
**Geotechnical investigation and
testing — Geohydraulic testing —**

**Part 4:
Pumping tests**

*Reconnaissance et essais géotechniques — Essais géohydrauliques —
Partie 4: Essais de pompage*



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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).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 182, *Geotechnics*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 341, *Geotechnical investigation and testing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 22282-4:2012), which has been technically revised.

The main changes compared to the previous edition are as follows:

- editorial changes;
- correction of formulae.

A list of all parts in the ISO 22282 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

General rules on the planning and execution of geohydraulic field tests are covered by ISO 22282-1.

A pumping test consists in principle of:

- drawing down the piezometric surface of the groundwater by pumping from a well (the test well);
- measuring the pumped discharge and the water level in the test well and piezometers, before, during and after pumping, as a function of time.

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Geotechnical investigation and testing — Geohydraulic testing —

Part 4: Pumping tests

1 Scope

This document establishes requirements for pumping tests as part of geotechnical investigation service in accordance with EN 1997-1 and EN 1997-2.

This document applies to pumping tests performed on aquifers whose permeability is such that pumping from a well can create a lowering of the piezometric head within hours or days depending on the ground conditions and the purpose. It covers pumping tests carried out in soils and rock.

The tests concerned by this document are those intended for evaluating the hydrodynamic parameters of an aquifer and well parameters, such as:

- permeability of the aquifer,
- radius of influence of pumping,
- pumping rate of a well,
- response of drawdown in an aquifer during pumping,
- skin effect,
- well storage,
- response of recovery in an aquifer after pumping.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14688-1, *Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description*

ISO 14689, *Geotechnical investigation and testing — Identification, description and classification of rock*

ISO 18674-4, *Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 4: Measurement of pore water pressure: Piezometers*

ISO 22282-1, *Geotechnical investigation and testing — Geohydraulic testing — Part 1: General rules*

ISO 22475-1, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for the sampling of soil, rock and groundwater*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 22282-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.2 Symbols

Symbol	Designation	Unit
D	drilled diameter of the well	m
d	thickness of the aquifer	m
L	wetted length of screen of the perforated pipe placed in the well	m
Q	flow rate	m ³ /s
Q_d	discharge rate, assessed pumping discharge at the end of the well preparation	m ³ /s
Q_e	discharge rate of the pumping test	m ³ /s
S	storage coefficient	—
T	transmissivity	m ² /s
t	time	s
v	velocity	—
a	slope of the line that characterizes the drawdown in the well	—
b	ordinate at the origin of the line that characterizes the drawdown in the well	—
c	conventional drawdown unit of the preliminary pump discharge	—
d_N	size which may be interpolated from the grading curve, of the square sieve mesh of side d for which the weight percent of undersize is equal to N percent	—
e	distance between the bottom of the well and the surface of the unconfined groundwater at rest in an aquifer	m
Δh	drawdown of the water level in the well	m
$\Delta h'$	drawdown of the water level in the well after 2 h	m
Δh_f	drawdown of the water level in the well, set during the preliminary test and not to be exceeded	m
$\Delta h_{\max}$	maximum drawdown of the water level in the well during the pumping test	m

4 Equipment

The following equipment and instruments shall be used to conduct a pumping test:

- a) a test well and piezometers in accordance with ISO 18674-4;
- b) a pump and associated pipework capable of pumping from the test well; the pumps shall be equipped with a suitably long discharge pipe so that the water from the pump is discharged sufficiently far away so that it does not affect the test area; the capacity of the pump shall be sufficient to extract from the well a discharge at least equal to that corresponding to that estimated to achieve the maximum planned drawdown;

NOTE Pumping tests are commonly carried out using electric submersible pumps, installed within the test well. However, depending on conditions, pumping tests can also be carried out using suction pumps located at the surface, airlift equipment, or special dewatering equipment such as well points or eductors.

- c) a system for regulating and measuring the discharge rate (m^3/s); devices for measuring the discharge rate shall be suitably calibrated and shall be accurate for a range of flow rates anticipated during the test;
- d) a system for measuring the water level in the test well and piezometers; the turbulence in the test well caused by pumping shall be considered; the devices shall be capable of measuring water levels over the range of drawdowns anticipated during the test;
- e) a time measuring and/or recording device, reading in seconds.

5 Test procedure

5.1 Test preparation

5.1.1 General

When preparing a pumping test, there are a number of things to investigate and consider in advance, such as:

- basic information on the ground and groundwater conditions according to ISO 22282-1;
- the required drawdown and/or the required discharge rate during the test;
- the discharge point for the pumped water and its location relative to the test well;
- the duration of the test.

5.1.2 Determining the discharge rate for the pumping test

The discharge rate Q_d shall be estimated to ensure that the test well can yield sufficient water, to allow a pump of appropriate capacity to be selected, and to ensure that the discharge can be accepted at the agreed disposal point.

