

Code of practice for

Test pumping of water wells

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Industrial-process Measurement and Control Standards Policy Committee (PCL/-) to Technical Committee PCL/3, upon which the following bodies were represented:

- Clyde River Purification Board
- Department of the Environment
- Department of the Environment for Northern Ireland
- Institute of Measurement and Control
- Institution of Civil Engineers
- Institution of Water and Environmental Management
- Ministry of Agriculture, Fisheries, and Food
- National Rivers Authority
- Water Services Association of England and Wales
- Welsh Office

This British Standard, having been prepared under the direction of the Industrial-process Measurement and Control Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 May 1992

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First published March 1983
Second edition May 1992

The following BSI references relate to the work on this standard:
Committee reference PCL/3
Draft for comment 91/24721 DC

ISBN 0 580 20538 X

Amendments issued since publication

Amd. No.	Date	Comments

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Foreword

This British Standard code of practice has been prepared under the direction of the Industrial-process Measurement and Control Standards Policy Committee. It supersedes BS 6316:1983 which is withdrawn.

The increasing demand for water makes it vital for water resources to be used efficiently, and this in turn adds great importance to reliable quantitative estimates of groundwater resources. The pumping test is, for the present, the most reliable way of evaluating the hydraulic behaviour of wells and aquifers. Development of groundwater resources without adequate pumping test data is a speculative operation which may have unforeseen consequences.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people, for whose guidance it has been prepared.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 62, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

0 Introduction

Pumping tests are normally carried out to obtain data with which to:

- a) assess the hydraulic behaviour of a well and so determine its ability to yield water, predict its performance under different pumping regimes, select the most suitable pumping plant for long term use and give some estimate of probable pumping costs;
- b) determine the hydraulic properties of the aquifer or aquifers which yield water to the well; these properties include the transmissivity and related hydraulic conductivities, storage coefficient and the presence, type and distance of any hydraulic boundaries;
- c) determine the effects of pumping upon neighbouring wells, watercourses, or spring discharges.

A pumping test also provides a good opportunity to obtain information on water quality and its variation with time and perhaps with discharge rate.

When water is pumped from a well, the head in the well is lowered, creating a drawdown or head loss and setting up a localized hydraulic gradient which causes water to flow to the well from the surrounding aquifer. The head in the aquifer is also reduced and the effect spreads outwards from the well. A cone of depression of the potentiometric surface is thus formed around the well and the shape and the manner of expansion of this cone depend on the pumping rate and on the hydraulic properties of the aquifer. By recording the changes in the position of the potentiometric surface in observation wells located around the pumping well it is possible to monitor the growth of the cone of depression and determine these hydraulic characteristics. The form of the cone of depression immediately around the well will generally be modified because additional head losses are incurred as the water crosses the well face. The drawdown may be considered to consist of two components:

- 1) head loss through the aquifer;
- 2) head loss in the well.

Consequently, there are two test objectives: an understanding of the characteristics of the well and those of the aquifer.

A test may be performed to serve any or all of the main objectives. If they are satisfied it may be said that the hydraulic regime of the well and aquifer has been evaluated. However it needs to be understood that other information, particularly about other factors affecting recharge, will be required to predict the long term effects of abstraction.

It needs to be recognized that there are inherent difficulties involved in carrying out a pumping test, e.g. making many physical measurements. In part these arise from the tendency of the measuring process or equipment to change the quantity being measured. For example, the drilling of boreholes to investigate the hydraulic regime of an aquifer may disturb that hydraulic regime by providing vertical communication between aquifer levels containing water at different heads. A second difficulty involves sampling. Only rarely will a cone of depression be circular and symmetrical; the relatively few observation boreholes which are usually available in effect provide a limited number of sampling points with which to determine the form of the cone. It is important that these limitations and difficulties are kept clearly in mind when designing and analysing a pumping test and, in particular, when using the results.

Figure 1 indicates the normal sequence of events in a pumping test.

1 Scope

This code of practice describes the factors which need to be considered and the measurements which need to be made when designing and performing a pumping test. However, there can be no such thing as a "standard" pumping test because of the great diversity of objectives, aquifers, groundwater conditions, available technology and legal contexts. This code therefore provides a set of guidelines for field practice, with an indication of how they may be varied to take account of particular local conditions. It deals with the usual types of pumping tests carried out for water supply purposes, in which water is abstracted from the entire screened, perforated, or unlined interval(s) of a well. Some guidance is also provided on slug tests and packer tests. Specialized tests, such as drill-stem tests, and tests of strata for engineering purposes, are not considered in detail. Guidance on some of these specialized tests is given in BS 5930.

Interpretation of the data collected during a pumping test is referred to in this code only in a general way. For full details of the analysis and interpretation of test data, e.g. with regard to stream flow depletion, reference should be made to specialized texts. Examples of such texts are included in a selected bibliography.

NOTE The titles of the publications referred to in this code of practice are listed on the inside back cover.

