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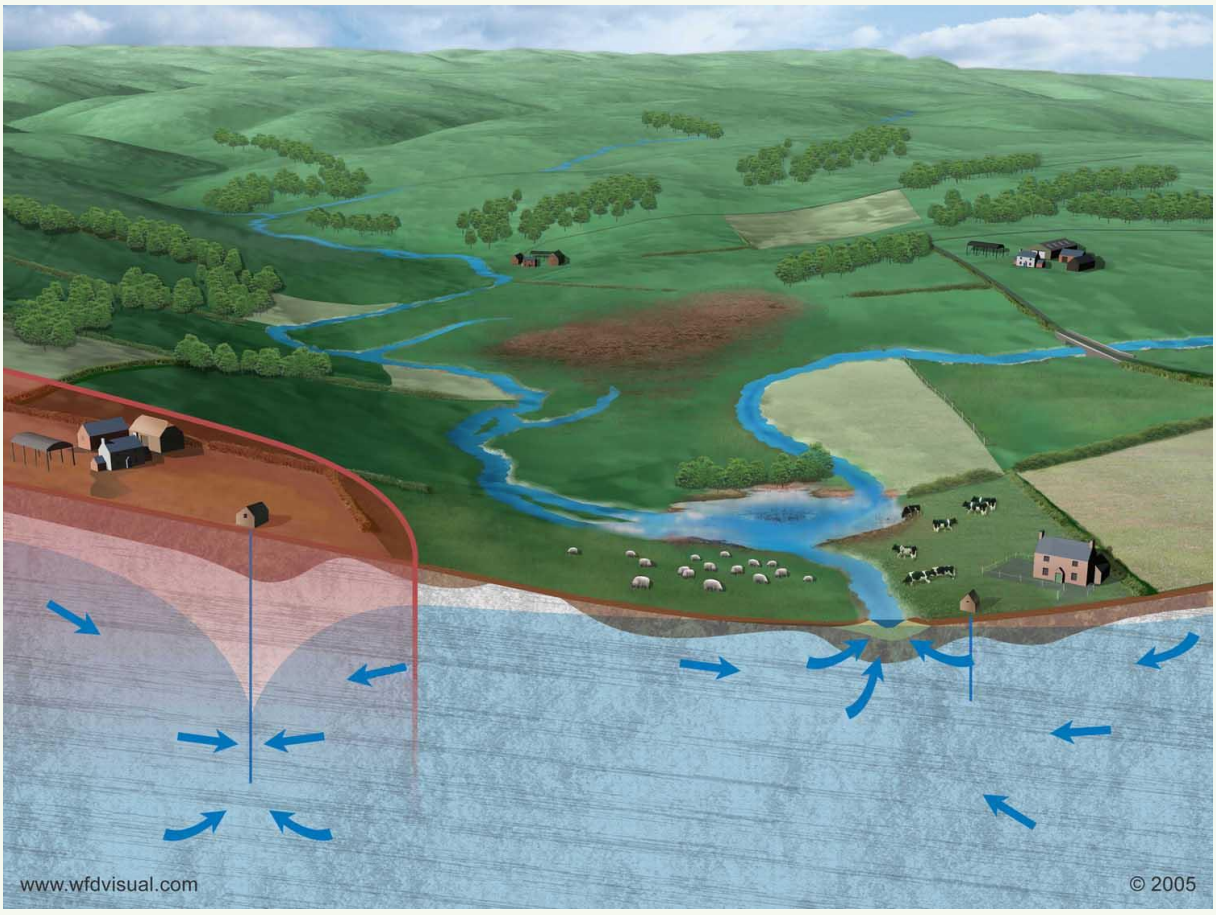
Environment Agency

AQUIFER CHARACTERISATION

MODULE HANDBOOK



Course Number T505

AQUIFER CHARACTERISATION

Module Handbook	Course T505

Overall aim

This module aims to provide the student with an understanding of the occurrence of groundwater in different geological environments, and of the methods used to determine the hydraulic properties of Earth materials *in-situ*.