The discharge rate can be estimated by one or more of the following methods:

- based on the purpose of the test and experience of local conditions;
- by theoretical assessment of the well capacity, according to the method described in [Annex B](#);
- by analysis of information from the preliminary pumping phase, according to the method described in [Annex B](#).

5.2 Arranging the disposal of discharge water

It is presupposed that the disposal of discharge water is in accordance with relevant rules and regulations.

If the discharge water is not disposed of via an engineered sewer network, it shall be disposed of at sufficient distance from the test well that it will not have a significant impact on the observed pattern of groundwater lowering.

5.3 Executing and equipping the well

5.3.1 Design of the test well

The test well shall be designed to satisfy the following criteria (see [Figure 1](#)):

- of sufficient depth to penetrate below the groundwater level in the strata of interest; if the test well does not fully penetrate the aquifer, it shall penetrate the saturated part of the aquifer to a depth of at least 25 times the well screen diameter with a minimum of 3 m;
- of sufficient drilled diameter to accommodate the necessary filter materials and well screen of sufficient diameter to accommodate pumping equipment of adequate capacity to achieve the required discharge rate;
- with sufficient length and capacity of well screen to ensure that the required discharge rate can be achieved;
- to have appropriate filter material to ensure that the discharge water contains an acceptably low sediment content to avoid the risk of pump damage and ground settlement as a result of the removal of fine particles from the soil; where the well is constructed in a stable rock, it may be possible to construct a test well without the need for filter material.

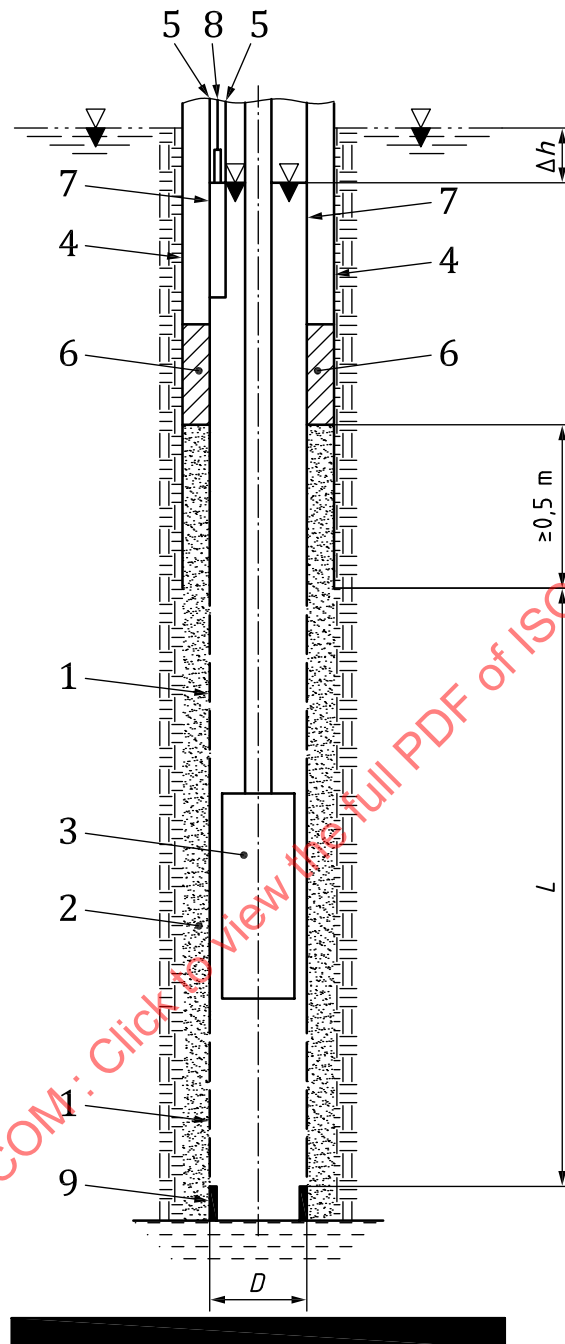
The filter material shall be a highly permeable granular material of closely controlled particle size and be formed of grains of inert minerals in relation to the aquifer groundwater chemistry (e.g. quartz, feldspar). In granular soils, the filter's grading curve shall satisfy the double inequality:

$$5 d_{15 \text{ soil}} \leq d_{15 \text{ filter}} \leq 5 d_{85 \text{ soil}}$$

where d_N designates the characteristic size of the filter or of the ground in place, such that the mass of the soil fraction passing through a sieve with a square mesh of side d represents N % of the total mass of material.

In fine grained soils or where the well screen is equipped with a geotextile mesh designed to act as a filter, the filter material's purpose is to backfill the annular space between the outside of the well screen and the borehole wall. In those circumstances the filter media should be highly permeable coarse sand or fine gravel, with a permeability coefficient at least 100 times that of the soil or rock being tested.