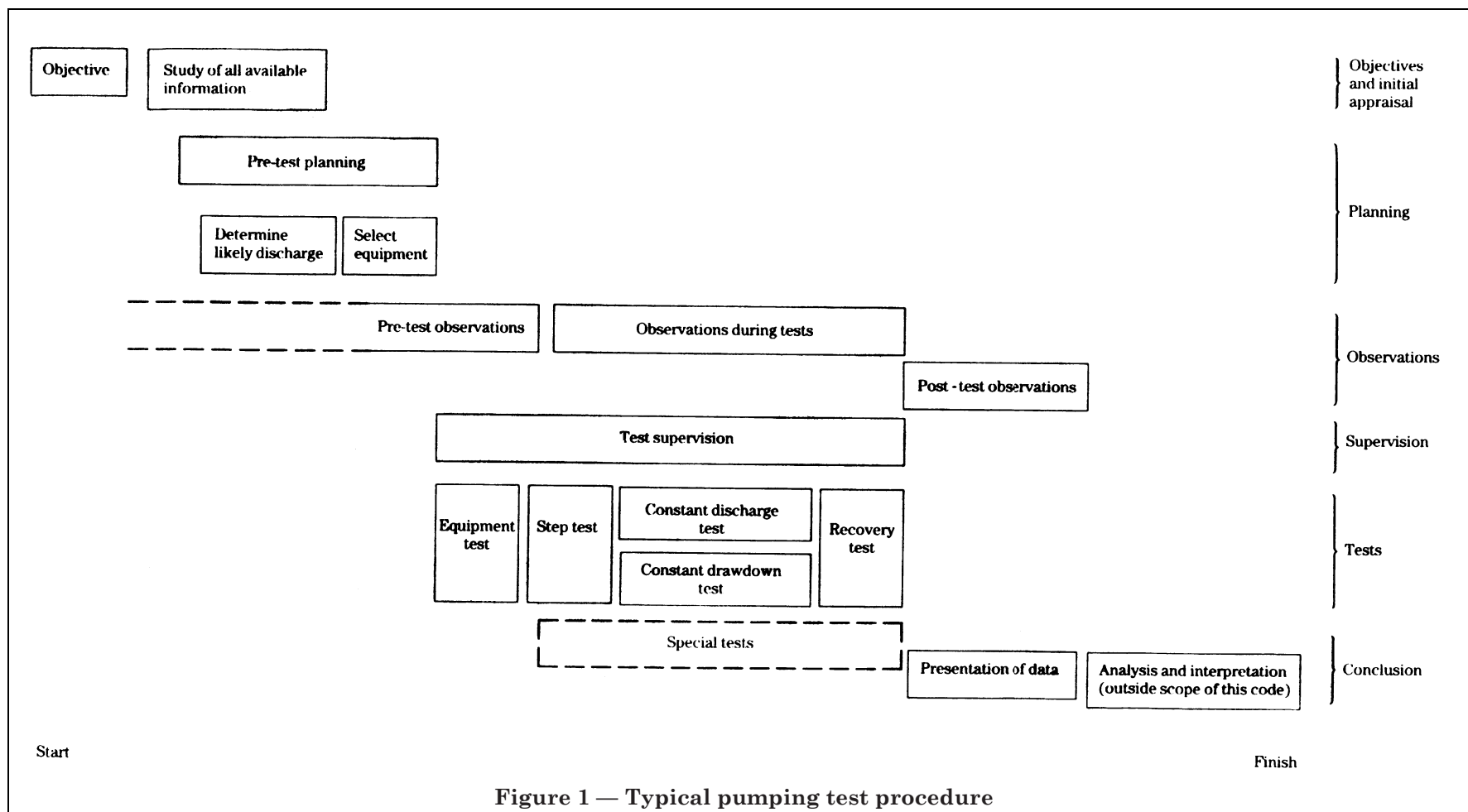


Figure 1 — Typical pumping test procedure

2 Definitions

For the purposes of this British Standard the following definitions apply.

2.1

abstraction

the removal of water from any source, either permanently or temporarily

2.2

access tube

a pipe inserted into a well to permit installation of instruments, and safeguarding them from touching or becoming entangled with the pump or other equipment in the well

2.3

aquifer

a lithological unit, group of lithological units, or part of a lithological unit containing sufficient saturated permeable material to yield significant quantities of water to wells or springs

NOTE It may contain unsaturated permeable material.

2.4

aquifer loss

the head loss at a pumped or overflowing well associated with groundwater flow through the aquifer to the well face

2.5

aquifer properties

the properties of an aquifer that determine its hydraulic behaviour and its response to abstraction

2.6

borehole

a hole, usually vertical, bored to determine ground conditions, for extraction of water or measurement of groundwater level

2.7

casing

a tube used as temporary or permanent lining for a well

2.8

column pipe

that part of the rising main within the well

2.9

cone of depression

that portion of the potentiometric surface that is perceptibly lowered as a result of abstraction of groundwater from a well

2.10

confining bed

a bed or body of impermeable material stratigraphically adjacent to an aquifer and restricting or reducing natural flow of groundwater to or from the aquifer

2.11

discharge

volumetric flow rate

2.12

drawdown

the reduction in static head within the aquifer resulting from abstraction

NOTE See also Appendix A.

2.13

filter pack

granular material introduced into a well between the aquifer and a screen or perforated lining to prevent or control the movement of particles from the aquifer into the well

2.14

steady flow

flow in which parameters such as velocity, pressure, density, and temperature do not vary sufficiently with time to affect the required accuracy of measurement

2.15

uniform flow

flow in which the magnitude and direction of flow at a given moment are constant with respect to distance

2.16

foot valve

a non-return valve fitted at the bottom of a suction pipe of a pump

2.17

groundwater

water within saturation zone

2.18

hydraulic conductivity

the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow

NOTE 1 See also Appendix A.

NOTE 2 This definition assumes an isotropic medium in which the pores are completely filled with water.

2.19

hydraulic gradient

the change in static head per unit of distance in a given direction

2.20**hydrogeology**

the study of subsurface water in its geological context

2.21**impermeable material**

material that does not permit water to move through it at perceptible rates under the hydraulic gradients normally present

2.22**incompetent stratum**

a stratum unable to stand without support

2.23**isotropic**

having the same properties in all directions

2.24**lining**

a tube or wall used to support the sides of a well, and sometimes to prevent the entry of water

2.25**lining tube**

a preformed tube used as the lining for a well

NOTE See also casing (defined in 2.7) and screen (defined in 2.38).

