TECHNICAL REPORT

ISO/TR 21414

First edition
2016-02-15

Hydrometry — Groundwater — Surface geophysical surveys for hydrogeological purposes

Hydrométrie — Eaux souterraines — Relevés géophysiques de surface pour des besoins hydrogéologiques

Reference number
ISO/TR 21414:2016(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information.

The committee responsible for this document is ISO/TC 113, *Hydrometry*, Subcommittee SC 8, *Ground water*.

Introduction

Groundwater is available almost everywhere. Access to clean water is a human right and a basic requirement for economic development. The safest kind of water supply is the use of groundwater. However, its distribution is not uniform due to varying hydrogeological, topographical and climatic conditions. As a result, groundwater is not always available in the required quantity and/or quality, particularly in hard rock terrains where fractures and weathered zones are the primary conduits for groundwater storage and flow. Detailed knowledge on the extent, hydraulic properties, and vulnerability of groundwater reservoirs is necessary to enable a sustainable use of the resources. Therefore, collection of information on prospective groundwater zones, although costly, is essential. Geophysical methods are currently recognized as cost-effective techniques useful for collecting groundwater information. Measuring physical properties of the earth and their variation and then associating these properties with hydrogeological characteristics is the objective of groundwater geophysics.

Of the various geophysical techniques available today, the electrical resistivity method is probably most commonly used due to its relatively simple and economical field operation, its effective response to groundwater conditions and the relative ease with which interpretations can be made. This type of survey is occasionally supplemented by other techniques such as induced polarization, spontaneous potential, and Mise-a-la-Masse galvanic electrical techniques. Other geophysical methods in order of preference used for hydrogeological purpose are electromagnetic, seismic refraction, magnetic, gravity and seismic reflection surveys. More recently developed geophysical techniques include ground probing radar and nuclear magnetic resonance. Because surface geophysical surveys are carried out at the surface of the earth, the responses received from different precisional demarcations. Ambiguity exists in interpreted results and the effective application of these methods often depends on the skill and experience of the investigator, knowledge of local hydrogeological conditions, and the utility (and limitations) of the technique(s) themselves. The application of two or more geophysical techniques is a useful approach to reduce ambiguity. Integration of information from other disciplines, such as remote sensing, geologic mapping, hydrogeological characterization, chemical analysis of well water samples, etc., is also useful for interpreting geophysical field data.

Modern geophysical techniques are highly advanced in terms of instrumentation, field data acquisition, and interpretation. Field data are digitized to enhance the signal-to-noise ratio and computers are used to more accurately analyse and interpret the data. However, the present-day potential of geophysical techniques has probably not been fully realized, not only because such surveys can be expensive, but also because of the inadequate understanding of the application of relevant techniques in diverse hydrogeological conditions.

Hydrometry — Groundwater — Surface geophysical surveys for hydrogeological purposes

1 Scope

The application of geophysical methods is an evolving science that can address a variety of objectives in groundwater investigations. However, because the successful application of geophysical methods depends on the available technology, logistics, and expertise of the investigator, there can be no single set of field procedures or approaches prescribed for all cases. This Technical Report provides guidelines that are useful for conducting geophysical surveys for a variety of objectives (including environmental aspects), within the limits of modern-day instrumentation and interpretive techniques, are provided. The more commonly used field techniques and practices are described, with an emphasis on electrical resistivity, electromagnetic, and seismic refraction techniques as these are widely used in groundwater exploration. Theoretical aspects and details of interpretational procedures are referred to only in a general way. For full details, reference is intended to be made to specialized texts listed in the Bibliography.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
acoustic impedance
product of seismic velocity and density of a layer

2.2
anisotropy
variation in physical property with direction of measurement

2.3
apparent resistivity
ratio of measured voltage to input current multiplied by the *geometric factor* (2.16) for the electrode configuration

2.4
blind zone
layer having seismic velocity less than that in the layer overlying it

2.5
Bouguer correction
correction made in observed gravity data to account for the attraction (gravitational) of the rock between the datum and the plane of measurement

2.6
Bouguer anomaly
anomaly obtained after applying latitude, terrain, and elevation (free air and Bouguer) corrections to the observed gravity value and finally subtracting it from measured value at some particular station in the survey area

2.7
contact resistance
electrical resistance developed between an electrode planted in the ground and the ground material immediately surrounding it

2.8
Dar Zarrouk parameters
longitudinal unit conductance and transverse unit resistance of a geoelectrical layer

2.9
deconvolution
process of inverse filtering to nullify the undesired effect of an earlier filter operation

2.10
dipole-dipole electrode configuration
configuration in which the spacing between the current electrode pair and that between the potential electrode pair is considerably small in comparison with the distance between these two pairs

2.11
diurnal correction
correction applied to magnetic data to compensate for daily fluctuations of the geomagnetic field

2.12
drift correction
quantitative adjustment to account for a uniform change in the reference value with time

2.13
eddy current
current induced in a conductive body by the primary electromagnetic (EM) field

2.14
equivalence
function of product or ratio of two parameters (e.g. bed thickness and resistivity) where variation in the parameters keeping the ratio or product constant can yield almost the same response

