SDG Indicator 6.3.2 Technical Guidance Document No. 3:

Monitoring and Reporting for Groundwater

Within the framework of SDG indicator 6.3.2 related to ambient water quality, this document provides further technical guidance on addressing the challenges facing monitoring and reporting for groundwater. It is a companion to the Step-by-Step Methodology and is one of a series of documents and case studies that provide more detailed technical guidance on specific aspects of the indicator methodology. These documents have been created in response to feedback from the baseline data drive of 2017. These and other resources are available on the Indicator 6.3.2 Knowledge Platform (https://communities.unep.org /display/sdg632).

This document is aimed at practitioners seeking further information on how to implement the indicator methodology for groundwater and how to strengthen groundwater monitoring in their own country. The document:

1. Provides guidance on identifying aquifers and defining bodies of groundwater.

2. Reviews options for groundwater sampling.

3. Discusses parameter choice and Level 1 and Level 2 reporting for groundwater quality.

Introduction

The monitoring data collected for SDG indicator 6.3.2 should provide sufficient information about ambient water quality status at a national scale, and it should allow long term trends to be identified. This requires data for the core parameter groups from sites across the country, and measurements to be taken in a standardised and consistent way. The first global data drive in 2017 was significantly less productive for groundwater than for surface water, with fewer countries reporting on the quality of their groundwaters. This is no surprise and has been a common and consistent feature of such activities in the past. This document explores why that should be and recommends how groundwater monitoring programmes can be strengthened to provide better information on ambient water quality, and how reporting for groundwater can be made more robust and comparable.

Why is Monitoring Groundwater More Difficult than Surface Water?

There are many reasons why water quality monitoring programmes do not provide the information they should. Monitoring should be thought of as a continuous circle or chain (UNECE, 2000), starting from information needs and passing through monitoring strategy, network design, sampling, analysis, data handling, analysis and reporting to provide information in a clear and timely fashion. If one step or link in the chain (Figure 1) is not undertaken adequately, the whole process can fail to generate useful data. Common contributions to failure arise from:

- not defining the information needs and objectives of the monitoring programme;

This document was produced by John Chilton, formerly Executive Manager of The International Association of Hydrogeologists. March 2020, on behalf of UN Environment Programme GEMS/Water.

- not taking adequate account of the physical setting in network design;
- insufficient planning of sample collection, handling, storage and analysis;
- lack of quality control and assurance;
- poor management and interpretation of the resulting data;
- lack of review, feedback and modification of the design if required.

The specific objective for indicator 6.3.2 is to provide a mechanism to determine whether efforts to sustain and improve ambient water quality are working, using data drawn from national monitoring programmes, which will have their own objectives.