2.26**lithology**

the physical character and mineralogical composition that gives rise to the appearance and properties of a rock

2.27**observation well**

a well used for observing groundwater head or quality

2.28**overflowing well**

a well from which groundwater is discharged at the ground surface without the aid of pumping

NOTE A deprecated term for this definition is an artesian well.

2.29**permeability**

the characteristic of a material that determines the rate at which fluids pass through it under the influence of differential pressure

2.30**permeable material**

material that permits water to move through it at perceptible rates under the hydraulic gradients normally present

2.31**phreatic surface**

the upper boundary of an unconfined groundwater body, at which the water pressure is equal to atmospheric

2.32**potentiometric surface**

the surface that represents the static head of groundwater

2.33**radius of influence**

the radius of the cone of depression

2.34**rising main**

the pipe carrying water from within a well to a point of discharge

2.35**rock**

a natural mass of one or more minerals that may be consolidated or loose (excluding top soil)

2.36**running plot**

a graph of a variable against elapsed time continually updated as measurements are taken

2.37**saturated zone**

that part of an aquifer, normally beneath the deepest water table, in which ideally all voids are filled with water under pressure greater than atmospheric

2.38**screen**

a type of lining tube, with apertures designed to permit the flow of water into a well while preventing the entry of aquifer or filter pack material

2.39**slurry**

the mixture of fluid and rock fragments formed when drilling or developing a borehole

2.40**specific capacity**

the rate of discharge of water from the well divided by the drawdown within the well

2.41**specific yield**

the ratio of the volume of water yielded by unit volume of permeable rock or soil when drained by gravity under specified conditions after being saturated to unit volume

2.42**static head**

the height, relative to an arbitrary reference level, of a column of water that can be supported by the static pressure at a given point

2.43**storage coefficient**

the ratio of the volume of water that a vertical column of an aquifer of unit cross-sectional area releases from storage as the head within the column declines unit distance to unit volume

2.44**transmissivity**

the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the saturated aquifer under a unit hydraulic gradient

2.45**unconsolidated rock**

rock that lacks natural cementation

2.46**unsaturated zone**

that part of an aquifer between the land surface and the deepest water table

2.47**viscosity**

the property of a fluid whereby it tends, within itself, to resist relative motion

NOTE See also Appendix A.

2.48**water table**

the surface of a groundwater body at which the water pressure is atmospheric

2.49**well**

a hole sunk into the ground for abstraction of water or for observation purposes

NOTE See also Appendix B.

2.50**well development**

the physical and chemical treatment of a well to achieve minimum resistance to movement of water between well and aquifer

2.51**well efficiency**

a measure of the performance of a production well

2.52**well loss**

the head loss resulting from flow of groundwater across the well face, including any part of the aquifer affected by drilling, and any filter pack or lining tube, into the well and up or down the well to the pump

Section 2. Hydrogeological considerations

3 General

Before a pumping test is planned a full assessment of the hydrogeological conditions at and around the test site should be carried out. Relevant information can be obtained from the regional offices of the responsible statutory bodies, such as the National Rivers Authority or the River Purification Boards in Scotland, or from the National Well record collection of the British Geological Survey. A survey of existing wells is necessary and, in areas where the hydrogeological data are inadequate, it may be desirable to expand these by a field survey.

Because of the wide range of circumstances in which pumping tests might be contemplated, and the probability that the aquifer will be partly and perhaps nearly fully developed already, a search for and analysis of existing borehole operational and test data and associated surface water levels and flows should be considered as prerequisites to such tests.

4 Aquifer response characteristics

Two parameters define the quantitative hydrogeological properties of an aquifer, namely permeability and storage. Permeability is concerned with the ability of an aquifer to permit groundwater flow under a hydraulic gradient. Storage concerns the volume of water available within the aquifer and subsequently released when water levels are depressed around a discharging well. Together these two parameters can be taken to control the response time for pumping effects in an aquifer. With a low permeability and a large storage coefficient, the radius of influence will increase slowly. An aquifer with a high permeability and a small storage coefficient would exhibit a rapid increase in the growth of the radius of influence.

A consideration of the aquifer response time is necessary when locating sites for observation wells.

5 Groundwater conditions (see also Appendix C)

The storage coefficient in a confined aquifer may be at least 100 times less than in the same aquifer in an unconfined state. This reduction is reflected in a much more rapid aquifer response time.

When the confining bed is not wholly impermeable the storage coefficient varies between the totally unconfined and the totally confined values and the aquifer response time will vary accordingly.

The presence of overlying impermeable strata does not necessarily imply a confined aquifer. The presence of an unsaturated zone beneath an impermeable stratum may permit the aquifer to demonstrate an unconfined response.

It is possible for confined and unconfined conditions to occur in different parts of the same aquifer, or in the same part of the aquifer, as a result of seasonal or other movements of the potentiometric surface.

6 Multi-layered aquifers

Most aquifers comprise sedimentary strata and these are deposited as a series of superimposed layers. Successive layers could have different lithological characteristics from the adjacent layers and consequently the hydraulic conductivity in the horizontal plane tends to be greater than that in the vertical plane. In extreme cases intervening layers may be impermeable resulting in a multi-layered aquifer. Wells penetrating such an aquifer may intersect an unconfined layer near the surface and one or more confined layers at depth. Failure to recognize this possibility may lead to inadequate monitoring of groundwater levels and to misleading data being obtained in a pumping test.