The thickness of the annular space for the filter pack shall be at least 50 mm. The inner diameter of the test well shall be selected according to the purpose.



Key

- | | | | |
|---|------------------------------------|-----|--------------------------------------|
| 1 | well screen (slotted tube) | 7 | plain tube |
| 2 | filter material (filter pack) | 8 | device for measuring the water level |
| 3 | submersible pump | 9 | base of the screen |
| 4 | borehole casing | L | filter length |
| 5 | tube for measuring the water level | D | drilled diameter of the well |
| 6 | sealing plug | | |

Figure 1 — Test well equipped for a pumping test — Example

5.3.2 Installation procedure

The test well shall be constructed in a similar way to piezometers in accordance with ISO 18674-4. Great care shall be taken when installing the well materials. Particular attention shall be paid to the following:

- The well screen shall be lowered into the borehole to the specified level and shall be installed centrally in the well, with the top and bottom of the screen located at the design level. Care shall be taken that the joints of the screen and casing do not leak, and that the screen and casing are installed vertically and straight.
- If necessary, filter material shall be inserted in the annular space between the screen and the temporary casing (or borehole wall). The filter material shall be placed progressively in stages to reduce the risk of a blockage in the annular space. The filter material should be placed via a tremie pipe.
- If necessary, a sealing plug of low permeability material (such as bentonite) shall be created in the annular space between the borehole wall and the well casing immediately above the filter material. The purpose of the sealing plug is to prevent infiltration of surface water, or water from other aquifers, into the well screen.

5.3.3 Preparation of the well

Prior to the pumping test the well shall be developed to increase the permeability of the soil around the shell by washing, and to remove any drilling residues and mobile soil particles that could be entrained by the water flow into the well. Such particles could clog the filter and damage the test pump.

Development shall be carried out by means of pumping. Possible methods include airlifting or pumping using a robust pump that is not damaged by the presence of particles in the discharge water. If airlift pumping is used, care shall be taken to avoid injecting air into the ground, as air bubbles in the ground can affect the permeability.

Other methods for well development may be used in combination with pumping, including:

- jetting with water inside the well screen;
- surging or swabbing inside the well screen to induce water flow into and out of the well;
- chemical treatment (e.g. use of acids in carbonate rocks).

5.4 Executing and equipping the piezometers

5.4.1 Installation procedure

Piezometers shall be installed in accordance with ISO 18674-4.

The piezometer tubes shall be installed at such a depth that the influence of the test well can be observed and recorded adequately. Where possible, the piezometer closest to the test well shall be located at the same depth as the bottom of the test well.

5.4.2 Preparation of piezometers

Before commencement of the test, piezometers shall be cleaned in accordance with ISO 18674-4. The water level in the piezometers shall be measured for a period before and after the test in order to find any natural variations in the groundwater level. Their response time shall be checked by watching the water rise in the piezometer tube. The period of monitoring depends on the nature of the aquifer and the purpose of the pumping test.

5.5 Execution of the test

5.5.1 General

The test comprises up to four phases:

- a pre-pumping phase to monitor the undisturbed groundwater levels;
- a preliminary pumping phase to determine the discharge from the pumping test;
- the pumping test phase;
- the post-pumping test phase to monitor recovery of groundwater levels.

5.5.2 Pre-pumping monitoring

Prior to commencement of the pumping phase of the test, water levels in the test well and piezometers shall be monitored to determine natural groundwater levels.

NOTE The duration of the pre-pumping phase depends on the purpose of the test and local conditions. Typical durations of pre-pumping monitoring are between one day and ten days. Longer periods of pre-pumping monitoring are necessary when groundwater levels are subject to tidal or other variations.

5.5.3 Preliminary pumping phase

Prior to the main pumping test, a short period of pumping shall be carried out to test the equipment.

NOTE Suitable durations for the equipment test are between 15 min and 2 h.

During the preliminary pumping phase, the correct functioning of pumps, control systems, valves, flow measurement devices and water level measurement devices shall be checked. Discharge pipe work shall be checked for leaks. Any corrective action deemed necessary shall be taken prior to commencement of the pumping test.

For large-scale or complex pumping tests, the preliminary pumping phase can be used to provide information on discharge rate and drawdown to assist in determination of discharge rate for the pumping test (see [Annex B](#)).

5.5.4 Pumping test

The pumping test shall not be started until water levels in the test well and the piezometers have stabilized following the preliminary pumping phase.

The pumping test can comprise:

- a variable rate test; this type of test involves pumping the test well in a step-wise fashion, either increasing or decreasing, up to the maximum capacity of the test well or the pump; a variable rate test can be used to assist in determination of the discharge rate for a constant rate test; and/or
- a constant rate test; this type of test involves pumping the test well at a constant rate for the duration on the test.