2.15
geoelectrical layer
subsurface layer having characteristic of uniform electrical resistivity

2.16
geometric factor
numerical value dependent upon the arrangement of electrodes which, when multiplied by the measured voltage-to-current ratio, gives the *apparent resistivity* (2.3)

2.17
geophone
instrument which detects seismic energy and converts it into electrical voltage

2.18
gradient configuration
variation of the *Schlumberger configuration* (2.38) where the current electrodes are kept at a great distance from one another and central space is scanned by a small potential dipole

2.19
half–Schlumberger configuration
configuration in which one of the current electrodes is kept at infinity (large distance) and need not be collinear with the other three electrodes

2.20
homogeneity
characteristic of a formation with uniform physical property or properties

2.21
in-phase
component of a secondary electromagnetic (EM) field with the same phase angle as that of the exciting primary EM field

2.22
Lee-partitioning configuration
variation of the Wenner array where one additional electrode is placed at the centre between the potential electrodes

2.23
longitudinal conductance
ratio of the thickness of a geoelectrical layer (2.15) to its resistivity

2.24
magnetic permeability
ratio of magnetic induction (flux density) in a body to the strength of the inducing magnetic field

2.25
magnetic susceptibility
ratio of the intensity of magnetization produced in a body to the strength of the magnetic field

2.26
migration
part of processing of seismic reflection data required to plot the dipping reflections at their correct position

2.27
non-polarizing electrode
electrode which is not affected by electrochemical potential generated between the electrode and ground material in which it is planted

2.28
normal moveout
effect of variation of shot-geophone distance on time of arrival of seismic reflection

2.29
off-set Wenner configuration
modification in *Wenner configuration* (2.48) to remove or minimize the effect of lateral inhomogeneities

2.30
overburden
part of the host medium which lies above the target and is usually of no interest in exploration, but has physical properties that affect the measurements

2.31
phasor diagram
graph obtained by plotting *in-phase* (2.21) and *quadrature* (2.35) components of secondary electromagnetic (EM) field for different frequencies of primary EM field

2.32
polar diagram
method of plotting resistivity sounding data

2.33
porosity
ratio of the volume of pore space in a sample to the bulk volume of that sample

2.34
proton precession magnetometer
instrument to measure the magnetic field normal to the earth's magnetic field

2.35
quadrature
out-of-phase or imaginary component of secondary electromagnetic (EM) field

2.36
reflector
interface which separates two layers of contrasting *acoustic impedance* (2.1) giving rise to reflection

2.37
refractor
layer along which the refracted or head wave travels at a velocity that is higher than that in the overlying layer

2.38
Schlumberger configuration
collinear four-electrode configuration of current and potential electrodes in which potential electrodes are kept close to the centre of the configuration

2.39
skin depth
depth of penetration of electromagnetic (EM) field in a medium where the intensity of the EM reduces to about 37 % of its original value at the surface of the earth

2.40
Snell's law
laws applied when a seismic wave encounters a boundary between two media having different velocities

2.41
stacking
process of compositing data, for the same parameter, from various data sets for the purpose of eliminating noise

2.42
suppressed layer
layer lacking a response because of its small thickness and/or contrast in physical property with the surrounding environment

2.43
terrain correction
correction applied to measured gravity data to nullify the effect of irregular topographic relief in the immediate vicinity of the station of measurement

2.44
transition
linear or exponential variation of a physical property with depth

2.45
transverse resistance
product of the thickness and resistivity of a *geoelectrical layer* (2.15)

2.46
two-electrode (pole-pole) configuration
one current and one potential electrode are kept at infinity (more than ten times the distance between active electrodes) and perpendicular to the profile along which the other two active electrodes are moved

2.47
vibroseis
seismic survey in which a vibrator is used as a non-destructive source, instead of an explosive, to generate controlled frequency seismic waves in the ground

2.48
Wenner configuration
collinear four-electrode configuration of potential and current electrodes in which all the electrodes are equidistant

3 Units of measurement

Table 1 list the parameters and units of measurement in common use.

Table 1 — List of commonly used geophysical techniques and units of measurement

Method	Technique	Physical property involved	Unit for parameters measured
Electrical Resistivity	Sounding	Resistivity	Ohm-m
	Profiling		
Magnetic		Mag. susceptibility	
		Mag. field intensity	NanoTesla
Electromagnetic	VLF	Conductivity/ Resistivity	Inphase/quadrature Component (%)
	HLEM		Secondary/primary magnetic field (%)
	TEM		Current decay, ohm-m, µs
Seismic	Refraction	Wave velocity	m/s
	Reflection (High Res.)	Acoustic Impedance	Ns/m^3 or Pa s/m
Induced polarization		Chargeability	millisecond (ms)
Self-Potential (electro kinetic)		Natural potential	milliVolt (mV)
Mise-a-la-masse	Charged-body	Development of Potential	milliVolt (mV)
Gravity		Density (lateral variation)	milligal (mgal)

4 Purpose of geophysical survey

Geophysical surveys play a vital role in groundwater exploration. Surveys can be used to conduct either shallow subsurface investigation that may be needed for many environmental-related projects or for deeper investigations that may be required to identify productive aquifers. Also, surveys can be used to delineate bedrock topography, estimate the thickness of weathered zones, demarcate fracture geometry, identify the presence of limestone cavities and/or paleo-channels, and to assess quality of groundwater. Furthermore, surveys can be used to assess groundwater contamination and the movement of plumes, define vadose zone characteristics required for waste disposal or artificial recharge projects, demarcate sea water intrusion, differentiate between aquifers and aquitards, monitor the quality and direction of groundwater movement, etc.; geophysical measurements are also used to estimate hydraulic parameters of aquifers.