7 Boundary conditions

Barrier boundaries are normally presented by geological discontinuities caused by faulting-out of the aquifer or by the aquifer itself having a rapid diminution in thickness or saturated thickness. Occasionally aquifers show a rapid, lateral, lithological change with a consequent severe reduction in the aquifer properties. Deep channels scoured in an aquifer and later filled with impermeable deposits may also form barriers. Barrier boundaries have the effect of increasing the drawdown. The pumping of another well in the same aquifer will have the same effect as a boundary if the cones of influence of the two wells intersect.

Recharge boundaries occur when water other than from groundwater storage effectively contributes to an aquifer drawn on by a pumping well. Such boundaries may be provided by surface watercourses, by lakes, or by the sea when these lie within the radius of influence of the well.

All these may be regarded as discrete recharge boundaries and often are definable as point or line recharge sources for the purpose of analysis. Recharge boundaries have the effect of decreasing the rate of drawdown, or checking the drawdown altogether. Downward leakage from overlying strata or the interception of natural flow through the aquifer may simulate a recharge boundary by decelerating the drawdown, but the effects cannot necessarily be identified with a localized source.

8 Other hydrogeological factors

There are several factors which may significantly affect the analysis of pumping test data although they may not affect the test itself.

The thickness of the aquifer should be ascertained, at least approximately. Corrections are necessary in the analysis for partial penetration by the pumping wells. The degree of penetration of the observation wells is also important to ensure the measurement of realistic water levels.

Unconfined aquifers may demonstrate the phenomenon of delayed yield from storage. The rate of drawdown during the early stages of the test may be temporarily reduced for a period ranging from an hour to several weeks before turning to a more normal rate of drawdown. It may be necessary in these circumstances to prolong the pumping test to obtain sufficient drawdown data after the effects of the delayed yield have ceased.

During the period of a pumping test in a confined aquifer water levels in the pumping well, and possibly in the observation wells, may fall below the confining bed. If this possibility exists, the depth of the base of the confining bed needs to be determined in all the wells to permit proper analysis of the test data.

Section 3. Pre-test planning

9 Statutory requirements

Attention is drawn to Acts, Byelaws, Regulations and any other statutory requirements relating to matters dealt with in this code of practice. Work should be carried out in accordance with, and the equipment in use should comply with, the appropriate regulations. Amongst others particular attention is drawn to the following provisions current in the United Kingdom at the date of publication of this code of practice:

- a) Public Utilities Street Works Act 1950;
- b) Rivers (Prevention of Pollution) (Scotland) Act 1951;
- c) The Construction (General Provisions) Regulations 1961;
- d) The Construction (Lifting Operations) Regulations 1961;
- e) The Construction (Working Places) Regulations 1966;
- f) The Construction (Health and Welfare) Regulations 1966;
- g) Health and Safety at Work etc. Act 1974;
- h) Control of Pollution Act 1974;
- i) Water (Scotland) Act 1980;
- j) Water Act 1989;
- k) Environmental Protection Act 1990;
- l) Water Resources Act 1991;
- m) National Heritage (Scotland) Act 1991.

Sites within designated areas such as national parks, areas of outstanding natural beauty, areas of special scientific interest, etc., or those close to or within residential areas may have special constraints imposed on test operations, and these should be ascertained before any drilling or test pumping operations commence.

Persons planning to sink and/or test pump a well are advised to discuss their proposals in advance with appropriate regulatory authorities. Unless specifically exempted by the regulations, it is essential that they ensure that procedures for obtaining permissions or consents are followed before any works are carried out.

10 Site facilities and organization

10.1 General

Guidance is given on general matters which affect the organization and activities of the test pumping site. The actual details will vary from site to site and may include matters not described in this clause which therefore should not be assumed to be exhaustive in its coverage. As well as the recommendations for site facilities and organization, and the requirements of the provisions listed in clause 9, the following publications offer guidance pertinent to test pumping activities:

- a) *Code of safe drilling practice: Part 1 Surface drilling*¹;
- b) National Joint Council Health and Safety Commission for the Water Industry Guidance NOTE *Health and safety at work*²;
- c) *Safety in wells and boreholes* (1972)³;
- d) BS 5573.

Before any drilling or test pumping commences a preliminary survey should be carried out bearing in mind these recommendations for site facilities and organization.

10.2 Space and headroom

At the outset it is necessary to ensure that sufficient space is available for any test equipment and pumping plant required on the site as well as lagoons for disposal of acid sludge, etc., where necessary. Parking space for vehicles should be designated, and overhead obstructions such as power cables, guy lines, trees and so forth should be noted and clearly marked if necessary.

10.3 Safety of personnel on site

Every care should be taken to reduce the risks to personnel working at the test pumping site. First aid kits should be provided on site as a part of the normal safety arrangements and should be additionally equipped with soda for the neutralization of acid when the acid is to be handled during the development of a well; an adequate supply of flowing fresh water should be available for washing acid from the eyes or sluicing it from the skin or clothing.

¹) Available from the British Drilling Association, PO Box 113, Brentwood, Essex CM15 9OS.

²) Available from National Water Council Publications, Queen Anne's Gate, London.

³) Available from the Institution of Civil Engineers, Great George Street, London W1.

Paths between the site hut, the test well, the observation wells, etc. should be clearly marked, as should hazards such as fences, cables, mud pits and spoil heaps. Sites which on initial inspection appear to be firm and dry often degenerate to a slippery morass around the well head. The nature of the ground therefore should be carefully inspected beforehand and if necessary arrangements made to provide duckboards and walkways for the working team.

If the test is prolonged through the hours of darkness adequate lighting should be provided.