Assessable learning outcomes

By the end of the module it is expected that students will be able to:

- describe in outline the characteristics of the major aquifers of England and Wales and the importance of groundwater in national water supply;
- understand the significance of aquifer boundaries and their effect on groundwater movement, recharge processes, and methods of estimating recharge;
- describe the basic techniques of downhole geophysical logging, and undertake simple interpretations;
- describe and plan different types of pumping test;
- describe the principal types of aquifer configuration – confined, leaky, unconfined and bounded – and understand and be able to select and use the appropriate method of aquifer-test analysis.

In addition, students will enhance their mathematical, analytical and group-working skills.

Whom is this module for?

This module is aimed at Environment Agency staff whose role requires them (or may in future require them) to have an understanding of the characteristics of different types of aquifer, and to evaluate and interpret the results of pumping tests, geophysical logging, and other methods of aquifer characterisation. This may be in connection with a wide variety of activities, including the following:

- Processing of applications for groundwater investigation consents and groundwater abstraction licences.
- Evaluation of technical reports by applicants or their consultants, on subjects such as environmental impact assessment of groundwater abstraction.
- Undertaking or reviewing 'appropriate assessments' under the Habitats Directive.
- Designing and interpreting contaminated land site investigation programmes.
- Processing of applications and evaluation of technical reports on landfill and waste disposal issues.

Context of the module

This module forms part of a developing programme for training staff of the Environment Agency to Masters level. This flexible programme provides Environment Agency staff with opportunities for training that is tailored to their career development. The overall objectives of the programme are to develop:

- fundamental knowledge and skills required by technical staff
- the confidence that comes from having applied that knowledge to solve problems
- the self-assurance gained from being taught by and having talked with people who are acknowledged experts in their fields
- a knowledge of sources of information, combined with an appreciation of when additional information is likely to be needed.

Method of delivery and Module Tutors

This module is delivered via contact sessions in two blocks, each of three days (six days in total), comprising lectures, discussion sessions and classroom practicals. Participants are encouraged to bring along for discussion real problems in aquifer characterisation that they have encountered in their work.

The module is supplemented by directed reading and individual work. The module is assessed by an examination (set and marked by the Module Tutors).

The Module Tutor is Dr Michael Price, and some lectures will also be given by Kim Beesley and Dr Rob Low.

The Environment Agency technical contact for this module is Phil Stewart;
email: phil.stewart@environment-agency.gov.uk

How to apply

If you are interested in this course then you will need to discuss this with your Team Leader, and identify this training need within your individual development section of the Learning Zone. To gain the most benefit from this module, ideally all candidates should have successfully completed the Groundwater Hydraulics module (T501).

Time commitment

This module requires a total input of 120 study hours. The breakdown is roughly as follows:

- Lectures and practical work, 48 hours (six days of residential courses).
- Directed learning, 32 hours (pre-course reading and independent learning directed by the Module Tutor).
- Preparation for and completion of a formal examination, 40 hours (assessed by the Module Tutor).

This time commitment needs to be discussed with your Team Leader but it should be noted that you cannot expect all of the time to come from official Environment Agency allocations. It should be noted that due to the intensive nature of the course, students must commit to attending every teaching day as catching up on missed taught material within the necessary timeframe is likely to be impossible.

Pre-course preparation

In order to gain maximum benefit from this module, it is essential that you prepare yourself by undertaking at least the following pre-course activities:

- Depending on how long ago you completed the Groundwater Hydraulics module, revise the content of that module as the foundation for consideration of aquifer characterisation.
- Read and become familiar with:

  Heath R C (1983). *Basic groundwater hydrology*. Water Supply Paper 2220, United States Geological Survey. You should have this document already, from the Groundwater Hydraulics module. Read Pages 34-51.

  Kruseman G P and de Ridder N A (1990). *Analysis and evaluation of pumping test data*. 2nd edition, Wageningen, The Netherlands, International Institute for Land Reclamation and Improvement. Read Chapters 1, 2 and 3.

  Price M (1996). *Introducing groundwater.* 2nd edition, London, Chapman and Hall. Read the section on 'Hydraulic measurements' in Chapter 10 (Measurements and models).

The pre-course activities will be discussed during the introductory session of the first residential course.

