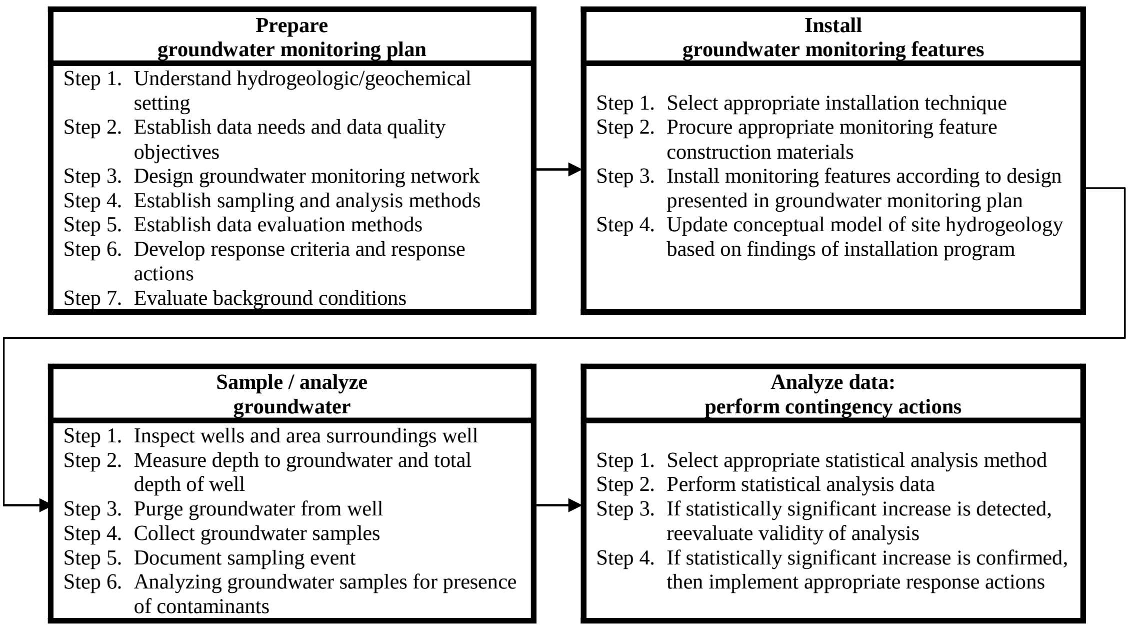

***Figure 1**: – Steps to define a groundwater monitoring plan [2]*

The type of data to be collected regarding the study area includes aquifer hydrogeological parameters (i.e., permeability, porosity, specific yield or specific capacity). It is also essential to have a geologic characterization of the site, as it is necessary to understand the main travel pathways expected for the contaminants if they were introduced into groundwater with certain characteristics of flow and transport.
The interconnection between surface water and groundwater is an interesting issue for a more deep knowledge as well.
The purpose of groundwater monitoring is to define the water's physical, chemical and biological characteristics within a certain site history which needs to be understood, and its aims should be defined before monitoring begins so that appropriate procedures, techniques, and analyses can be planned in order to meet the specific project needs.

2.3.2. Selection of the parameters to analyze

For exploratory efforts, it is useful to obtain slightly more chemical and hydrologic data than those required by the immediate information needs of the program. Nevertheless, these parameters should be targeted to give a general picture of the water quality and not a too detailed view. After these first results, then more specific parameters can be chosen to clarify exactly what are the parameters causing the global quality previously measured. The added data can normally be put to good use as the site conditions become better defined. The results of the complete mineral analysis and field determinations define the major ion solution chemistry, which is quite valuable to obtaining an overall picture of the subsurface system of interest [5].
The process of selecting parameters should also consider eventual pollution sources present in the study area.
Table 1 contains an example of parameters that can be analyzed in groundwater sampling, as the final group should always be defined according to the above described. The basis of a successful monitoring program is a robust, integral sampling protocol, coupled with proven analytical schemes.

Table 1

Example of groundwater parameters to analyse [6]

Measure in situ	***Chemical Analysis***		
Temperature	Total Organic Carbon	Anions: Cl, HCO_3, SO_4	Cu
pH	Biochemical Oxygen Demand	Cations: Ca, Mg, Na, K, Mn	Zn
Redox Potential	Chemical Oxygen Demand	Cd	Fe
Electric Conductivity	Nitrate	Cr	
Dissolved Oxygen	Total Phosphorus	Pb	

2.3.3. Groundwater monitoring points

The preliminary locations and depths of monitoring wells should be selected on the basis of the best available pre-drilling data. Then, as the actual installation of these wells progresses, new geologic and hydrologic data should be incorporated into the overall monitoring plan to ensure that the finished wells will perform the tasks for which they are designed [1, 5].

2.4. Sampling frequency

Sampling frequency will result from a balance between the required number of samples to have representative data and the available budget [5].When quality trends are identified along a given period, it is possible to adopt a sampling frequency that better adjusts to the representative sampling collection [6].