The site inspection should have revealed the presence of any overhead electric cables likely to be a hazard. Unless details are already available a check should be made for the presence of any underground electric cables or other services under the site, such as gas mains, telecommunication cables, etc., and the route of these should be temporarily marked. In the case of overhead cables a vehicle route beneath them should be established and clearly marked giving also the minimum overhead clearance.

NOTE 1 Additional safety advice on the danger from overhead electricity lines and underground cables is given in Guidance Note GS6 *Avoidance of danger from overhead electric lines* published by the Health and Safety Executive⁴⁾ and in the booklet *Recommendations on the avoidance of danger from underground electricity cables* published by the National Joint Utilities Group of British Telecom, the Electricity Council, British Gas and the National Water Council.

NOTE 2 The presence of either overhead or underground power lines may also affect certain types of electronic equipment, notably pH and ion-selective meters and down-hole logging equipment.

10.4 Utility services

If electrically powered equipment is to be used, the possibility of making available a supply from the mains will need to be investigated. This should be done well ahead of mobilization to site since a temporary incoming switchboard and metering point will be required and the precise requirements for this are likely to vary between different electricity supply authorities. At the same time earthing arrangements should be settled. In many cases the supply authorities will be able to provide an earth terminal either from a continuous earth wire system or from a protective multiple earthing system. It is important to ascertain which form of earthing any electricity supply authority will provide as the requirements imposed on the customer are different (see the IEE Regulations for Electrical Installations)⁵⁾. If there is any doubt about the mains earthing arrangements it is essential to provide an earth leakage circuit breaker of suitable capacity.

If a mains supply is not available it will be necessary to supply a generator of suitable capacity (see 13.3). In this case electrical earthing requirements can be met by cross bonding the lifting rig, pump pipework and generator and providing an earth probe. The earth loop impedance of the complete system should not be greater than 2Ω .

All electrical installations on the site should comply with the requirements and recommendations of the IEE Regulations for Electrical Installations and CP 1017 as appropriate. Surface power cables between generator and well head should be armoured. Flexible braid armoured cable is more suitable and easier to handle in this application than single wire armoured cable. Single wire armoured cable should comply with BS 6346. A watertight emergency stop lock-out button should be mounted within easy reach.

Special tests, such as certain types of packer test, will require a water supply. Constraints may be applied on the type of water to be used; tankers may be required, and possibly storage on site arranged. If the site is residential it will be necessary to provide a supply of potable water as well as water for general use. Where this is provided in containers these should be marked to distinguish potable from non-potable water.

If a telephone is required, it should be installed prior to the test commencing.

⁴⁾ Available from HMSO.

⁵⁾ Available from the Institution of Electrical Engineers, Savoy Place, London WC2R 0BL.

10.5 Site accommodation

A suitable hut or shelter should be erected upon the site, adequately lit and, if necessary, heated. Such accommodation should include tables and seating for the partaking of meals and facilities for boiling water and heating food.

The accommodation should be sufficiently secure to store first aid and fire-fighting equipment, test equipment, records, etc. If the test is to continue for one or more nights, sleeping accommodation should be arranged for off-duty personnel.

Latrines and washing facilities should be made available on site; if the operation is of a long term nature, consideration should be given to the provision of shower facilities.

10.6 Site communications

Signalling between the observation and pumping wells during the test can be carried out by visual or audible means, appropriate to the circumstances, e.g. by radio. Under some conditions visual signals may be inadequate.

10.7 Avoidance of pollution and disposal of wastes

Care should be taken to dispose of liquid or solid wastes carefully and safely and in a manner that will not pollute the wells or the surrounding area. If it is not possible to dispose of contaminated waste water directly into the sewerage system it should be collected and removed from site for treatment and disposal. Disposal of contaminated waste waters to a soakaway, albeit remote from the well head, ditches and watercourses, should not be undertaken without the consent of the regulatory authority. Solid wastes should be removed from the site for disposal at a licensed waste facility.

If an internal combustion engine is to be employed, either for power supply or direct drive, precautions should be taken to ensure that any oil or fuel spillages are contained. This point needs particular attention when an internal combustion engine is connected through a right angle gearbox to a long shaft turbine pump at the well head. The engine should be mounted on a firm platform with means to ensure that any fuel or oil spillage can be contained. Adequate storage of fuel will also need to be provided with suitable precautions taken against leakage and fire.

In addition to the prevention of pollution by oil and fuel, precautions should be taken to prevent the well being infected by pathogenic and non-pathogenic organisms. The most likely source of pathogenic organisms is from latrine accommodation which should therefore be sited as far as possible from the well. Sterilization of any equipment to be placed in the well will reduce the risk of introducing infections from other sources (see 10.10).

10.8 Disposal of pumped discharge

Arrangements should be made for the disposal of the pumped discharge, including any pipelines required. Ideally, the discharge point should be such as to exclude any possibility of recharge occurring of the abstracted water into the aquifer. The location of the discharge point should be cleared with the local authorities, landowners, and the National Rivers Authority (NRA). In many cases, discharge of turbid water into water courses will not be permitted so early advice should be sought from the regional NRA office. It should be noted that in wooded or forested areas, particularly with regard to coniferous trees, soakway disposal is undesirable because weakening of the root structure and consequent possible wind damage may result. In some cases the quantities of pumped discharge involved may make it impractical to use lagoons or soakway disposal for anything but the first small quantities of slurry or acid residue from the borehole. Discharges into watercourses should be so directed that scouring of the bed and banks does not occur.

10.9 Noise

Continuous noise can be exhausting and have a deadening effect on the reactions of personnel. This therefore is an important consideration in the location and silencing of any internal combustion engine employed. There is added significance when the site is located near permanent habitation where noise nuisance during the night may be unacceptable. Special arrangements should therefore be made for damping engine noise by the use of sound deadening enclosures around internal combustion engines, by using "super-silenced" plant or by the use of baffle screens, e.g. a wall of straw bales. Additional general guidance on the avoidance of problems associated with noise from surface sites may be found in BS 5228 and in the Health and Safety Executive publication *Code of practice for reducing the exposure of employed persons to noise*⁶⁾.