Syllabus for residential courses

As already mentioned, the Aquifer Characterisation module is designed to be delivered over six days, in two blocks of three days each. The main topics covered by the module are:

Day 1 The importance of groundwater, introduction to hydrostratigraphy, what happens when aquifers ‘leak’, and the importance of rocks of low permeability.

Day 2 Methods of analysis for different types of pumping test and different aquifer configurations, including real case studies; the synergetic approach to aquifer characterisation; behaviour of sandstones.

Day 3 Methods of analysis for bounded aquifers, recovery tests and step tests. The characteristics of the Chalk and the synergetic approach applied to the Chalk.

Day 4 Basic techniques of downhole geophysical logging; uses, applications, limitations and constraints of logs; data management and logging contracts.

Day 5 Planning and undertaking pumping tests, including an introduction to slug tests, packer tests, recovery tests, step tests, etc. Groundwater origins and travel times, tracer tests.

Day 6 Special considerations of karst; water balances. Pumping and monitoring equipment used in testing.

Students are expected to arrive at the training venue by 9.30 am at the start of each three-day block, so that there can be a prompt start to Days 1 and 4. Also, Days 3 and 6 (the last days of each three-day block) are full teaching days, and students should not expect to be able to leave before 17:00.

The topics will now be described in more detail. In practice, there may be some variation in the order in which topics are covered, partly to break up long periods of lectures with some practical exercises.

You should note that most days involve problem-solving exercises. These are intended to build up into a set of worked examples, which you can refer to along with the course handouts and your own notes, in your Agency work. Any special stationery, such as graph or tracing papers, will be provided, but **you will need to bring pens, pencils, erasers, rulers, and plenty of paper** for notes and problem solving. You will also need **a scientific calculator** and the ability to use it. In addition to the usual arithmetic functions of the calculator, you should make sure that you are familiar with the following:

- powers, roots and reciprocals
- logarithms and antilogarithms (common and to base *e*)
- basic trigonometric functions.

You must also be familiar with the SI system of units and be able to convert quantities (e.g. from km^3 to m^3, from litres to m^3 or from litres/s to m^3/day) quickly and easily.

Attendance Block 1 (3 days)

DAY 1

Main topics for the day:
The importance of groundwater, introduction to hydrostratigraphy, what happens when aquifers 'leak', and the importance of rocks of low permeability.

Session	*Topic*
1	Importance of groundwater to national water resources (showing regional variations in proportions supplied from groundwater and surface water), and the advantages of groundwater over surface water (storage volume, good quality, ease of exploitation etc), with reference to the influence of geology, relief, rainfall and population on water supply. Virtual water.
2	Brief review of Thiem (steady-state), and Theis and Cooper-Jacob (non-equilibrium) methods for confined aquifers.
3	Introduction to hydrostratigraphy (aquifers, aquitards, etc), using a selection of hydrogeological maps as the basis, comparing them with geological maps, illustrating the difference between productive and unproductive units, and how units are grouped or divided.
4	Analysis of tests in leaky aquifers: Walton's method.
5	The importance of minor aquifers and non-aquifers in regional flow systems and groundwater occurrence. Sources of information.
	Rocks of low permeability and their importance as minor aquifers and in delineating groundwater flow systems; problems of characterisation; properties of mudrocks.

Notes: Day 1 is based entirely in the classroom and consists of lectures, map and graphical demonstrations, and practicals. Students will be using paper hydrogeological and geological maps during Session 3 and graphical analysis techniques in Session 4.

DAY 2

Main subjects for the day: Methods of analysis for different types of pumping test and different aquifer configurations, including real case studies; the synergetic approach to aquifer characterisation; behaviour of the Chalk aquifer.

Session	*Topic*
1	Dealing with unconfined aquifers: the problem of delayed yield.
	The Dupuit method applied to steady-state water-table conditions. The Boulton and Neuman approaches to non-equilibrium conditions.
2	Neuman (type-curve) method of analysis for non-equilibrium unconfined conditions. Practical example.
	Cooper-Jacob (straight-line) method of analysis for non-equilibrium unconfined conditions. Practical example.
3	The synergetic (combined) approach to aquifer characterisation (logging, core analysis, packer tests, pumping tests). Behaviour of Permo-Triassic sandstones. A case study from the Penrith Sandstone of the Eden Valley
4	Extent and origin of some sandstone fissures.

