16th Romanian International Conference on Chemistry and Chemical Engineering
September 9 – 12, 2009, Sinaia – Romania Sno. O-xx

GROUNDWATER MONITORING

Patrícia TERCEIRO[1], João Paulo LOBO FERREIRA[2], Teresa LEITÃO[3], Aurelia MEGHEA[4], Rodica CECLAN[5], Mihail CECLAN[6]

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, as a result of a joint collaboration between the National Laboratory for Civil Engineering in Lisbon and Research Institute for Electrical Engineering Bucharest, during the common activity developed in the European FP 6 project, Marie Curie ToK – IAP: KnowEnTech, MTKI-CT-2005-029758.

Keywords: Groundwater monitoring, pollution sources, Water Framework Directive (WFD), Groundwater Directive.

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. Groundwater extraction through wells provides an important source of water supply, not only for drinking water, but also for other uses like agriculture or industry. 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.

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[1] Msc., at Groundwater Division, National Laboratory for Civil Engineering, Lisbon, Portugal.

[2] Dr.-Ing. Habil., Groundwater Division Head, National Laboratory for Civil Engineering, Lisbon, Portugal.

[3] PhD Researcher at Groundwater Division, National Laboratory for Civil Engineering, Lisbon, Portugal

[4] Prof., Faculty of Applied Chemistry and Material Science, University “Politehnica” of Bucharest, Romania

[5] Prof., Faculty of Applied Chemistry and Material Science, University “Politehnica” of Bucharest, Romania

[6] Prof., Faculty of Mechanical Engineering, University “Politehnica” of Bucharest, Romania

At the European Union level, the need to protect groundwater has been highlighted with the publishing of important legislative instruments, like the Water Framework Directive (2000/60/EC) and, more recently, with the Groundwater Directive (2006/118/EC) on the protection of groundwater against pollution and deterioration. Both pieces of legislation refer to the need to monitor groundwater systems, in order to better understand their state and to define protection measures, maintaining the resources in a good state.

This paper presents a general overview of groundwater monitoring techniques and a summary of sampling procedures.

2. Pressures on Groundwater Resources

Pressures on groundwater resources have been increasing all around the world, mainly due to human activities and climate changes. Monitoring the aquifer characteristics is crucial for quantifying and understanding the consequences of these pressures.

Water pollution results on the loss of the actual or potential beneficial uses of water, and is caused by any change in its composition due to human activity. There are many specific causes for water pollution, which fit on one of these two broad categories: Point Pollution or Non Point Pollution.

Point-source pollutants in groundwater are usually found in a plume shape, where the highest concentrations of the pollutant are near the source (such as the end of a pipe) and diminish further away from the source. In this case, harmful substances can be emitted directly into the water body. 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 is fundamental, in order to recognize expected type of pollutants, a possible concentration range, and to define monitoring programmes and sampling procedures. This identification 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.

3. European Legal Framework

Even though the need to protect the European Union waters has been highlighted for more than two decades, the major step towards an integrated management of the water resources inside the community space was taken with the 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.

It is in the physical space of the river basin that changes resulting from pressures, caused mainly by human activities are felt, and where water quality and quantity issues should be addressed. It is also inside the river basin that management and planning measures should be defined. In the river basin area should be also implemented monitoring programs, required by the WFD, to examine coherently and comprehensively the state of the water bodies. Monitoring is, therefore, a tool to support decision making in the water resources management [3].

In order to understand the current status of the waters and to define measures to achieve the goals imposed by WFD, it's essential to develop a monitoring programme, also foreseen in the Directive. The Directive sets a five-class scale - high, good, moderate, poor and bad. Article 8 sets out the monitoring requirements for monitoring surface water, groundwater and protected areas, which "are required to establish a coherent and comprehensive overview of water status within each river basin district". Monitoring will provide the information needed to assess the state of the water environment, to manage pressures on the water resources, and to assess long term trends.

For groundwater, the programmes referred in WFD shall cover monitoring of the chemical and quantitative status. Once Member States have determined the current status of their water bodies, monitoring then helps Member States to track the effectiveness of measures implemented to clean up water bodies and achieve a good 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.