⁶⁾ Available from HMSO, 49 High Holborn, London WC1 for personal callers, or by post from HMSO, PO Box 276, London SW8 5DT.

10.10 Maintenance and storage of equipment

Structures, plant, machinery and test and measuring equipment should be inspected at regular intervals in accordance with the manufacturer's recommendations. In the case of plant which is subject to corrosion, steps should be taken to effect repairs before corrosion reaches dangerous limits.

Electrically operated hand tools and lamps, together with leads and earth wires, should be inspected at regular intervals to ensure that they have been maintained in good order and such inspections should be recorded. Trailing cables, except for hand lamps and small portable tools, should comply with BS 6708. Pliable armoured cables are preferred.

It is recommended that equipment is sterilized before installation in the well, in order to avoid introducing any infection resulting from the previous use of the pump and column pipe in an infected well. The simplest method is immersion in a 1 % solution of sodium hypochlorite by volume. Phenolic agents should not be used to sterilize pumping equipment. Subsequent storage and handling of the pumping equipment should be such as to avoid the introduction of any polluting material into the wells.

11 Design of the test

11.1 General considerations

The pumping test should be designed keeping in mind the objectives stated in the introduction and taking into account also the hydrogeological conditions of the site and the methods by which the results are to be analysed. A systematic approach ensures that the maximum information will be learned about both the well and the aquifer. Such an approach requires close control of the design and running of the test, but this can be achieved with little or no additional expense. It should be appreciated that the test is a scientific exercise providing a good database both for the aquifer and the abstraction of water therefrom.

Five types of pumping test may be considered as applicable. These are the equipment test, the step test, the constant discharge test, the constant drawdown test and the recovery test. The equipment test is carried out to check that the equipment is fully functional and to guide the operator with regard to obtaining suitable valve settings for the tests. In the main the step test provides information on the well hydraulics. The constant discharge and constant drawdown tests provide information on the aquifer properties.

11.2 Equipment test

The equipment test provides a check that the pumping equipment, discharge measuring devices and water level measuring instruments are functioning satisfactorily, and that all the equipment is in a safe condition with all safety devices fully functional. It will also give sufficient data for planning the tests in 11.3 to 11.5, including data with which to determine appropriate values for valve settings for subsequent pumping tests.

11.3 Step test

The purpose of a step test is to establish short term yield-drawdown relationships and thereby define those elements of head loss attributable to laminar flow and those attributable to turbulent flow. The step test comprises pumping the well in a series of steps, each of which is at a different discharge rate. At least four steps are advisable, and the final discharge rate should approach the estimated maximum yield of the well. If the latter cannot be attained then the maximum capacity of the pump should be substituted. Care should be taken to avoid excessive drawdown as this could result in the pump running dry and so being damaged.

The steps may be taken consecutively, the pumping rate being changed at the end of each step, or intermittently, pumping being stopped after each step to permit groundwater levels to recover before commencing the next step. In consecutive steps the pumping rate should be either increased in equal increments from the first to the last step, or decreased in equal decrements from the first to the last step. The latter is less usual. In intermittent steps the pumping rate may be changed at random, the resultant data being analysed as a series of discrete tests.

Normally each of the steps should be of equal duration. It is rarely necessary for each step to last for more than 2 h but it is often convenient, both operationally and for plotting graphs, etc. for each step to last 100 min.

Where observation wells are present groundwater level measurements should be taken in them in addition to the pumping well. Observation wells are not necessary in the analysis of well performance but some indication will be given of the range of groundwater level fluctuation that will be produced in a test of longer duration.

11.4 Constant discharge test

Constant discharge tests are carried out by pumping at a constant rate for a period of time dictated by the discharge rate and the local hydrogeological conditions. The purpose of a constant discharge test is to obtain data on the hydraulic characteristics of an aquifer within the radius of influence of the pumped well. Observation wells are necessary in order to determine fully the aquifer properties. Table 1 gives the minimum durations that should be allowed for constant discharge tests. In certain situations, such as those described in this subclause, in clause 8 and in 11.7, increases or decreases to these periods will be appropriate.

Table 1 — Minimum duration of constant discharge tests

Discharge rate	Minimum duration of constant discharge
m ³ /day	days (of 24 h constant discharge)
Up to 500	1
500 to 1 000	2
1 000 to 3 000	4
3 000 to 5 000	7
Over 5 000	10

The effect of a recharge boundary (see clause 7) is a deceleration in the rate of drawdown. Where the recharge source is a specific feature, such as a watercourse or a lake, the elapsed time before the onset of this deceleration will increase in proportion to the square of the distance between the pumping well and the recharge source. Eventually drawdown will stabilize for the remainder of the test.

If a delayed yield effect (see clause 8) occurs the development of the time-drawdown relationship will be delayed. It is not possible to estimate accurately in advance the length of this delay unless it has occurred in nearby wells previously tested in the same aquifer. If a delayed yield is expected an extension of the duration of the test should be considered.

Barrier boundaries (see clause 7) have the effect of accelerating the rate of drawdown and present a serious constraint on the yield of the well. The shorter periods given in Table 1 may therefore require extending by one or two days to observe the effects adequately, particularly if they appear towards the end of the period as initially specified.