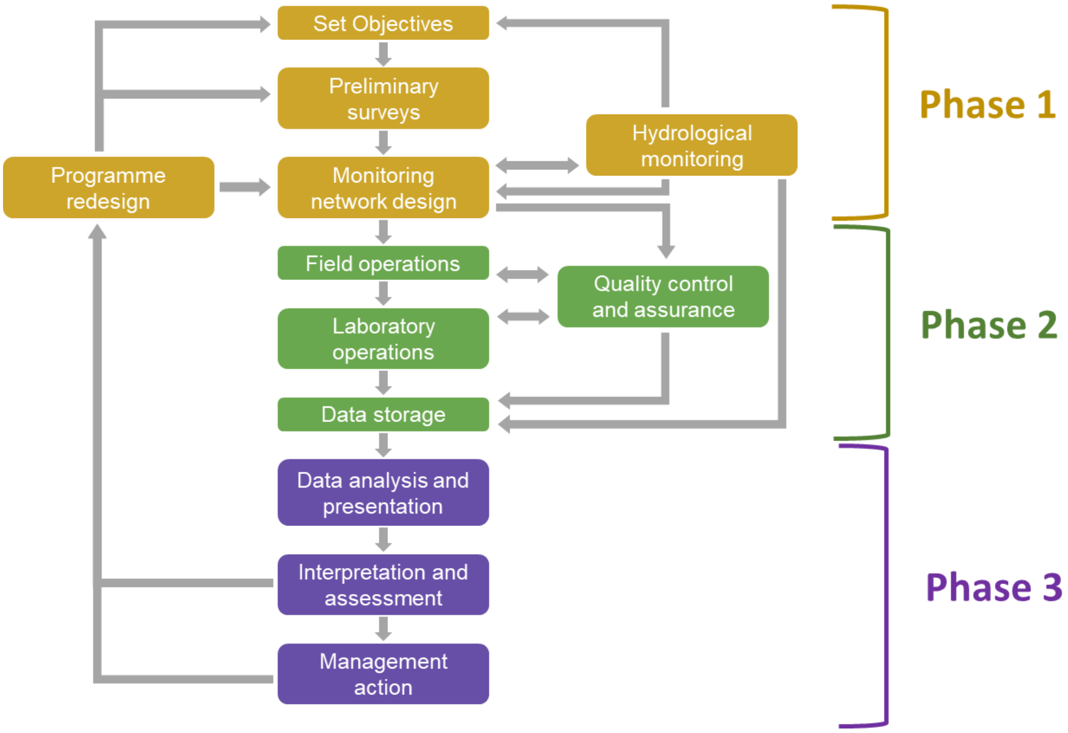

Figure 1. Water quality monitoring programme design flow chart. Modified from Chapman et al. (2005)

The challenge of groundwater quality monitoring is fundamentally different from that for rivers and lakes (IAH, 2017). River monitoring can provide a composite picture for an extensive catchment, buffering-out the effect of factors local to the sampling station. The reverse is generally true for groundwater, for which the influence of very local factors, such as wellhead contamination, well depths, pumping rates, the immediate catchment and sampling protocols, can dominate. This can distort the broader picture of groundwater quality for the aquifer, and needs to be understood and taken into account.

For groundwater, the general constraints outlined above are often supplemented by a lack of hydrogeological knowledge, weakening both the design of the monitoring network and interpretation of the results. Sometimes this is because groundwater monitoring is established by surface water professionals as an extension of an existing surface water programme without proper consideration of the hydrogeology; often the necessary hydrogeological information or groundwater expertise just doesn’t exist. This is important because aquifers, and the bodies of groundwater they contain, are usually more complex than surface waters and much less accessible for sampling. The inaccessibility contributes to the attraction of groundwater as a source of supply. If aquifers are less accessible, then they are likely to have good natural water quality (with some exceptions) and to be protected from polluting activities at the land surface. Once polluted, however, the slow movement of the water in the aquifer means that groundwater quality can take decades to recover.

Most groundwaters have much longer residence times than surface waters. This allows time for physico-chemical interactions to take place between the slow-moving groundwater and the material forming the aquifer, and the chemical composition of the water can change as it flows (Chilton, 1996). From a monitoring point of view the slow movement means that, in general, groundwaters need to be sampled less frequently than surface waters, but obtaining a representative picture of groundwater quality may require a greater density of sampling (IAH, 2017). Moreover, the depth and subsurface complexity of aquifers has a major bearing on the choice of sampling point for the groundwater network and the interpretation of the results obtained. Samples taken from wells in close proximity can produce very different results, especially if they draw water from different depths in the aquifer or even from different aquifers.

IDENTIFYING AQUIFERS AND DEFINING GROUNDWATER BODIES

The first two steps of indicator 6.3.2 methodology comprise 1) the establishment of Reporting Basin Districts (RBDs) based on river basins and 2) defining water bodies within them. For groundwater, this means identifying the location of the productive aquifers and how they might be subdivided into groundwater bodies. As for surface waters, the elements defined as bodies of groundwater form the discrete units which are classified as either “good” or “not good”.

In some countries, particularly EU Member States and others aligned to EU environmental legislation, considerable effort has already been made by national geological surveys or environmental agencies to meet their obligations to define groundwater bodies. Technical guidance supporting the legislation helps them to do this is in a consistent and comparable way (EC, 2004), but the data requirements and the expertise to do this are substantial. These countries are also likely to have well-developed groundwater quality monitoring programmes and are encouraged to use the same reporting units for indicator 6.3.2 reporting.

For many other countries, the locations of aquifers and their importance as sources of groundwater are known. However, the nature of the groundwater flow systems in these aquifers - where the groundwater comes from and goes to - may not be well known and there may be no national requirement to define groundwater bodies. Existing monitoring programmes may be highly variable in terms of network coverage, suitability of sampling points, frequency of sampling and choice of parameters. Other countries may know even less about their aquifers and groundwaters, they may have little or no regular monitoring in place and very scarce data about their groundwater quality. Some countries may have no monitoring data at all, but have aspirations to develop a groundwater quality monitoring programme.

In all these cases, as a basis for identifying aquifers and understanding groundwater flow systems, it is essential to develop simple conceptual hydrogeological models. These may be no more sophisticated than a map showing the surface extent of the outcrop of various aquifers and non-aquifers, and simple cross-sections. These sections should show the origins of the groundwater, directions of flow and locations of discharge (Figure 2). This is important, because the source of recharge, which could be infiltration from rainfall or from surface water bodies, is also likely to be a source of pollution inputs to the aquifer, thereby contributing to quality deterioration. Similarly, the locations of discharge to springs, rivers, lakes or wetlands, or to water wells, are the points at which poor groundwater quality impacts on receptors (Figure 2).