In addition to these three main types of monitoring, Member States need to carry out more detailed analysis in areas that are protected for drinking water or for natural habitats and species.

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.

This Directive establishes threshold values for the pollutants, groups of pollutants and indicators of pollution which, if exceeded, will indicate that a given groundwater body is at risk. As a minimum, Member States must establish threshold values for: ammonium, nitrate, arsenic, cadmium, chloride, lead, mercury, sulphate, pesticides and derivatives, trichloroethylene and tetrachloroethylene.

4. Guidelines to delineate a groundwater monitoring plan

4.1. 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.

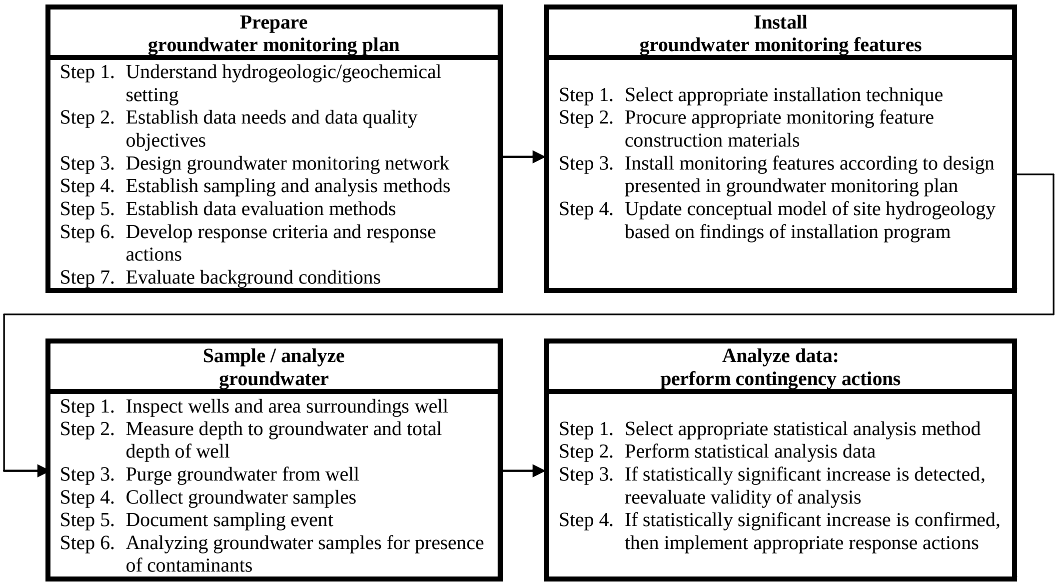

Fig. 1 – Steps to define a groundwater monitoring plan. Source: [2]

Developing a groundwater monitoring plan requires an in-depth understanding of site conditions, contaminant properties, regulatory requirements, and other technical considerations. An understanding of the factors that could affect the quality, validity or representativeness of groundwater samples is also essential.

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. These plans ought to be able not only to describe each and every aspect of the groundwater monitoring, but also to control monitoring activities in order to guarantee that the overall goals of the groundwater monitoring strategy are fulfilled. 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.

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.

Other examples of information that should be obtained before installing groundwater monitoring features include the limits of the aquifers, anisotropies in aquifer material, presence of discontinuities (e.g., fractures, solution cavities, channel deposits, etc.) within or between stratigraphic units or the surface topography of the site, as it may provide an indication of the potential impact of a contaminant release to groundwater, and also of the path these contaminants took until reaching an aquifer after being released from the ground surface. The interconnection between surface water and groundwater is another interesting issue for a more deep knowledge.

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.

4.2. Selection of the parameters to analyze

Parameter selection for chemical analysis is essential to the effective planning of sampling and analytical protocols. 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. For example, in a situation where essentially no chemical data exist for a site, a complete general mineral analysis should be included. The results provide an internal consistency check on major ionic constituents, field determinations, and the potential effects of unusually high levels of metals or nutrient anions. 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].

Having a complete mineral analysis and a clear view of information needs, it is possible to select any additional chemical parameters of interest. These parameters may be characterized as general groundwater quality parameters, pollution indicator parameters, and specific chemical constituents.

