GROUNDWATER MONITORING

Masanori Ando
Musashino University, Japan

Keywords: groundwater, monitoring, sampling, monitoring program, monitoring location, sampling programs, flow measurement, sampling techniques, sampling equipment, transport and storage, record

Contents

Summary

Groundwater flows through the spaces and cracks in the rock being pulled by gravity and pushed by the force of the water above and behind it. The water moves form an area where water enters the aquifer (a recharge zone) to an area where water exits the aquifer (a discharge zone). The slope of the water table, or potentiometric surface, which is termed the hydraulic gradient, will dictate the direction of groundwater flow. Groundwater generally flows much more slowly than surface water. This chapter gives guidance on the outline of groundwater, monitoring program, sampling program, selection of sampling point location, contaminants in groundwater, sampling frequency,

sampling equipment and techniques and the collection of samples when monitoring groundwater.

1. Introduction

Groundwater is a valuable resource. It can be found beneath most land and most of the available fresh water on earth is groundwater. Because it is hidden from our view it tends to be somewhat mysterious. Despite much available information, groundwater existence, movement, quantity and quality remains obscure to the broader community. Yet billions of people depend on groundwater as a source of water for drinking, irrigation and many other uses. As industrial and agricultural development of the world increases, the demand for water also steadily grows. Understanding the basic processes and facts about groundwater as well as the factors that can affect its quality are of vital importance in managing this significant resource.

2. Outline of Groundwater

2.1. The Hydrologic Cycle

The term hydrologic cycle refers to a series of processes involving the constant movement of atmospheric water, surface water and groundwater above, on, and below the Earth’s surface. First of all, Evapotranspiration entails the release of water vapor to the air by plant transpiration and by evaporation from moist surfaces including the land surface, lakes and the oceans. The water vapor in the air forms clouds that return water by condensation to the land surface or to the ocean in the form of precipitation. Precipitation includes rain, dew snow and hail. The water may also enter streams, lakes, or oceans from below the land surface. Water that reaches streams or other surface water bodies, both by overland flow and by groundwater discharge, moves to larger streams and rivers, and then to the lakes or oceans, where it is evaporated in a continuation of the hydrologic cycle. Approximately 2~3% of the earth’s water exists in land as freshwater, 97~98% are the oceans as salt water. 77~87% of water on the land exists in the form of ice, 12~22% of world freshwater is groundwater, and the rest only accounts for less than 1% of the world fresh water is surface water such as river and lake water.

2.2. Principles of Groundwater

Precipitation infiltrates the soil by the force of gravity after wetting the land surface and the vegetation. The rate of infiltration varies depending on the amount of precipitation and the soil surface itself. The infiltration rate of clay-rich and salt soils may allow precipitation to penetrate and wet the soil beneath the surface, sandy soils may allow the water to penetrate as much as hundreds millimeters per hour. Since there is a limit as to how much water the soil can hold, once the rate of precipitation exceeds the rate of infiltration, overland flow occurs; that is, the water flows directly over the land surface.

When water infiltrates the soil, it first enters the soil zone or root zone. The excess water then percolates slowly down and across the intermediate zone to the saturated zone. Soil, root zone, intermediate zone and capillary fringe which are above the saturation zone are known as the unsaturated zone. Just above the saturation zone is the capillary fringe, this is where water is drawn upward from the zone of saturation by capillary forces. The saturation zone is where the spaces in soil or rock are filled with water. The top of the saturation zone is the water table surface, the pressure of the water filling the spaces in the soil or rock equals the atmospheric pressure. Besides moving downward, water in both the unsaturated and saturated zones moves laterally. The water below the water table surface is known as groundwater. This may result in sites of groundwater discharge such as springs on hillsides. A frequent misconception of ground water is considering it as some sort of underground river. Mostly this is untrue, however in some areas, for example where there are limestone caves, underground rivers can be found.

2.3. Groundwater Use

Most groundwater contains high concentrations of dissolved salts and is too saline for human use. Groundwater is extensively used for irrigation, industry and human consumption. Billions of people in world depend totally or partially on groundwater for domestic water supplies. About 21% of freshwater used in most countries is derived from groundwater sources. A large proportion of groundwater extracted from aquifers is wasted. Water losses occur through leaks in bores, evaporation or seepage from channels. Over-extraction of groundwater poses a significant threat to sustainability of groundwater-dependent ecosystems (such as springs and soaks) and groundwater resources, along with possible impacts on surface water.

3. Monitoring Program for Groundwater

In some situations it becomes necessary to define programs for the monitoring of groundwater subject to risk of contamination. Groundwater sampling can be carried out as a single exercise as part of a larger site or environmental investigation or as part of a regional/national program.

It is important to develop measurement techniques capable of providing reliable instruments and measurements which are easily installed for long term measuring campaigns. Traditional parameters are temperature, pH, conductivity, dissolved oxygen, Redox, potential, turbidity and pressure. Further development of sensors, other than those for traditional parameters, should include those relative to the substances on water quality. The configurations of measurement and performance must be adapted to the monitoring procedures referred to autonomous units with reduced maintenance needs, long operation times and continuous data recording.

3.1. Objectives of Groundwater Monitoring

The networks of groundwater quality monitoring are as follows.

- Basic/reference monitoring: to provide data on a background situation which enables to determine trends;
- Compliance monitoring: serving to protect the population from violations of regulations, laws and directives (concerning soil and groundwater pollution);

Special monitoring networks, such as for

- Water supply wells: establishment of protection zones; monitoring of impact of groundwater extraction and compliance with restrictions in groundwater protection zones; early-warning monitoring;
- The investigation and implementation of groundwater remediation and restoration measures;
- The investigation of the interrelation between groundwater and surface water;
- The development of scenarios for contaminant migration;
- The investigation of the behavior public health hazards related e.g. to accidental spills possibly affecting the public water supply, impacts from waste disposal sites and contaminated land, etc.