2.4.1. Procedures to collect samples

A general approach to the sampling of groundwater monitoring wells should include a set of steps, for each monitoring point, including the localization and identification of the groundwater monitoring point, inspection of wells and surrounding areas, measurement of depth to water table and total depth of the well, collection of groundwater samples using appropriate techniques and, finally, measurement of physical-chemical parameters of the collected samples.
The monitoring plan should include a written protocol of the sampling procedures, including instructions and tasks to perform [6].

2.4.2. Equipment

Some groundwater monitoring programmes may include the use of direct monitoring devices, such as sensors or probes that allow analyzing groundwater quality *in situ* or *on site*. Multiparameter probes can be used for *in situ* measurements of the physical characteristics of water. These probes can be equipped with different electrodes, in order to monitor several parameters, like pH, conductivity or temperature. Sampling devices are used to collect on point samples, representing water characteristics at the moment of collection.

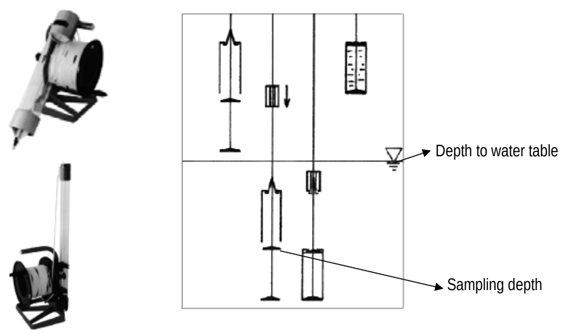

Figure 2 – *Groundwater sampling devices and schematic representation of its operation [6]*

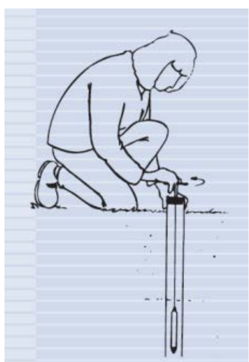

Figure 3 – *Diver operation. [http://www.surechem.com.my/]*

The procedure used to collect groundwater samples with this equipment consists on placing the device inside the monitoring point, at a given depth (Figure 2).
The diver (Figure 3) allows automatic measurement and registration of groundwater levels and groundwater temperatures.

2.4.3. Sampling conservation and storage

The purpose of sample preservation is to minimize any physical, chemical, and/or biological changes that may take place from the time of sample collection to the time of sample analysis [7]. Table 2 presents an example for summary of sample conservation processes for a set of common groundwater parameters.

Table 2

Summary of sample conservation processes [6, 8]

Parameter	Type of container	Conservation	Maximum holding time
0	*1*	*2*	*3*
Solids	Plastic (polyethylene or equivalent) or glass	Refrigerate	7 days
Hardness		Add HNO_3 until pH<2	6 months
COD		Analyze as soon as possible or add H_2SO_4 until pH < 2; Refrigerate	7 days
BOD5		Refrigerate	6 hours
TOC	Glass	Analyze as soon as possible or add HCl until pH<2; Refrigerate	7 days
Metals (general)	Plastic (polyethylene or equivalent) or glass, rinsed with 1 + 1 HNO_3;	Add HNO_3 until pH<2	6 months
Oil and Fats	Glass wide-mouth calibrated	Add H_2SO_4 until pH<2; Refrigerate	28 days
Total Hydrocarbons	Glass		
Nitrate	Plastic (polyethylene or equivalent) or glass	Analyze as soon as possible, Refrigerate	48 hours
Ammonia	Plastic (polyethylene or equivalent), teflon or glass	Add H2SO4 or HCl until pH<2 or Refrigerate	7 days
Total Phosphorus	Plastic (polyethylene or equivalent) or glass	Add H_2SO_4 or HCl until pH<2 or freeze without any additive	28 days

0	1	2	3
Sulphate	Plastic (polyethylene or equivalent) or glass	Refrigerate	28 days
Dissolved gases	Glass	Dark	35 hours
Iron, Manganese Sodium Potassium Calcium Magnesium	Plastic (polyethylene or equivalent) or teflon	Add HNO_3 until pH<2	6 months
Phosphate Chloride, Fluor Silicate	Plastic (polyethylene or equivalent), Teflon or glass	Refrigerate	35 hours 7 days 7 days
Phenols	Teflon or glass	Add H_3PO_4 until pH<4 or Refrigerate	35 hours

3. Conclusions

WFD imposes EU Member states to undertake monitoring programmes aiming not only to develop river basin management plans but also to define programmes of measures in order to achieve "good status" objectives by 2015. Regarding groundwater, these obligations concern chemical and quantitative status objectives.

Monitoring networks are a key feature to provide knowledge and understanding of the groundwater status, both at a river basin and regional scale. With this in mind, it is fundamental to develop strong and effective monitoring programmes, in order to define groundwater efficient protection and/or remediation measures.

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