The process of selecting parameters should also consider eventual pollution sources present in the study area. Land use should be used to support this choice, as for instance, pollutants found in agricultural areas will necessary be different from those found in industrial or urbanized areas.

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. Regardless the amount of base information, the planning effort must incorporate flexibility to meet a variety of contingencies. 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. Source: [6]

Measure in situ	***Chemical Analysis***	
Temperature	Total Organic Carbon	Cadmium
pH	Biochemical Oxygen Demand	Chromium
Redox Potential	Chemical Oxygen Demand	Lead
Electric Conductivity	Nitrate	Copper
Dissolved Oxygen	Total Phosphorus	Zinc
	Anions: Chloride, bicarbonate, sulphate	Iron
	Cations: Calcium, magnesium, sodium, potassium, manganese	

4.3. Groundwater monitoring points

Locating the appropriate monitoring point locations is fundamental in designing a monitoring network capable of providing data to achieve the program objectives. 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 [5]. If wells or boreholes already exist on the field they can be included in the monitoring network, therefore reducing costs. However, it is important that they have good supporting geological information and construction details.

The density of monitoring wells should depend on the size and heterogeneity of the groundwater body, the geological and hydrogeological characteristics of the groundwater system, the aquifer vulnerability, and the risk posed to the aquifer from potential contaminant sources [1].

4.4. Sampling frequency

A possible approach to define sampling frequency can begin with a first evaluation of the type of source that is being monitored: a spill, slug, intermittent source, or continuous source. Then, it should be considered the likely pulse or continuous plumes of contaminants to be monitored, determine the minimum desired sampling frequency in terms of length along the ground-water flow path, and use hydrologic data to calculate the required frequency to satisfy these goals. However, ultimately, sampling frequency will result from a balance between the required number of samples to have representative data and the available budget [5].

In the initial monitoring phases, and whenever possible, it is recommended to perform more frequent measurements of the main parameters like pH, electrical conductivity, temperature, dissolved oxygen and redox potential, using proper devices. 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].

4.5. 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 entire sampling event should be documented. All the material used in the field work should be properly prepared in the laboratory.

The monitoring plan should include a written protocol of the sampling procedures, including instructions and tasks to perform, as it follows [6]:

- Make a record of every sample collected and identify every bottle with a unique sample number, preferably by attaching an appropriately inscribed tag or label;
- Wash sampling devices with distilled water;
- Measure temperature, pH, electrical conductivity, redox potential, dissolved oxygen placing the electrodes submerged and about 2 cm away from the side and bottom of the water container; wait some minutes and register the parameter’s value;
- Wash the bottles at least twice with sampling water, unless they contain conservative substances or are sterilized;
- Collect the water sample directly on the bottle that will be transported;
- Use proper bottles according to the parameters that will be analyzed;
- Fill in a field report with sample identification, date and place of collection and parameters that will be analyzed.

- Depending on determinations to be performed, the container may be totally filled (most organics determinations) or a space left for aeration, mixing, etc., for example for microbiological analyses;
- For samples that will be shipped, it is recommended to leave an air space of about 1% of container capacity to allow for thermal expansion;
- For samples containing organic compounds and trace metals special precautions are necessary, because of small concentrations (µg/l) of some constituents, they may be totally or partially lost if proper sampling and preservation procedures are not followed.

4.6. Equipment

Typically groundwater samples are collected in monitoring wells. However, piezometers and groundwater discharges can also be used to collect samples. Each feature has a purpose and a situation for which it is best suited.

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 (Fig. 2) 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. To guarantee the quality of the measurements, the electrodes should be calibrated with adequate standard solutions. These solutions are generally provided with the equipment, and each parameter as its proper type of solution.

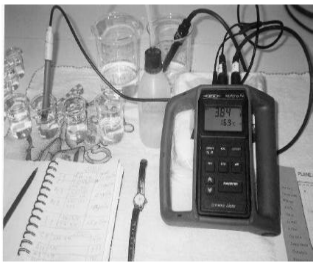

Fig. 2 – Multiparameter probe

Fig. 3 – Sampling devices used to collect groundwater samples

Ion selective probes are another type of direct device commonly used at groundwater monitoring sites. These devices are designed to detect specific ions in groundwater, by producing an electric signal that can be compared to a reference signal for a specific ion constituent. This method is particularly useful for preliminary groundwater characterization and tracer studies.