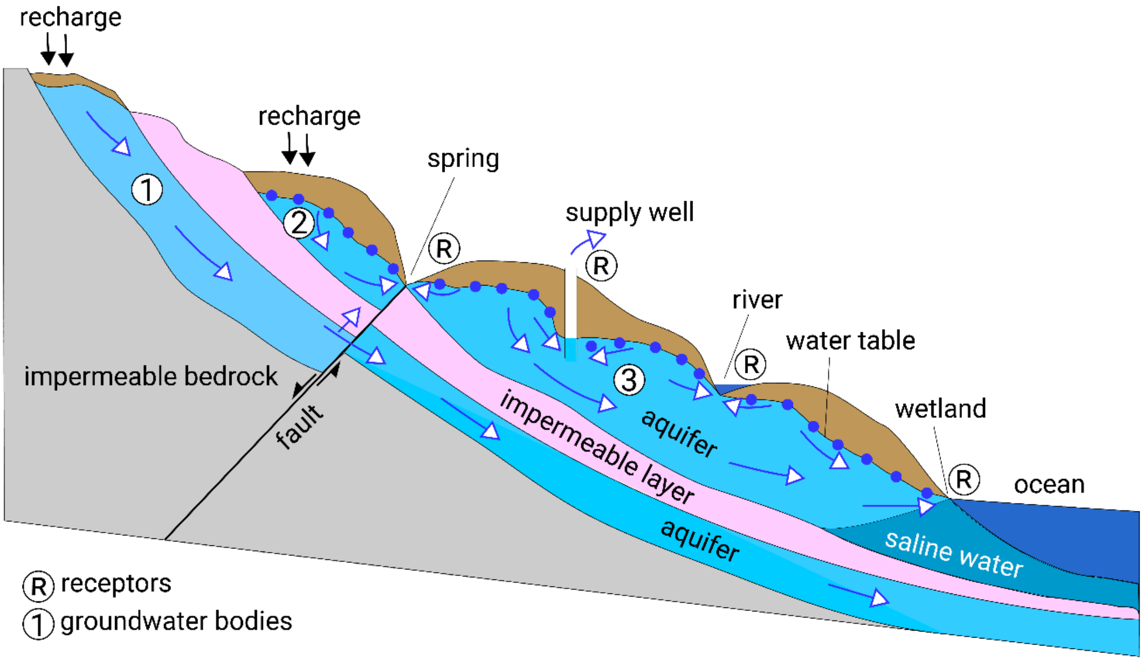

Figure 2: Simple conceptual hydrogeological model to help visualise aquifer outcrops, locations of groundwater recharge, directions of groundwater flow and discharge points

Even where conceptual hydrogeological models are not already available, almost all countries have geological maps, perhaps prepared for mineral prospecting or oil exploration. From these, the main types of geological formation can be seen and those likely to provide productive aquifers identified. Of course, this may be easily confirmed if the aquifers are already extensively used to provide water. If the agency responsible for monitoring does not itself have groundwater expertise, support to do this should be sought from the national geological survey, a local university or a suitable consulting company.

Within RBDs based on river basins, groundwater bodies should be defined to allow for the description of ambient quality. The methodology for indicator 6.3.2 envisages that, ideally, water bodies should be sized to ensure that they are homogeneous in terms of water quality, and can be classified using relatively few monitoring points (Guidance Doc 1). However, as has been made clear, aquifers can be complex and far from homogeneous. Where an aquifer is to be further divided into groundwater bodies, these should be discrete flow systems in which groundwater does not move across the boundaries. The following can provide useful criteria for such subdivision.

- Where there is sufficient data from which maps of groundwater level can be prepared, the bodies can be bounded by groundwater flow divides. Figure 3 shows three such groundwater bodies in an aquifer overlying impermeable rocks and dipping below overlying strata. However, unlike the boundaries of surface water bodies, the boundaries of groundwater bodies defined in this way may not be static and can move seasonally, in response to long term climate change and recharge and to the effects of pumping from wells near the boundaries.