If the pumping test comprises a variable rate test followed by a constant rate test, there may be a period of post pumping monitoring following the end of the variable rate test. In this case, the period between the end of the variable rate test and the beginning of the constant rate test should be long enough to allow water levels to stabilize.

Whenever the discharge is started or changed, the change in pumping rate shall be carried out rapidly. At the start of the pumping test the discharge rate shall be stabilized within 2 min after starting the pumping.

The time at the start of the test is defined as $t = 0$.

During the pumping test measurements of water level shall be made according to the requirements of the purpose of the test and the ground conditions. In general, measurements shall be taken more frequently at the start of the pumping test, or when flow rate has been changed during a variable rate test, when water levels are likely to be changing rapidly. During the later stages of a pumping test, when water levels are changing more slowly, readings can be taken less frequently.

The following time increments between readings should be used unless alternative time increments can be justified based on the purpose of the test and the ground conditions. If the groundwater levels in the test well and piezometers are likely to continue to change at a significant rate, it may be necessary to take readings more frequently than the guidelines below:

- ≤ 30 s for $t \leq 5$ min;
- ≤ 1 min for $t = 5$ min to 15 min;
- ≤ 5 min for $t = 15$ min to 30 min;
- ≤ 10 min for $t = 30$ min to 1 h;
- ≤ 30 min for $t = 1$ h to 4 h;
- ≤ 1 h for $t > 4$ h.

Where a pumping test is carried out in conditions where groundwater is subject to tidal variations, water level readings shall be taken at frequent intervals throughout the test duration. In tidal conditions the interval between readings should not exceed 15 min.

The pump discharge shall be measured at least four times in the first hour. If the discharge is stable, the discharge can be measured once a day. If the discharge is not stable, the pump discharge shall be determined each hour.

Levels of open water bodies in the vicinity of the test site, where variation is likely to interfere with the pumping test (and vice versa), shall be recorded periodically throughout the test.

Pumping shall be continued until the end of the specified pump test period or, if the test is required to achieve steady-state conditions, until three successive readings, spaced at least 1 h apart, of the water levels in the piezometers do not differ from one another by more than 1 cm.

5.5.5 Post-pumping monitoring

When pumping is stopped at the end of the pumping phase, post-pumping monitoring shall commence. During this phase, the water levels in the well and piezometers shall be recorded. Starting from the beginning of the post-pumping phase, the intervals between readings should be the same as during the pumping phase.

The duration of the post-pumping phase will depend on the purpose of the test and the local conditions. Unless justified by the purpose of the test and the ground conditions, monitoring time shall be at least equal to the duration of decreasing groundwater levels in the pumping phase, or until three successive readings, spaced at least 1 h apart, do not differ from one another by more than 1 cm.

Once readings are less frequent, the pumping equipment may be removed by keeping the monitoring equipment in operation, provided that monitoring is not disturbed.

Backflow should be avoided.

5.6 Uncertainty of measurement

The uncertainty of automatic measurement shall, and of manual measurement should, not be greater than:

- 1 s for time or 1 % of the time increment, whatever gives the greater value;

- 1 cm for levels;
- 5 % of the maximum flow for discharges.

5.7 Interruptions in pumping

During the pumping test phase, it is important that pumping be continuous, other than equipment shutdowns for periodic maintenance. During a variable rate test or the first 24 h of a constant rate test, there shall be no equipment shutdowns for maintenance. All pumping plants should be adequately maintained and serviced before the test commences.

If mechanical breakdown or other problems cause interruption to pumping during a variable rate test or during the first 24 h of a constant discharge rate test, the test shall be abandoned. Groundwater levels shall be allowed to recover and the test restarted from $t = 0$ for a constant rate test, or from the start of the previous step for a variable rate test.

Once a constant rate test has been in progress for more than 24 h, interruptions in pumping of up to 1 h may be acceptable depending on the purpose of the test, although any interruptions in pumping should be kept to an absolute minimum.

5.8 Decommissioning

After the test has been completed, the pumping and monitoring equipment shall be removed. The test well and piezometers shall be locked, backfilled or grouted up according to ISO 18674-4.

6 Test results

The principal test results are:

- drawdown and recovery of water levels in the test well and piezometer as a function of time;
- discharge from the test well as a function of time.

During the test, the test results should be plotted graphically.

The test results can be used to evaluate aquifer properties (including permeability, transmissivity, storage coefficient) and the performance parameters of the test well.

For constant rate tests, analyses can be either steady-state or transient-state. Steady-state analyses are relatively simple to apply, but do not allow storage coefficients to be determined. Transient-state analyses are more complex, but allow a wider range of parameters to be determined.

The most common methods of analysis of test results are described in [Annex C](#).