11.5 Constant drawdown test

A constant drawdown test⁷⁾ may have the same purpose as a constant discharge test. In theory constant drawdown tests can be performed upon any aquifer, providing that a pump with a variable discharge rate can be controlled in such a manner as to keep the drawdown to a particular constant amount. If the groundwater rest level is not expected to vary during the test period then the constant drawdown is at a constant level, otherwise it is essential that the levels in control observation wells be used to estimate the pumping level needed to maintain constant drawdown.

Constant drawdown tests are used for tests with suction pumps, for design of dewatering schemes, for overflowing wells, for tests in piezometers and for tests using over capacity pumps.

In a well which is not overflowing the test should be carried out in the same manner as a constant discharge test, except that the discharge rate should be controlled so as to keep the drawdown constant. Particularly accurate measurement of the discharge rate is necessary.

In a well which is overflowing no pumping is necessary. The procedure is to shut off the flow at the well head, and then to measure the head of water thus contained. The well is then uncapped as near instantaneously as possible, thus reducing the head to near well head level. The discharge rate is then measured at the frequency recommended for a constant discharge rate. The advantage of this type of test is that no pumping plant is required. Estimates for transmissivity, and crude estimates of the storage coefficient, can be made without use of observation wells but such estimates are no more valid than similar estimates made without observation wells during conventional pumping tests.

The minimum duration of the test should be sufficient for the discharge to reduce to about 1 % of the initial rate.

NOTE The minimum duration cannot be the same as for a constant discharge test (see Table 1).

11.6 Recovery test

The recovery test can be carried out upon any aquifer after a constant discharge test or a variable discharge test.

⁷⁾ This is also known as a constant head test.

The recovery test requires careful measurement of the duration and rate of pumped discharge prior to the discharge ceasing. The recovery test can form a useful check on values of transmissivity derived from a discharge test. The specific yield or storage coefficient may be determined less accurately by this means. This is largely due to the incomplete resaturation of the interstices within the aquifer dewatered during the test.

A recovery test dependent upon water levels measured in the test well should only be performed if a foot valve has been fitted to the rising main. This is because, in the absence of such a valve, there tends to be a rapid rise in water level as water surges in from the rising main and perhaps also from the weir tank if used. A recovery test may be performed using only water level data obtained from observation wells if the rising main in the test well is not fitted with a foot valve.

11.7 Surface water flow

Abstraction of groundwater will have an effect upon the natural discharge of water at the surface. Spring and stream flow depletion is often a major factor to consider during a programme of test pumping groundwater, particularly if the proposed discharge is high. The feasibility of a study of this kind will depend upon the accuracy of estimating the difference between the flow measured during the test and the flow that would have occurred if the abstraction had not taken place. This in turn will depend upon a number of factors including the scale of the abstraction relative to the surface flow, the distance between the test well and the surface flow, the point of discharge of the abstracted water and the accuracy and frequency of the surface flow measurement. In favourable conditions the effects may be observable within a few days. This is not commonly the case; it is more usual for the test to have to last at least 2 weeks and in some cases 12 weeks or more in order to permit satisfactory analysis of the surface water flows. This is particularly the case when recirculation occurs with groundwater being discharged to a river and induced recharge taking place from the same river into the pumped aquifer. It will be necessary also to consider the timing of the test in relation to the normal seasonal variations in surface water flow and the impact of climatic changes.

12 Observation wells

12.1 Purpose and characteristics of observation wells

In a constant discharge test observation wells are necessary for the accurate determination of the properties of transmissivity and storage coefficient of the aquifer. The value of the transmissivity is obtained by a study of the shape of the cone of depression which is indicated by water levels in the observation wells surrounding the pumping well. Existing wells should be used if their dimensions and locations are suitable. In other cases observation wells may need to be constructed before the test takes place. Additionally, as part of the test pumping consent requirements, existing wells within a specified distance of the test well may need to be monitored.

The time taken for the drawdown to affect the observation wells is proportional to their distance from the pumped well. Once drawdown commences at any point it may be rapid, irrespective of the radial distance from the test well. The magnitude of the drawdown is attenuated in proportion to the square of the distance from the pumped well.

12.2 Number and location of purpose-drilled observation wells

Preliminary calculations using estimated transmissivities, e.g. estimated from existing borehole data, should be made to indicate the likely response in observation wells to pumping and hence to determine their spacing from the test well and the timing of the observations.

Ideally the minimum number of observation wells is four, arranged in two rows at right angles to each other, but in most instances one to two observation wells will suffice. When a number of observation wells is required their distances from the test well should approximate to a geometrical series. Based simply on the response and the state of the aquifer the spacings in Table 2 are a guide to the most favourable spacing of the closest of the observation wells. A spacing of less than 10 m from the test well is undesirable, the data obtained from closer distances presenting difficulty in analysis.

Attention should be paid to boundary conditions which may affect the location (see clause 7). The distance from the test well may need to be reduced if the boundary is in close proximity.

12.3 Depth of observation wells

Ideally observation wells should be constructed to the same stratigraphic level as the test well. In certain cases however, in order to investigate particular localized phenomena, they may be drilled to a shallower depth than the test well.

In multi-layered aquifers inaccuracies will arise where observation wells penetrate only the uppermost layer or layers. The options available in this case are to drill one of the following:

- a) a single observation well to the full depth of the test well and to install piezometers against each aquifer level;
- b) a number of observation wells to different levels, lining out all levels except one in each well;
- c) a single observation well open to the same stratigraphic levels as in the production well.

Unless an extensive analysis is to be performed, 12.3 c) should give reasonable results.