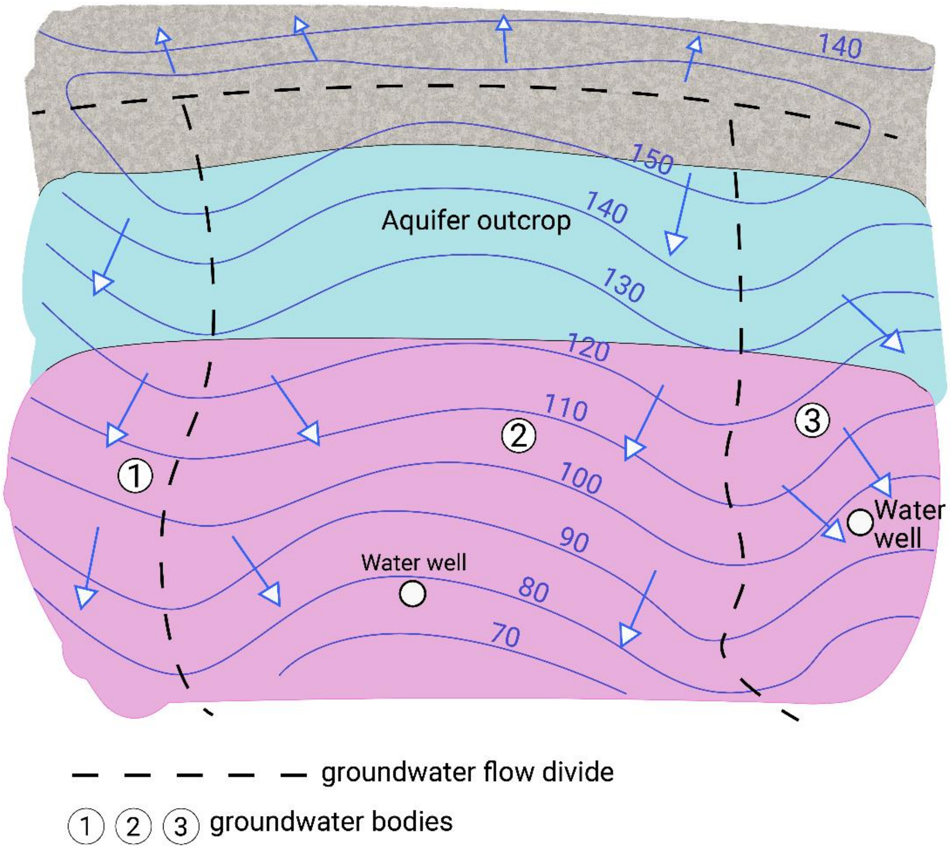

Figure 3. Groundwater bodies defined by flow divides

- If such data are not available, the boundaries could be based on surface water catchments, which in many cases are closely followed by groundwater divides. Figure 4 shows two groundwater bodies defined in this way.

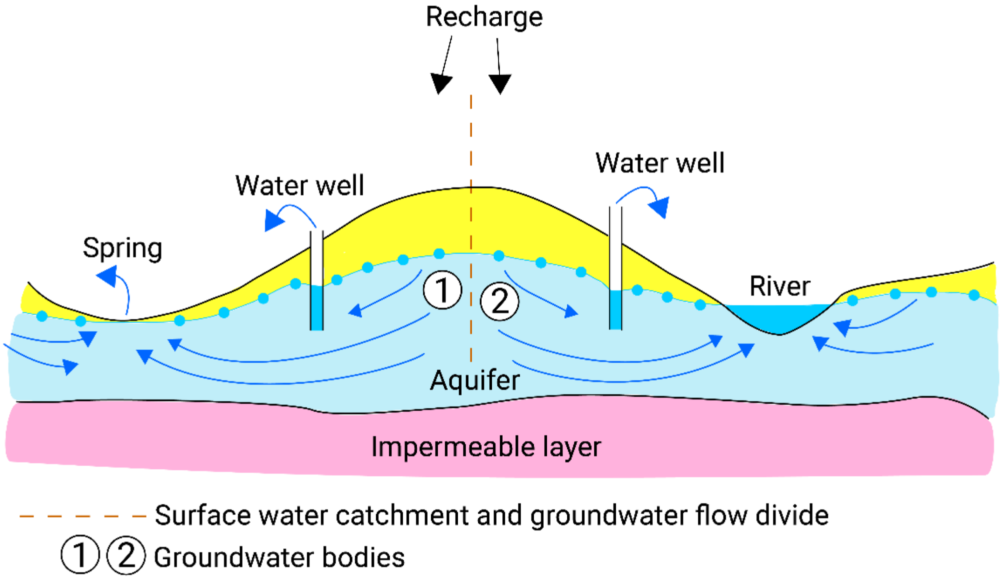

Figure 4 Groundwater bodies defined by surface catchments and groundwater divides

- Where major geological faults bring impermeable material against an aquifer, restricting groundwater flow, this may also form a suitable boundary. In Figure 2, the upper unconfined aquifer is divided into two groundwater bodies (one of which is quite small) by a large fault. In the underlying confined aquifer, the displacement of the fault is not sufficient to impede groundwater flow.