7 Reports

7.1 Field report

7.1.1 General

At the project site, a field report shall be completed. This field report shall consist of the following, if applicable:

- a) summary log according to ISO 22475-1;
- b) drilling record according to ISO 22475-1;
- c) sampling record according to ISO 22475-1;

- d) record of installation of wells and piezometers according to ISO 18674-4;
- e) record of identification and description of soil and rock according to ISO 14688-1 and ISO 14689;
- f) installation record according to [7.1.2](#);
- g) calibration record according to ISO 22282-1;
- h) decommissioning record;
- i) record of measured values and test results according to [7.1.3](#).

All field investigations shall be reported such that third persons are able to check and understand the results.

7.1.2 Installation record

The installation record shall be attached to the summary log and include the following essential information, if applicable:

- a) type of equipment;
- b) test well;
- c) piezometers;
- d) pumps;
- e) water level measuring unit;
- f) flow rate measuring unit;
- g) dates and times of installation;
- h) groundwater levels before and after installation;
- i) name and signature of the test operator.

7.1.3 Record of measured values and test results

The record of measured values and test results shall be attached to the summary log and include the following essential information, if applicable (see also [Annex A](#)):

- a) name of the enterprise performing the test;
- b) name of the client;
- c) test date(s) and time;
- d) name and number of project;
- e) number of wells and piezometers;
- f) a reference to this document, i.e. ISO 22282-4;
- g) elevation of the water and its depth in the well before the start of pumping;
- h) a table showing, in terms of elapsed time since the beginning of the test, the discharge rates and the water levels measured in the well and in each piezometer;
- i) name and signature of the test operator.

7.2 Test report

The test report shall include the following essential information:

- a) the field report (in original and/or computerized form);
- b) a graphical presentation of the test results;
- c) the name and signature of the responsible expert.

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Annex A (informative)

Record of measured values and test results of the pumping test — Example

A.1 Variable rate discharge test

REPORT: Pumping test				Variable rate discharge test conducted according to ISO 22282-4														
Enterprise:	$Q_d =$ $Q_1 =$ $Q_2 =$ $Q_3 =$ $Q_4 =$	m^3/s m^3/s m^3/s m^3/s m^3/s	Date:					File No.:										
Test operator:			Start time:					Site:										
			Test well:					Bottom: screen					Top: screen					
STEP No.	t	min	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	6	7	8	9	
TEST WELL	h	m																
	Δh	m																
	Q	m^3/s																
	t	min	10	11	12	13	14	15	20	25	30	40	50	60	90	120		
TEST WELL	h	m																
	Δh	m																
	Q	m^3/s																
	t	min	10	11	12	13	14	15	20	25	30	40	50	60	90	120		
TEST WELL	h	m																
	Δh	m																
	Q	m^3/s																
	t	min	10	11	12	13	14	15	20	25	30	40	50	60	90	120		
TEST WELL	h	m																
	Δh	m																
	Q	m^3/s																
	t	min	10	11	12	13	14	15	20	25	30	40	50	60	90	120		
TEST WELL	h	m																
	Δh	m																
	Q	m^3/s																
	t	min	10	11	12	13	14	15	20	25	30	40	50	60	90	120		

REPORT: Pumping test				Variable rate discharge test conducted according to ISO 22282-4												
Enterprise:	$Q_d =$	m^3/s	Date:	File No.:												
Test operator:	$Q_1 =$	m^3/s	Start time:	Site:												
	$Q_2 =$	m^3/s	Test well:	Bottom: screen				Top: screen								
	$Q_3 =$	m^3/s														
	$Q_4 =$	m^3/s														
TEST WELL	h	m														
	Δh	m														
	Q	m^3/s														

A.2 Pumping test — Example

REPORT: Pumping test										File No.:									
Conducted according to ISO 22282-4										Site:									
TEST WELL:			TEST PHASE (delete as appropriate)							PIEZOMETERS									
Ground level			Pre-pumping/preliminary/pumping/post-pumping							No. Distance from well BH name Base screen									
WELL DIAGRAM			DRILLING							1 $X_1 = m$									
			Height of wellhead $L_0 = m$							2 $X_2 = m$									
			Depth of base $L_1 = m$							3 $X_3 = m$									
			WELL CASING																
			Internal diameter: m																
Key 1 ground surface 2 seal D diameter of the borehole h_0 water level in rest h drawdown water level e distance between the bottom of the well and the water level in rest			Depth of base $L_2 = m$																
			Depth of seal $L_3 = m$																
			Filter length $L_4 = m$																
			WELL SCREEN																
Key 1 well axis BH borehole Diagram of piezometer placements			Internal diameter = m							Pump discharge $Q_e = m^3/s$									
			Length $L = m$																
Start of pumping			Date:							End of pumping			Date:						
			Time:										Time:						
ELAPSED TIME	t	min	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	6	7	8	9		
WELL	h	min																	
	$\Delta h = h - h_0$	m																	
	Q	m^3/s																	
PIEZO X_1	h_1	m																	
	$\Delta h_1 = h_1 - h_{1,0}$	m																	
PIEZO X_2	h_2	m																	
	Δh_2	m																	
PIEZO X_3	h_3	m																	
	Δh_3	m																	
PUMPING	t	min	10	11	12	13	14	15	20	25	30	40	50	60	90	120	150		