Notes: Day 2 is based entirely in the classroom, and consists of a mixture of lectures and practical exercises. The practical exercises in pumping test analysis will be done by plotting data by hand onto graph paper, using rulers and calculators, etc. It is important that students gain a feel for test pumping data and the analysis methods, which is best done in this way.

DAY 3

Main subjects for the day: Methods of analysis for bounded aquifers, recovery tests and step tests. The synergetic approach applied to the sandstones.

Session	*Topic*
1	The concept of image wells in aquifer-test analysis. The use of image wells in dealing with bounded aquifers. Analysis of data sets.
2	Analysis of recovery tests, with a practical example of analysis of the results from a case study.
3	Main hydrogeological characteristics and distribution of the Chalk, concentrating on information that is not readily available in the literature. Influence of Chalk characteristics on water resources and problems of modelling.
4	A case study from the Chalk, involving synergetic approaches and analysis of an unconfined pumping test.
5	Components of drawdown in a pumped well. The use of step tests to define borehole performance curves (drawdown against discharge), and changes in borehole performance over time. Analysis of step tests using the Hantush-Bierschenk method (including a discussion of the debate on well losses, aquifer losses and well efficiency). Skin effect and effective well radius. Real examples and some of the difficulties of interpretation.

Notes: Day 3 is based entirely in the classroom, and consists of a mixture of lectures and practical exercises. As with Day 2, the practical exercises in pumping test analysis will be done by plotting data by hand onto graph paper.

Independent Learning 1

In between the first and second residential courses, students should if necessary revise the pre-course reading. You should also read and become familiar with:

British Standard BS ISO 14686:2003. *Hydrometric determinations - Pumping tests for water wells – Considerations and guidelines for design, performance and use.* BSi, March 2006. This is the main standard used when specifying pumping tests, and it includes recommendations for the duration of tests, the location of observation wells, and the frequency of water level measurements.

Driscoll F G (1986). *Groundwater and Wells.* 2nd edition, St Paul, MN, Johnson Filtration Systems Inc. Found on the bookshelves of most hydrogeologists, this book gives practical descriptions of all aspects of designing, drilling, developing, test pumping and equipping boreholes and wells. Read Chapter 16 (Collection and analysis of pumping test data).

A third edition of *Groundwater and wells* (edited by Robert J Sterrett) has been published (in 2007) but is less likely to be readily available. In this edition the relevant chapter is Chapter 6, entitled 'Aquifer-test data collection and analysis' (less grammatical but technically more correct!). There are significant differences in the coverage; the new edition has the benefit, among others, of more use of metric units. Copies are available from the National Groundwater Association but the price is $150 plus postage.

Kruseman G P and de Ridder N A (1990). *Analysis and evaluation of pumping test data*. 2nd edition, Wageningen, The Netherlands, International Institute for Land Reclamation and Improvement. Chapters 4, 5, 6, 13 and 14.

Attendance Block 2

DAY 4

Main topics for the day: Basic techniques of downhole geophysical logging, uses, applications, limitations and constraints of logs, data management, and logging contracts.

Session	*Topic*
1	Basic principles of downhole geophysical logging, including fluid logs, formation logs and construction logs.
	Uses and applications of geophysical logging, when to log, preparations, safety and access.
2	Limitations and constraints of different logging methods, including borehole conditions and quality checks.
	Case histories and examples, illustrating different lithologies, flow patterns, groundwater quality and borehole defects.
3	Management of geophysical logging data, including formats, presentation styles, and archiving.
	Ordering geophysical logging, including drawing up specifications and contracts.
4	Case studies of geophysical logs, for group comment and interpretation.

Notes: Day 4 confines itself to *downhole* geophysics, as it is more commonly used in water resources investigations (surface geophysics tending to be used in contaminated land studies). The day is based in the classroom, and largely consists of lectures, case studies and group exercises. There will also be the opportunity to see and handle geophysical logging equipment.