- In the case of relatively small, shallow aquifers formed by alluvial or glacio-fluvial sediments and overlying less permeable bedrock, then the whole aquifer can constitute a groundwater body.

The complexities of aquifers, their vertical dimension in quality variation, and the slow movement, mean that even relatively small bodies of groundwater are unlikely to be properly represented by one, or even a small number of monitoring points.

Arid and semi-arid countries are often characterised by extensive aquifers but little or no surface water, so that there are hardly any catchment boundaries for either RBD or groundwater body definition. Moreover, these aquifers are often deep, thick, flat-lying with low groundwater gradients, and with groundwater residence times measured in centuries rather than decades. Often, they do not receive significant groundwater recharge under current climatic conditions. Such "fossil" or non-renewable groundwater resources are often heavily exploited, with considerable management challenges in terms of water quantity. However, they are well protected against possible quality impacts from activities at the land surface, and groundwater quality will change only very slowly. It is appropriate, therefore, to make use of aquifer-based reporting units for indicator 6.3.2 for these settings, which may also be one of the few examples of bodies of groundwater which can be characterised by a small number of sampling points.

A word of caution is, however, necessary. Within these arid regions there are also much smaller and shallower sand and gravel aquifers, often associated with dry river beds, wadis and oases. These aquifers may be very important to local communities for water supply and intensive irrigated agriculture, with the resultant potential for significant quantity and quality impact on their groundwater. Each may be a separate groundwater body disconnected from the next and will need more frequent monitoring attuned to local pressures and the more rapid responses of these shallow groundwater systems.

Aquifers, and hence potentially groundwater bodies, can be crossed by international frontiers. An aquifer may receive recharge in one country and produce discharge in a neighbouring country. Again, conceptual groundwater models can help to determine if this is likely to occur (Lipponen & Chilton, 2018) and, if it does, cross-border exchange of information and collaboration on monitoring may be required.

SELECTING GROUNDWATER SAMPLING POINTS

If there are a good number of sampling options, the general location of monitoring points should be chosen to reflect as far as possible the whole groundwater body, especially the source – pathway – receptor groundwater flow system outlined above. In addition, the network may need to take account of population and land use distribution, with greater densities of monitoring points where agricultural, urban and industrial pressures are most prevalent. Choice may also need to take account of very localised factors around the monitoring point which could influence groundwater quality and the reliability of sampling. Any monitoring points that are seriously compromised in this way should not be used.

The choice of sampling point type also influences the reliability and representivity. Samples of groundwater can be taken from existing wells supplying water for domestic, municipal, irrigation or industrial uses, from springs or from purpose-built monitoring wells. Each has advantages and disadvantages (Table 1) with respect to practicality, cost and technical aspects. These also need to be understood in the context of the local hydrogeological setting.

Table 1 Characteristics of potential groundwater sampling points

Sampling Point	Advantages	Disadvantages
Municipal supply well	• cheap and easy to sample • repeat sampling, regular visits • high discharge, representative of quality in the aquifer	• possible uncertain construction and sample source, mixed water from several depths • possible long time-lag after pollution has occurred

	• pumps usually operating • may have existing time series data	• locations fixed by population distribution, skews spatial coverage • municipality/water company may not allow sampling
Irrigation well	• as first three above, but less likely to have existing time series	• as first two above, but less likely to have construction data • spatial coverage skewed to agricultural areas • may operate seasonally only
Industrial well	• as for irrigation well above	• as for municipal well, but less likely to have construction data
Domestic well	• cheap and easy to sample • repeat sampling, regular visits	• low, intermittent discharge, especially with a handpump • may need purging to remove stagnant water from within the well • may be broken down and not pumping • may be shallow and less representative of the aquifer • vulnerable to very local pollution
Shallow monitoring borehole	• may provide early warning of pollutants arriving at the water table • repeat, regular sampling • construction likely to be fully known • inert materials can be used	• moderate construction costs • needs pump to collect sample • care needed to remove stagnant water • not very representative of the aquifer
Multi-level piezometers	• construction should be fully known • inert materials can be used • early warning of pollutants at water table • may indicate vertical stratification of groundwater quality • may indicate vertical head differences and up or down movement of water	• high construction costs • needs specialist contractor and materials • may be difficult to install correctly with good seals between sampling intervals • requires special sampling devices and skilled operator
Springs	• cheap and easy to sample • repeat sampling and regular visits • large springs may be representative of significant bodies of groundwater • springs used for public supply may have existing time series data	• vulnerable to local pollution sources • may be vulnerable to direct rainfall • small springs may represent superficial flow