WELL	h	min															
	$\Delta h = h - h_0$	m															
	Q	m ³ /s															
PIEZO X ₁	h_1	m															
	Δh_1	m															
PIEZO X ₂	h_2	m															
	Δh_2	m															
PIEZO X ₃	h_3	m															
	Δh_3	m															
	$\Delta h_3 = h_3 - h_{3,0}$																
Enterprise													Test operator				

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Annex B (informative)

Determining the pumping test discharge

B.1 Generals

The discharge rate Q_d should be estimated to ensure that the test well can yield sufficient water, to allow a pump of appropriate capacity to be selected, and to ensure that the discharge can be accepted at the agreed disposal point.

The discharge rate is an estimation by one or more of the following methods:

- based on the purpose of the test and experience of local conditions;
- by theoretical assessment of the well capacity, according to the method described in this annex;
- by analysis of information from the preliminary pumping phase, according to the method described in this annex.

B.2 Theoretical assessment of well capacity

The maximum discharge rate can be set to ensure that:

- the velocity at the entry to the filter given in [Formula \(B.1\)](#):

$$v = \frac{Q_d}{\pi D L} \quad (\text{B.1})$$

is no greater than 1 cm/s;

- the depth of water above the pump inlet is more than 0,5 m;
- the drawdown for a discharge of 0,2 Q_d can be accurately measured using the equipment proposed.

B.3 Analysis of information from the preliminary pumping phase

B.3.1 General

To determine the appropriate discharge rate to be used in the pumping test a preliminary pumping phase can be carried out.

B.3.2 Determining the well's characteristic curve

The characteristic curve of the drawdown Δh in the well, for a pumping period at a fixed discharge Q , is given by [Formula \(B.2\)](#):

$$\Delta h = aQ^2 + bQ \quad (\text{B.2})$$

The coefficients a and b are calculated from the data collected during the preliminary pumping phase.

B.3.3 Preliminary pumping in the well

The preliminary phase consists of pumping with four successive steps at constant discharge in each step for a duration of 2 h for the first stage, and 1 h for the next three.

The discharges Q_i selected for the four steps are a function of the maximum discharge rate that can be obtained from the well Q_d and are such that:

$$Q_i = 0,8 Q_d / (5 - i) \quad (\text{B.3})$$

where i is step 1 to step 4.

For each step, the water level in the well is measured at least every 5 min during the first 30 min, and then every 10 min thereafter.

During the first pumping step at discharge Q_1 , the specific drawdown $(\Delta h/Q)$ of the water level in the well as a function of time allows us to calculate:

- the slope α of the tangent to the curve giving the specific drawdown plotted against $\log_{10}$ of time, for a pumping maintained for 2 h;
- the specific drawdown $c = (\Delta h/Q_1)_{(48 \text{ h})}$ for pumping at discharge Q_1 whose duration has been extrapolated logarithmically to 48 h.

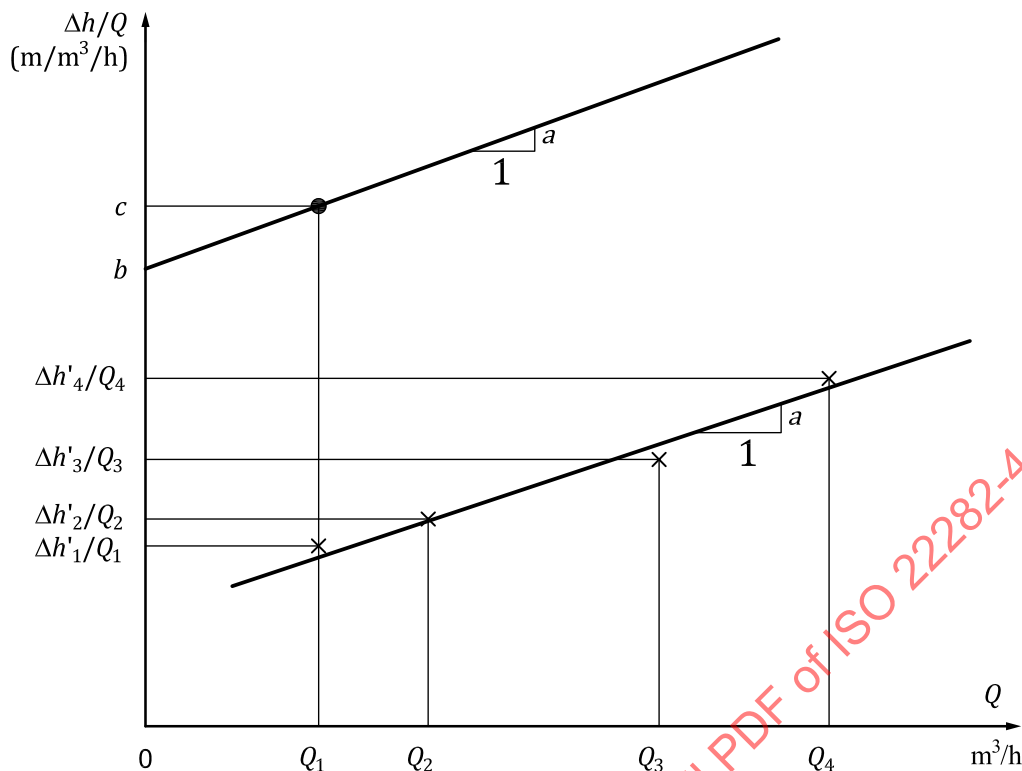
B.3.4 Determining coefficients a and b of the well's characteristic curve