Geophysical methods can be grouped into two categories: natural field methods and artificial source methods. Commonly used natural field methods include gravity, magnetic, and self-potential methods, which measure variations in the earth's gravity field, magnetization of rocks and earth's natural kinetic potential. Microgravity techniques can detect changes in groundwater storage and identify saturated cavernous limestone features. Artificial source methods measure the response of the subsurface to artificially induced energy like seismic and electromagnetic waves and electrical currents. These methods include electrical resistivity, induced polarization, Very Low Frequency (VLF) electromagnetic, controlled-source electromagnetic, seismic refraction and, occasionally, seismic reflection.

5 Planning

Geophysical surveys need to be carefully planned in order to meet project objectives, particularly for surveys conducted in remote areas or harsh terrains. Planning should include the following.

5.1 General considerations

— Selection of appropriate method

— Effectiveness and accuracy of equipment and power supply

— Easy operation and maintenance

— Ready to use accessories

— Suitability of vehicle for transportation

— Safety of equipment

5.2 Access to the area

— Suitable access to the area/site

— Permission to work in the area

— Physical constraints in the area

— Clearance along profile line(s)

— Noise and cultural disturbances

— Overhead power line

5.3 Equipment

— Maintenance should be performed as required

— Should be stored in a stable, dust free, and dry environment

— Pre-operation checking should be carried out

— Power supply should be checked regularly

— Precautions given for each equipment are to be observed

— Any deterioration in equipment condition should be rectified immediately

5.4 Safety and precautions in operation

A safety code or plan should be developed prior to surveys to account for potential hazards in the field. Common hazards include working with high voltage power lines, in electrical storms, in extremely remote areas, and with explosives. If possible, surveys should be conducted in dry weather periods to avoid damage to equipment by lightening.

Unnecessary use of high voltage input should be avoided and care should be used when working with systems of 100 volts or more, or with systems having 120 mA or more of current. In the event of rain or lightening, the current and potential cable connections should be removed from the instrument and no one should be allowed to touch the terminals. Even at a distance of 5 km to 6 km, lightening can damage the circuit.

In seismic surveys, explosives should be handled by trained personnel and stored safely. Overhead power lines should not be located near the explosive shot hole, which should be dampened by water and covered with a blast blanket. Detonators should be always kept short circuited, even during transportation to the site.

5.5 Planning of survey

Field crews should be informed of operational procedures prior to the survey. Profile lines should be straight and the distances between transmitter and receiver should be accurately determined. Spacing should be repeatedly checked or confirmed. Other considerations are itemized below.

— Crew should not touch the electrodes or the cable until instructed to do so by the operator.

— Movement of the crew near the profile should be restricted and the cable should not be passed through water or near high voltage power lines. Also, the crew should not stand in water with bare feet.

— Data should be plotted at the site so that errors can be removed or readings repeated.

— Electrodes should not be located near lateral inhomogeneities such as boulders in rocky terrain or buried objects such as pipelines or telephone cables.

— Line should be checked regularly irrespective of the applied voltage.

— The charge (explosive) should not be placed in a highly-weathered zone so as not to overlay dissipate the energy.

— For shallow investigations, the depth of weathering should be estimated by special shooting so that charge can be placed below the weathered zone.

— For EM equipment with multiple frequency selections, frequencies should be changed only after switching-off the instrument.

— In magnetic surveys, ferrous objects should not be placed near the sensor.

5.6 Quality control in field data collection

Quality control considerations are a function of the selected equipment and the required level of accuracy. In any case, measurements should be repeated and profile orientations should be checked.

5.7 Site/area details

Investigators should become familiar with the local geologic and hydrogeological characteristics of a targeted site prior to conducting a survey. Characteristics may include, but not be limited to, lineament details, lithostratigraphic information, water-level information, and water-quality information. A well inventory should be conducted to identify sources of pertinent data and information.

Depending on the objectives of the survey, candidate sites for field surveys may be selected on the basis of existing information. Final site selection, however, should be based on a more rigorous study of geomorphic features and geological structures in the field. Local representatives may be consulted to help plan the surveys. Final site selection should be based on geophysical anomaly positions, accessibility, local conditions, and avoiding physical constraints such as electrical lines, metallic structures, crossing of roads, streams, or bridges, and topographic depressions.

6 Electrical resistivity

6.1 Purpose

To identify groundwater potential zones (whether granular or fractured), geometry, variations in the chemical quality of groundwater and the directions of groundwater movement.