Sampling devices (Fig. 3) are used to collect on point samples, representing water characteristics at the moment of collection.

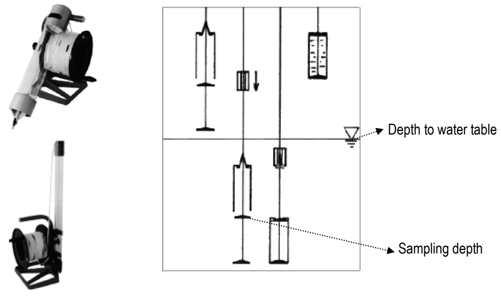

Fig. 4 – Groundwater sampling devices and schematic representation of its operation. Source: [6]

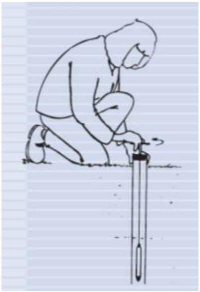

Fig. 5 – Diver operation. Source: http://www.surechem.com.my/

The procedure used to collect groundwater samples with this equipment consists on placing the device inside the monitoring point, at a given depth (Fig. 4). It is necessary to wait some minutes before collecting the sample, in order to restore water's natural circulation processes.

The diver (Fig. 5) allows automatic measurement and registration of groundwater levels and groundwater temperatures. This equipment can be installed on the monitoring well, suspended from a steel wire. Once installed, no part of the monitoring system should be left above the ground level, which reduces the risk of vandalism. The diver measures automatically both groundwater level and temperature, and registers these data in the internal memory, in a pre-defined time interval and for a certain period. This device needs to be programmed with location, starting time, rate, and measuring frequency. The data from the diver can be collected with a laptop.

Under certain circumstances, sampling can be an extremely hazardous operation. Safety harnesses and suitable protective clothing should be used when necessary, and often it is advisable that samplers should work in pairs for added protection.

4.7. Sampling conservation and storage

After the well has been sampled, the water must be properly transferred to the sampler container and preserved for the transport to the laboratory. During sampling, every effort must be made to minimize changes in chemistry of the sample, through a correct collection, preservation 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]. Three approaches (i.e., refrigeration, use of proper sample container, and addition of preserving chemicals) are generally used to retard volatile loss and chemical reactions such as oxidation, biodegradation and sorption.

Table 2

Summary of sample conservation processes. Source: [6] and [8]

Parameter	Type of container	Conservation	Maximum holding time
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
Sulphate	Plastic (polyethylene or equivalent) or glass	Refrigerate	28 days
Dissolved gases (O_2, CH_4, CO_2)	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	Plastic (polyethylene or equivalent), Teflon or glass	Refrigerate	35 hours
Chloride,			7 days
Fluor			7 days
Silicate			
Phenols	Teflon or glass	Add H_3PO_4 until pH<4 or Refrigerate	35 hours

The proper selection of containers (material type and headspace) is critical to reduce losses through several physical processes, such as volatilization, adsorption, absorption and diffusion.

All the sampling materials should be cleaned and quality assured before using. Table 2 presents an example for summary of sample conservation processes for a set of common groundwater parameters. Sample conservation refers to the actions taken to maintain sample quality during transportation. Samples should be cooled to a temperature of 4°C (in insulated coolers) as soon as possible after they are collected and should be maintained at that temperature until they are received at the laboratory.

Nonetheless, even with proper preservation, no samples can be stored for an extended period of time without significant degradation. The maximum holding time is the period of time for which a sample can be stored after collection and prior to analysis (or pre-treatment) without the analytical results being significantly affected. Maximum holding time starts at the moment of sampling and ends with the beginning of the analytical procedure. Samples that exceed this period should be discarded, in order not to jeopardize data quality [7].

Each step of the sampling event should be recorded, including the time of sampling, weather conditions, time required to purge the well, volume of water purged, purge water characteristics, decontamination procedures, sample equipment calibration, and procedures for the preservation of samples [2]. These records should be kept for future reference.

5. 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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