Coefficient a is the slope of the mean straight line passing through the coordinate points $(Q_i, \Delta h'_i/Q_i)$ calculated for the four steps of index i (see [Figure B.1](#) and [Figure B.2](#)). $\Delta h'_1$ is the drawdown measured after 2 h at discharge Q_1 ($\Delta h'_1 = \Delta h_1$).

For the other steps, $\Delta h'_i$ is the drawdown extrapolated for discharges Q_i maintained constant for 2 h. It is determined as follows:

- for the step at discharge Q_2 having produced a drawdown Δh_2 at the end of 1 h:

$$\Delta h'_2 = \Delta h_2 + \{ (0,3 Q_2 - 0,48 Q_1) \quad (\text{B.4})$$



Key

1 well axis

Figure B.2 — Determination of coefficients a and b of the characteristic drawdown curve in the well during the preliminary test

B.3.5 Determining the test pumping discharge rate Q_e

The test discharge rate is the solution of the formula of the characteristic well drawdown curve determined in [B.2](#):

$$Q_e = [(b^2 + 4a\Delta h_f)^{0,5} - b]/2a \text{ and } Q_e \leq 1 \cdot 10^{-2} \pi DL \quad (\text{B.7})$$

where Δh_f is the target drawdown for the end of the test.

For a well that has penetrated an aquifer whose unconfined groundwater surface at rest lies at a height e above the bottom of the well, $\Delta h_f \leq e/3$.

For a well in an aquifer with confined groundwater, Δh_f is the final drawdown that brings the water level in the well no lower than 0,5 m above the level of the top of the aquifer, such that in general $\Delta h_f \leq e/3$. The drawdown shall always leave water in the well to a height of at least 0,5 m above the upper part of the screen.

Annex C

(informative)

Interpretation of the pumping test results

C.1 Variable rate pumping tests

Well characteristics can be deduced from variable rate tests according to [B.2](#).

C.2 Constant rate pumping tests — Steady-state analysis

C.2.1 General

Steady-state is defined as the condition, in the later stages of a pumping test, when groundwater levels remain constant, or vary so slowly as to be effectively constant.

The interpretation methods presented in this section are based upon (among other things) the following basic assumptions:

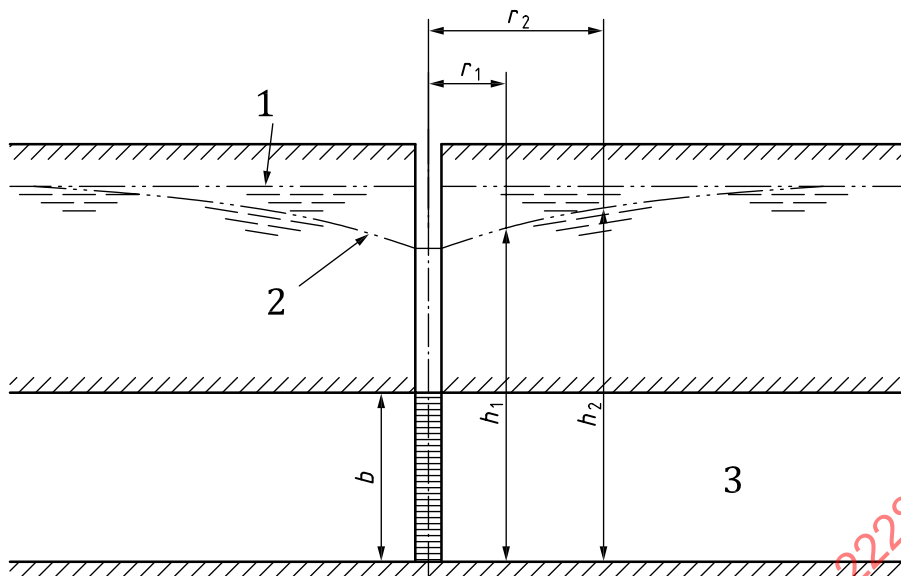
- homogenous and isotropic aquifer of constant thickness and infinite horizontal extent;
- horizontal groundwater level prior to the start of pumping;
- constant discharge rate;
- a test well that fully penetrates the aquifer.