Early-warning monitoring: to determine public health hazards related e.g. to accidental spills possibly affecting the public water supply, impacts from waste disposal sites and contaminated land, etc.

3.2. Classification of Monitoring Program

Groundwater quality monitoring can be distinguishing the following kinds of monitoring objectives:

- Trend monitoring: to indicate trends in groundwater quality and or quantity changes derived from natural causes, the impact of diffuse pollution sources, and changes in the hydraulic regime.
- Baseline monitoring: to provide background information on groundwater quality so that the impacts of future, as yet undefined, human activities can be detected;
- Spatial distribution monitoring: to provide information on the three-dimensional distribution of groundwater quality within aquifers;
- Early-warning monitoring systems; to provide early-warning information on the impacts of diffuse sources of pollution on water sources.

3.3. Strategies of Groundwater Monitoring

For each individual objective there are different methods for well drilling, well design, and sampling being used. However, a number of other factors also have a strong influence on the results, such as: drilling method, well design, materials used, sampling conditions (e.g. hydraulic conditions, weather), sampling method, sample conservation and storage method, analysis method. Groundwater monitoring and characterization activities have resulted in the construction of penetrometric units capable of collecting soil, interstitial air and water samples, at the same time. In most cases, the availability of sufficiently trained staff and of the financial resources, however, are the main constraints for groundwater quality monitoring. When complying with all the below mentioned criteria, water quality monitoring may become rather expensive. A careful balance needs to be stricken between the costs of these measures and the overall benefits. However, when neglecting some of these measures, one has to be aware of the consequences and the implications on the results. If financial resources are limited, the program should be downsized in such a way that the objectives are still achievable.

4. Sampling Groundwater

It informs the user of the necessary considerations when planning and undertaking ground water sampling to survey the quality of groundwater supply, to detect and assess ground water contamination and to assist in groundwater resource management, protection and remediation. The groundwater in this section includes samples collected from both the saturated zone and unsaturated zone. It should be noted that, normally, groundwater sampling from the saturated zone alone can not fully assess the level of contamination in the subsurface in situations where an unsaturated zone of considerable thickness exists. The potential consequence of ignoring the unsaturated zone is that the unsaturated zone and groundwater system could become extensively contaminated before any tangible evidence of leakage or contamination is evident in samples collected from below the water table.

4.1. General

Installations suitable for groundwater monitoring typically involve placement (or use) of access tubes for portable sampling devices or burial of sensors or samplers in situ. These installations can be positioned within the saturated zone (below the water table) or above it (unsaturated zone). In addition to sampling groundwater, installations below the water table can be used to measure water levels and installations above the water table can measure soil gas and soil moisture content.

4.2. Unsaturated Zone Monitoring

Sampling techniques that are used for collection of groundwater from the unsaturated zone can be divided into two types:

- Extraction from solid samples (solid sampling followed by extraction of groundwater (pore fluids)): The extraction of pore fluids from solid samples is the most widely used method for sampling groundwater in the unsaturated zone. Collection of solid samples as part of this method can also allow useful geological information to be obtained.
- Pore-liquid sampling (unsaturated pore- fluid sampling): Two types of method can be used to extract pore liquid directly from the subsurface; percolate soil water samplers and vacuum soil water samplers. Both have advantages over solid sampling in allowing sequential sampling from fixed locations in the unsaturated zone to determine trends.

-
-
-

Bibliography

Colin F. and Quevauviller P.,(1998) Monitoring of water quality [This report describes the Proceedings of the European Workshop on Standards, Measurements and Testing for the Monitoring of Water Quality]

Jousma G. and Roelofsen F.J.,(2004) World-wide inventory on groundwater monitoring. International groundwater resources assessment centre [This report describes the groundwater monitoring]

International Standard ISO5667-1 Water quality-Sampling- Part 1: Guidance on the design of sampling programs and sampling techniques 2006 [This report provides guidelines for the design of sampling programs and sampling techniques]

International Standard ISO5667-5 Water quality-Sampling- Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems 2006 [This report provides guidelines for sampling of drinking water from treatment works and piped distribution systems]

International Standard ISO5667-11 Water quality-Sampling- Part 11: Guidance on the sampling of groundwaters (combined revision of ISO 5667-11:1993 and ISO 5667-18: 2001) [This report provides guidelines for the sampling of groundwaters]

Ralph G. Nash and Anne R.Leslie, (1991) Groundwater residue sampling design. ACS, Washington, DC [This report describes the sampling design of groundwater]

Biographical Sketch

Masanori Ando is with the Faculty of Pharmaceutical Sciences of Musashino University as professor, where he has been in his present post since 2004. He obtained a Bachelor Degree in Meiji Pharmaceutical College in 1970. He worked for National Institute of Health Sciences until 2004. In the meantime, he obtained a Ph.D in Pharmaceutical Sciences from Tokyo University. He has written and edited books on risk assessment, management and analytical standard methods of drinking water, indoor air chemicals, air toxicants and cosmetic strategy. He has been the author or co-author of approximately 120 research articles. He is member of Japan Society on Water Environment, Pharmaceutical Society of Japan, Japan Society for Environmental Chemistry, Japan Society of Endocrine Disrupters Research, Japan Water Works Association, Society of Indoor Environment Japan, The Japanese Society of Toxicology