DAY 5

Main topics for the day:
Planning and undertaking pumping tests, including an introduction to slug tests, packer tests, recovery tests, step tests, etc.
Groundwater origins and travel times, tracer tests.

Session	*Topic*
1	Introduction to pumping tests (why they are done, what information is gained from them, what information is *not* gained from them, the importance of stressing the aquifer, etc).
	Descriptions of the main types of pumping test (equipment test, step test, constant discharge test, recovery test).
	Brief descriptions of other types of pumping test (constant drawdown test, slug test, packer test).
2	Designing a pumping test (choice of type of test, pumping rates, length of test, time of year, water features survey, permissions).
	Monitoring and data collection for pumping tests (pre-test monitoring, choice of water features to monitor, design of monitoring network, frequency of taking readings).
3	Origin and age of groundwater (meteoric, connate, juvenile, oceanic waters, with brief review of methods of dating water), plus explanation of time of travel.
4	Tracer tests as a method of aquifer characterisation (covering types of tracer, basic principles, practical aspects, recommended procedures, and interpretation of results, including the dangers of misinterpreting the non-appearance of the tracer).

Notes: Day 5 is based entirely in the classroom, and consists mostly of lectures. There will be frequent use of real-life examples, photos and diagrams to illustrate the points being made, including examples of things to avoid and where things have gone wrong. There will also be some group exercises, for example analysing tracer test results.

DAY 6

Main topics for the day:
Special considerations of karst; water balances. Pumping and monitoring equipment used in testing.

Session	*Topic*
1	Special considerations of karstic limestone (including basic karst classification system, properties of karst, differences between active karst and palaeo-karst, uncertainty when predicting impacts in karst, and the debate on whether or not Chalk is karstic).
2	Water balances (basic concepts, steady-state, time-variant, components, etc).
3	Pumping and monitoring equipment (installed pumps, temporary pumps, weir tanks, flow meters, V-notch weirs, dippers, transducers, data-loggers, quality sampling, sand sampling, equipment calibration).
4	Practical considerations when undertaking pumping tests (arrangements for discharge of water, turbulence or seepage face in pumping well, dip tubes, access constraints).
5	Reminder of outside influences to be aware of (barometric pressure, tides, earth tides, other abstractions, natural seasonal changes, pre-test conditions, variable density in coastal aquifers).

Notes: Day 6 is based entirely in the classroom, and consists mostly of lectures.

Independent Learning 2

After the second residential course, students should do the following;

- Familiarise yourself with the analysis methods you have used; see the relevant sections of Kruseman and de Ridder.

Assessment

The assessment for this module consists of a professional practice examination based on the content of the module. The examination will be marked by the Module Tutors, on a pass or fail basis (50 per cent pass mark). The exam regulations can be found in Appendix 2. Sample questions will be provided by the Module Tutors during the final teaching session.

Completing the module

In summary, successful completion of the Aquifer Characterisation module consists of the following elements:

1) Attendance on all six days of the residential courses (a register will be kept to record attendance).
2) Passing the examination, as assessed by the Module Tutors.

In the event that the examination pass mark of 50 per cent is not attained, there will be one opportunity to re-sit the examination without course attendance, when the module is next run.

Module dates

Once approval has been received from National Learning & Development to run the course, the dates for each element of the module (two teaching sessions and an exam) will be made available on the Learning Zone. When booking a place on this course, be sure to book on each of the two taught elements of the course as well as the final exam.

Appendix 1: Module reading list

British Standard BS ISO 14686:2003. *Hydrometric determinations - Pumping tests for water wells – Considerations and guidelines for design, performance and use.* BSi, March 2006.

Driscoll F G (1986). *Groundwater and Wells.* 2nd edition, St Paul, MN, Johnson Filtration Systems Inc. Chapter 16 (Collection and analysis of pumping test data). (See also Sterrett, R J, below.)

Heath R C (1983). *Basic groundwater hydrology*. Water Supply Paper 2220, United States Geological Survey. You should have this document already, from the Groundwater Hydraulics module. Pages 34-51.

Kruseman, G P and de Ridder N A (1990). *Analysis and Evaluation of Pumping Test Data.* 2nd edn. Publication 47, Wageningen, The Netherlands, International Institute for Land Reclamation and Improvement.