Many national groundwater quality programmes depend entirely, or almost so, on existing supply wells for the cheapness and ease of sampling, and the general accessibility for regular visits, providing the monitoring agency has an arrangement to do so with the well operator. Because these wells are operated frequently or even more or less continuously, the abstracted water is likely to be representative of that in the aquifer (Table 1). Frequently the biggest disadvantage of such wells is that there may be little or no information available on depths of wells, screened intervals and pumps, water levels, construction materials, and pump discharge rates and times. This lack of metadata can hinder the interpretation and reporting of the monitoring results – some wells may draw shallow, polluted groundwater from the upper part of an aquifer, others from less polluted deeper sections, or even from different aquifers in a layered sequence. Where possible, the monitoring wells should be selected from those for which construction data are available.

A combination of municipal, industrial and irrigation wells may provide adequate network coverage of urban and agricultural areas. Where there is little or no irrigation or industrial development, sampling in rural areas from domestic wells may be the only other option. Selecting small motorised pumps at schools or clinics may provide more reliable regular access, and samples that are more representative, than community wells with handpumps.

Springs are often under-valued as an option for groundwater quality monitoring; they are cheap and easy to sample without the instability arising from bringing groundwater to the surface, and they are usually accessible for regular visits. Large springs may be representative of substantial groundwater bodies and have reliable discharges even in the dry season. Small seepages with short and shallow flow paths are much less sustained and highly vulnerable to local pollution, and should be avoided. In some karstic limestone areas, groundwater movement may be largely restricted to fractures and conduits connected to spring discharges, and therefore springs may be the only realistic monitoring option.

Boreholes constructed specifically for observation are used in some national programmes to improve network coverage where existing pumping wells are absent, and to provide early warning of pollution reaching the groundwater table before it impacts on deeper supply wells. However, their use requires considerable capital and technical resources for construction and for sampling pumps, and expertise for sampling, including purging stagnant water (Misstear *et al.*, 2017). Such boreholes are widely used for monitoring local groundwater conditions around sources of groundwater pollution such as landfills. Depth-specific installations, including nested piezometers and multi-level sampling devices are rarely used in large-scale ambient water quality monitoring because of their cost and complexity of installation and sampling, which requires highly trained drilling contractors and sampling technicians, respectively. Their use is largely restricted to monitoring major sources of pollution, such as landfills or industrial plumes, where a well-characterised depth dimension to the quality assessment is essential to observe the growth and spread of the plume or to evaluate the impact of costly remedial actions.

SAMPLING FREQUENCY FOR GROUNDWATER

As for surface water (Guidance Doc 1), sampling frequency for groundwater should take account of hydrological and hydrogeological settings and their influence on the likely rates of variation in groundwater quality. Historical data or a preliminary survey provide relevant information. From a monitoring design perspective, it is essential to know whether aquifers are composed of unconsolidated material such as sands and gravels in alluvial formations or are consolidated formations such as sandstones and limestones. In the former, groundwater moves slowly between the grains and in the latter groundwater can move much more quickly in fractures.

Thus, the absolute minimum for groundwater sampling should be once per year but with the following considerations modifying the sampling regime as required. Higher frequencies of at least twice per year are needed for shallow groundwaters which are sensitive to seasonal influences from rainfall, recharge, pumping and from irrigation, and also those susceptible to urban impacts. Samples should be taken before and after the rainy season and/or at the times of high and low groundwater levels, taking particular account of the parameter groups most responsive to these influences (Table 2) and providing the basis for Level 1 reporting. Higher frequencies of at least four times per year are needed for karstic limestones. Shallow coastal and island limestone aquifers are particularly sensitive to more rapid changes in quality because they are often densely populated and the groundwater regime heavily modified by abstraction, causing or risking saline intrusion. The minimum sampling interval of once per year can be maintained for confined aquifers (Figure 2) and for those with very old groundwater which do not currently receive active recharge. In both of these, quality changes are likely to be very slow. Parameter groups for indicator 6.3.2 reporting are unlikely to vary much and others indicative of specific human impacts (Table 2) are unlikely to be detected. This framework for setting monitoring frequencies should be the goal for a new or improved groundwater monitoring network, although it is recognised that resources may not immediately allow this.