12.4 Observation well design

Where observation wells are not to be fitted with instruments using floats or transducers, and water sampling is not to be undertaken, a large internal diameter is not necessary. A sufficient guide is for the internal diameter of the completed well to be three times the diameter of the probe on the dipper. Sensitive continuous recording equipment is needed to discriminate between drawdown and other effects on water level in distant observation wells. The justification for automatic equipment in observation wells relatively close to the pumping well is reduced if the test is of only a few days' duration. In this case manual or visual water level recording should be adequate.

Where a means of automatic water level measurement is used the installation and operation should be in accordance with the instructions of the manufacturer in every respect.

The usual size of recorder float used in observation wells is between 75 mm and 115 mm. Where steel lining tubes are used, and the depth to water level does not exceed 30 m (at full drawdown), an internal diameter of 150 mm is sufficient. Where the depth to water level is greater than 30 m, an internal diameter of 200 mm is advisable since this reduces the possibility of the float and cable catching on the lining wall and producing steps or "jumps" on the time-drawdown curve. If internally smooth thermoplastics or glass reinforced plastics lining tubes are used, a minimum internal diameter of 200 mm should be used. This is because there may be difficulty in maintaining sufficient verticality in a narrower lining tube to avoid fouling the float cable. Transducers can be of smaller diameter than floats and, since they do not travel continuously up and down the well, the diameter of the well need be sufficient only to contain the instrument.

Lining tubes should be carried down, if possible, to 2 m below the maximum expected depression of the water level. Floats tend to catch on the bare aquifer walls and may be lost if they catch on the end of the lining tubes when being withdrawn.

If screens are fitted a minimum of 5 % open area should be ensured to minimize lag between change of water level in the aquifer and that in the observation well. The type of screen is relatively unimportant.

If instruments are being inserted into an existing well these recommendations and those in Appendix D should be taken into account.

12.5 Drilling methods

The method by which an observation well is drilled should be recorded. The use of non-degradable drilling fluids such as bentonite mud should be avoided and development of the completed well should be undertaken to ensure the maximum hydraulic continuity between the well and the aquifer (see Appendix E). This is particularly important in wells penetrating clay or chalk where the slurry may make an effective seal. When existing wells are used for observation purposes, the drilling method used for their construction should be considered and appropriate development undertaken.

13 Test well

13.1 General

The four basic objectives in correctly designing a test well are to facilitate the entry of groundwater into the well and the operation of pumping equipment, the collection of data from within the well and the measurement of pumped discharge.

13.2 Groundwater entry into the well

The design of the well should enable free entry of water from the aquifer but preclude entry of aquifer particles, and also needs to ensure that the well does not collapse and that the yield does not decrease over the long term.

The depth of the well needs to be adequate to penetrate sufficient saturated aquifer to provide the required yield without the drawdown becoming excessive. In the analysis and reporting of the test pumping it should be recognized that the measured transmissivity will probably relate only to that thickness of the aquifer which is screened or open in the test and observation wells.

The well construction should be such as to contain the pump and column pipe and any additional equipment required in the well. The diameter should also be sufficient to prevent restriction of flow to the pump.

Table 2 — Location of observation wells

Aquifer state	Transmissivity	Measurable response	Typical lithology	Spacing from test well
	m ² /day			m
Unconfined	50 to 500	Slow	Unfissured sandstone	25 to 35
Unconfined	Over 500	Fast	Fissured limestone	45 to 60
Confined	50 to 500	Slow	Unfissured sandstone	60 to 100
Confined	Over 500	Fast	Fissured limestone	10 to 200

In all wells it is essential that a sufficient length of plain lining tube is emplaced to prevent the ingress of surface water and soil water as well as to guard against collapse of the well in the zone of loose, weathered strata usually present close to the ground surface. The casing should be carried to greater depth if certain aquifers are to be excluded or if incompetent strata, such as soft clay, are penetrated.

In unconsolidated intergranular aquifers, screens are necessary to prevent collapse of the well and to permit groundwater entry. Filter packs around the screen are usually essential and may be either artificial packs of a uniform or graded type, or natural packs developed in situ from the aquifer.

13.3 Pumping equipment

One objective of the pumping test is to determine the type of pump suitable for permanent use in the well. The test pump may require a wide range of operative yields although some indication of the probable range required should be available from other wells in the same locality. The fact that a test pump is operating at less than the optimum efficiency is of little significance except in very prolonged tests.

It is advisable to avoid using the pump destined for permanent duty in the well since test pumping is a demanding and often abrasive duty. If the test programme calls for a wide range of discharge volume there is a possibility that an electrically driven submersible pump may overload at the extremes of the range. There is also excessive end thrust under “nearly closed” valve conditions (see 23.2) which may give rise to thrust bearing failure if the condition is prolonged. This would be minimized by using a variable speed drive. It is recommended that the pump capacity is sufficient to allow a discharge of up to 25 % more than the required yield of the well for normal duty. The selection of a suitable capacity pump is discussed further in Appendix F. The pump should be installed as low as possible, so that maximum drawdown of water level is available to determine well capacity, but sufficient space should be left underneath the pump to allow the settlement of any sediment and so avoid any risk of blockage of the pump. To protect the pump from dry running the pumping water level should always be kept a few metres above the pump suction level.

Wherever possible the pump should be positioned within the lined section of the well. In all cases the pump should be so placed as to avoid damage to the well screen or the collapse of an open well during the pump’s installation or operation.

The rising main needs to be of sufficient diameter to enable the maximum yield required to pass without undue head loss.

It is recommended that the rising main is fitted with a non-return valve (see Figure 2). This may be either positioned at the bottom of the column pipe or mounted on the surface. The first is the recommended arrangement, the foot valve being located in the discharge of a submersible pump or on the suction of a spindle pump, and if recovery levels are to be measured in the test well after completion of pumping, a non-return valve at the foot of the column pipe is essential.