Price M (1996). *Introducing Groundwater.* 2nd edition, London, Chapman and Hall. Section on 'Hydraulic measurements' in Chapter 10 (Measurements and models).

Sterrett, R J (2007) Groundwater and Wells. 3rd edition, New Brighton, MN, Johnson Screens (now part of Bilfinger Water Technologies, which has been renamed as Aqseptence Group since its sale to a Chinese company).

Appendix 2: Exam regulations

Detailed instructions for examination candidates

a) Candidates will be admitted to the examination room **ten** minutes before the start of each examination and will find the question paper, answer books and any other special requirements waiting for them on their desk. **They may read the question paper in the ten-minute period before the examination is due to start, but may not write anything until the scheduled time for the paper to begin.** Candidates will be given five minutes at the end of each paper to complete the front of each answer book correctly.

b) The title of the examination paper should be written on the cover of each answer book used.

c) In accordance with the system of anonymous marking, candidates should write their Examination Number on the front of each answer book. **It is therefore essential that candidates are aware of their examination number.** They should also write their name in the top right-hand corner of each answer book, and seal the corner so that the name is then obscured. This is to ensure that the Examiners do not know the identity of the candidate whose script they are marking. The seal will be broken only if there is a mistake in the examination number written down by the candidate, or after the mark for the script has been agreed. Candidates will find instructions on the cover of each book.

d) Use both sides of the paper in writing answers, **but start the answer to each question at the top of a right-hand page**. All rough work should be done in the answer book and should be crossed through before the end of the examination.

e) If you have any queries about the material provided or about possible errors in your question paper, please consult the Invigilator immediately.

f) Candidates must bring their own drawing instruments as appropriate.

g) Candidates will not be allowed to bring any books or papers to the examination room, except where specified by the Examiners.

h) No candidate will be permitted to enter the examination room after half-an-hour from the beginning of any examination, and no candidate will be permitted to leave until half-an-hour has elapsed **or in the last half-an-hour of any examination session**.

i) If you wish to leave the room before the end of the examination, whether temporarily to use the toilet or permanently, you must seek permission from the Invigilator.

Calculators

Scientific calculators are admissible in the examinations. Programmable permanent memory calculators are liable to be checked by the Invigilators.

Dictionaries

Dictionaries are not permitted.

Valuables

Candidates are advised not to bring valuables to examinations and to keep money and keys on their person. The Environment Agency cannot accept any liability for loss of, or damage to, any property in examination centres, howsoever caused.

Academic misconduct

Cheating, which is the attempt to gain an advantage for oneself or another by deceit, and other misconduct, are punishable by a range of sanctions. Cheating and other academic misconduct in written examinations includes:

- Taking into the examination room, or possessing while in that room, any books, memoranda, notes or other similar material (including material held electronically) except such as may have been supplied by the Invigilator or authorised by the Examiners;
- Copying from, consulting or otherwise making use of another candidate's script; or attempting to copy from, consult or otherwise make use of another candidate's script;
- Improperly aiding or attempting to aid another candidate, or improperly obtaining or attempting to obtain aid from any person;
- Consulting or attempting to consult, any books, memoranda, notes or any other similar material (including material held electronically) while present in the examination room or temporarily outside the examination room during the period of the examination;
- Impersonating or attempting to impersonate another candidate or being impersonated.

Other misconduct in written examinations

Candidates are not allowed under any circumstances to talk to each other or to behave in a manner likely to disturb or distract other candidates during an examination. Candidates are not permitted to smoke or eat in the examination room, and are permitted to drink still water only. Candidates are not permitted to bring mobile phones into the examination room. It is forbidden to remove an examination script or a part of an examination script from the examination room.

Candidates are not allowed to leave the examination before it has finished without the permission of the Invigilator or to leave the examination room temporarily for any purpose without the permission of the Invigilator.

Other information

Students with specific learning difficulties: In the case of students who have been formally assessed as having specific learning difficulties, special arrangements may apply in respect of examinations and the marking of written work. Such candidates must provide written evidence of their assessment.