FIELD OPERATIONS FOR GROUNDWATER

Many aspects of field operations for groundwater are the same as those for surface waters, including health and safety considerations. Fieldwork should also follow a standard operating procedure (Guidance Doc 1) to ensure consistency and reliability. Quality assurance (QA) and Quality Control (QC) arrangements are also equally important for groundwater, and apply to all steps in the monitoring programme (Figure 1). Field notes are useful to support interpretation and reporting, and should include the estimated discharge rate and the length of time the pump has been working, together withobservations of conditions around the groundwater sampling point, such as any evidence of very localised pollution impacts.

Groundwater quality may be influenced by hydrological conditions and seasonal variations in groundwater levels and discharges. Although it may be difficult or impossible to access the well to measure the groundwater level, which in any case will be disturbed by pumping, knowledge of local variations in level and the likely undisturbed level at the time of sampling, provide valuable context for the water quality data. The well operator may be able to provide such information. Where springs are sampled, discharge should be estimated; very high discharges after heavy rainfall may be diluted by local runoff and the quality would not necessarily be representative of that in the aquifer.

To be confident that the sample is representative of water in the aquifer, it should be taken from a sampling tap in the rising main as close as possible to the pump head, rather than from a tank or tap in the water distribution system. Bringing groundwater from depth to the different pressure, temperature and oxygen conditions at the surface can alter its character, which is one reason for measuring unstable parameters on site. For low or intermittent discharges, the column of stagnant water in the well should be removed with the pump before taking the sample; guidance exists on the estimation of the volume to be removed to be sure of drawing water from the aquifer rather than the well (ASTM, 2006). This can also be checked by monitoring the discharge temperature and conductivity until a stable reading represents aquifer water.

PARAMETER GROUPS FOR GROUNDWATER

To maintain global comparability in reporting for indicator 6.3.2, the proposed Level 1 parameters for groundwater are electrical conductivity, pH and nitrate (Table 2) which, together with temperature need to be measured in the field at the well, borehole or spring. These simple to measure characteristics represent the impacts of salinization, acidification and nutrient enrichment (Table 2) which are relevant everywhere, but they cannot represent all impacts on groundwater quality, and the suitability of a well or spring for drinking water cannot be based only on a Level 1 assessment.

Table 2 Parameter groups for monitoring groundwater quality (adapted from IAH, 2017)

Parameters		**Comments and Reason for Inclusion**
Level 1 Parameter Group for Groundwater for periodic measurement in all situations–frequency to depend on groundwater system flow characteristics		
EC	electrical conductivity	Measure of salinization and helps to characterise the water body
pH	acidity	Measure of acidification and helps to characterise the groundwater body
(T)	Temperature	Should be measured and recorded at the same time as other parameters
NO_3	nitrate	Ubiquitous contaminant, stable in oxic conditions, health concern for human consumption
Additional Parameters from which those for Level 2 reporting could be selected at lower frequency following marked changes in those above		
Ca, Mg, Na, K	major cations	Will help evaluate hydrogeological processes and detect and diagnose significant temporal changes. Chloride can be a sensitive indicator of a range of agricultural, urban and industrial impacts
Cl, HCO_3 SO_4	major anions	
TDS	total dissolved solids	EC used at Level 1 as a surrogate
Microbiological Monitoring of Drinking Water Sources sources designated at risk by sanitary inspection		
FC	faecal coliforms	Some monitoring needed for sources routinely used without disinfection, but high temporal variability and sampling difficulties mean that this should be combined
FS	faecal streptococci	
E Coli	*Escherichia coli*	

		with other approaches, including sanitary inspection to assess vulnerability to microbial pollution
Additional Parameters required in specific hydrogeologic settings for which they could be reported at Level 2		
F	fluoride	Essential in some hydrogeological conditions as indicators of variations in natural groundwater quality which affect human health
As	soluble arsenic	
U	soluble uranium	
NH_4	ammonium	Only in strongly anoxic/reducing conditions
Fe	soluble iron	
Mn	soluble manganese	
P	orthophosphate	Only in karstic aquifers with intensive agricultural pressures
Supplementary Parameters indicative of pollution where specific agricultural, urban or industrial pressures have been identified		
	specific pesticides	Each parameter will require specific sampling protocols used by skilled personnel, and analysis to very low detection limits at laboratories with expensive equipment and specialist staff
	selected volatile organics	
	selected hydrocarbons	
	heavy metals	
	emerging contaminants	

From the suggested Level 2 data sources (Introduction Doc, Figure 1) additional chemical parameters are likely to be the most useful indicators of other pressures on groundwater, and also the most likely to be available from national monitoring programmes. Table 2 provides a hierarchical approach for selecting parameter groups which is intended to inform and support the establishment of new groundwater monitoring or the augmentation of existing programmes, and which can also be used for Level 2 reporting.