In cases of significant difference to the above-mentioned simplifying conditions, corrections should be made according to the literature.

C.2.2 Confined aquifer

C.2.2.1 General

The hydrogeological conditions of a confined aquifer are shown in [Figure C.1](#).

**Key**

- b thickness of confined aquifer
- 1 static water level
- 2 equilibrium water level
- 3 confined aquifer

Figure C.1 — Confined aquifer**C.2.2.2 Method according to Dupuit/Thiem: mathematical solution**

In the case of an aquifer confined at the top and bottom (Figure C.1), transmissivity can be computed according to the solution of Thiem.

$$T = \frac{Q}{2\pi(h_2 - h_1)} \ln\left(\frac{r_2}{r_1}\right) \quad (\text{C.1})$$

where

T is the aquifer transmissivity, in m^2/s ;

Q is the flow rate, in m^3/s ;

h_1 is the piezometric head at distance r_1 from the pumping well, in m;

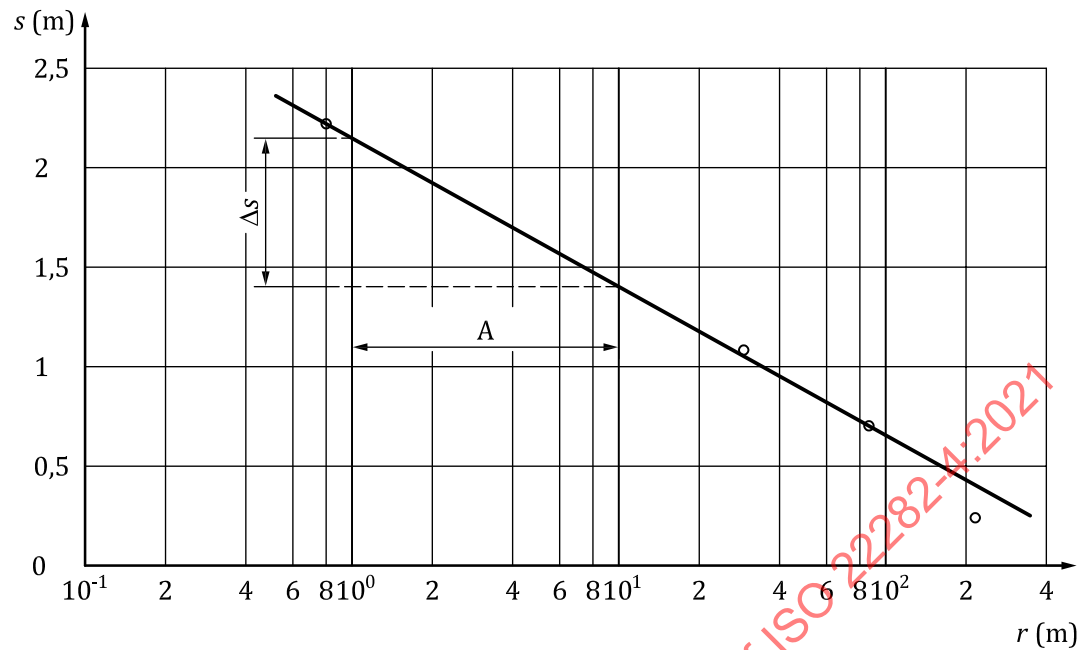
h_2 is the piezometric head at distance r_2 from the pumping well, in m.

The permeability coefficient k (in m/s) can be determined from $k = T/d$ where d is the thickness of the aquifer (in m).

C.2.2.3 Method according to Dupuit/Thiem: graphical solution

A graphical solution can be applied, as follows:

- drawdown in each observation well is to be plotted against its distance from the test well on semi-logarithmic axes as shown in Figure C.2.

**Key**

A log cycle

Figure C.2 — Graphical solution according to Dupuit/Thiem

- Δs is the change in drawdown per log cycle of distance from the test well, is determined from the graphical plot and is substituted in [Formula \(C.2\)](#):

$$T = \frac{2,30 Q}{2\pi \Delta s} \quad (\text{C.2})$$

where

T is the aquifer transmissivity, in m^2/s ;

Q is the flow rate, in m^3/s ;

Δs is the change in drawdown per log cycle of time, in m.

C.2.3 Unconfined aquifer

For the case of an unconfined aquifer underlain by a horizontal aquiclude ([Figure C.3](#)), the modified Dupuit/Thiem formula can be used.