The choice of further parameters for monitoring and reporting should be related to local pressures and to the hydrogeological setting (Table 2). Major ions are often routinely included and can provide evidence of quality evolution along the groundwater flow system, for example where interaction with carbonate aquifers increases mineralisation. Microbial quality is included in Table 2 as a reminder that this is often an essential monitoring requirement related to human consumption, although not for ambient quality in SDG indicator 6.3.2. The pressures on groundwater may already be apparent from established agricultural, urban or industrial development and existing monitoring programmes, or can be identified in preliminary surveys. This means there is no single, universal "correct" answer in terms of the choice of monitoring parameters, but Table 2 can provide a suitable framework. The practitioner should note that the collection of groundwater samples may require special containers or field procedures; for example, samples for cation and trace element analyses should be filtered and acidified and stored in appropriate containers that do not adversely affect the sample quality (Misstear *et al*., 2017).

Natural groundwater quality variations of geological origin can be damaging to human health, principally arsenic and fluoride (Table 2). The health impacts may already be apparent and mitigation measures, such as arsenic and fluoride removal from the abstracted groundwater, may be in use. Monitoring of groundwater should be maintained to see whether there are trends in quality, bearing in mind that abstraction of groundwater may modify subsurface conditions and encourage mobilisation of these contaminants. Where monitoring does not already exist in hydrogeological settings where these parameters are most likely to be problematic, such as large alluvial basins for arsenic and volcanic, rift valleys, and some crystalline basement areas for fluoride, it should be established.

TARGET SETTING FOR GROUNDWATER

Ambient groundwater quality can be highly variable between aquifers, depending on the hydrological and hydrogeological conditions. Aquifers in humid, temperate regions are likely to have low overall mineralisation, indicated by low ambient EC values, whereas those in more arid terrains with less recharge may have EC values up to four or five times higher. Long flow paths in deep aquifers will also tend to produce elevated mineralisation and higher EC values. Thus, a range of baselines for ambient status is to be expected, where higher EC values do not necessarily represent pollution of groundwater resources.

The use of existing guideline values to assess ambient groundwater quality for SDG indicator 6.3.2 may not always be appropriate. The approach in setting targets is to determine values that are derived from locally-relevant background or baseline groundwater quality. This implies that, at least for EC, targets set for aquifers or groundwater bodies, may be preferable to national targets. On the other hand, as nitrate monitoring and reporting is related to potential human health impacts, national targets are likely to be appropriate.

SUMMARY

This document provides specific technical guidance on monitoring the ambient quality of groundwater in the context of SDG indicator 6.3.2. The particular challenges of monitoring groundwater are explained. Aquifers should be identified and groundwater bodies defined using simple conceptual hydrogeological models based on available data. The advantages and disadvantages of using existing supply wells, new monitoring wells or springs for groundwater sampling are discussed. A proposed framework of parameter groups for groundwater monitoring can be used to identify potential Level 2 parameter groups and to support the establishment or improvement of national groundwater quality monitoring.

REFERENCES

ASTM, 2006. Standard Guide to Purging Methods for Wells Used for Ground-Water Quality Investigations, ASTM Standard D 6452, ASTM International, West Conshohocken, PA, USA.

Chapman, D.V., Meybeck, M. and Peters, N.E., 2005. Water Quality Monitoring. In: Anderson, M.G. [Ed.] *Encyclopaedia of Hydrological Sciences*. John Wiley & Sons

Chilton P. J, 1996. Chapter 9: Groundwater. In Chapman, D. [Ed.] *Water Quality Assessments – A Guide to Use of Biota, Sediments and Water in Environmental Monitoring*. Second Edition Published by E&FN Spon on behalf of United Nations Educational, Scientific and Cultural Organization, World Health Organization and United Nations Environment Programme. Available at: https://www.who.int/water_sanitation_health/resourcesquality/wqachapter9.pdf

EC, 2004 Groundwater body characterisation. Technical Report No 2. Available at: https://ec.europa.eu/environment/water/water-framework/groundwater/activities.htm

IAH, 2017 The UN-SDGs for 2030: Essential indicators for groundwater. Available at: https://iah.org/education/professionals/strategic-overview-series

Lipponen A. & Chilton P. J., 2018. Development of cooperation on managing transboundary groundwaters in the pan-European region: The role of international frameworks and joint assessments. Journal of Hydrology Regional Studies; 20: 145-157.

Misstear B. D. R., Banks D. & Clark L., 2017. Water wells and boreholes, 2nd edition. J Wiley & Sons, UK.

UNECE, 2000 Guidelines on monitoring and assessment of transboundary groundwaters. UNECE, Geneva.