Water Use

Regulatory Method (WAT-RM-26)

Determination of Aquifer Properties

Version: v4.0

Released: Apr 2013

Copyright and Legal Information

Update Summary

Version	Description
v1.0	First issue for Water Use reference using approved content from the following documents: *GWABS 7: Determination of Aquifer Properties from Constant Rate Pumping Test Data*.doc]
v2.0	Doc references revised.
v3.0	Document updated to reflect changes to *WAT-RM-11: Licensing Groundwater Abstractions including Dewatering*.
v4.0	Expired CMS links reviewed and updated.

Notes

References: Linked references to other documents have been disabled in this web version of the document. See the References section for details of all referenced documents.

Printing the Document: This document is uncontrolled if printed and is only intended to be viewed online.

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Always refer to the online document for accurate and up-to-date information.

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1. Introduction, Purpose & Scope

1.1 Introduction

When SEPA receives an application to abstract groundwater it undertakes a screening to determine if there may be an adverse environmental impacts as a result of the abstraction. In these cases further information may be required to determine the licence and a time limited drill and pump test licence may be issued to allow test pumping to take place in order to better assess the environmental impact of the abstraction.

1.2 Purpose and Scope

The purpose of this document is to provide guidance for SEPA's Groundwater Unit on how to:

- Identify the aquifer type from the raw constant rate pumping test data
- Use the data to calculate the aquifer properties

The aquifer properties can then be used to calculate long term drawdown of groundwater levels within the aquifer and the potential impact upon identified water features or potential intrusion from saline or other waters of different chemical composition. It should be noted that in some cases a pumping test is not required and that aquifer properties may be based on literature or other values.

2. Key Steps

The accurate interpretation of pump tests is critical for the determination of aquifer properties (Transmissivity, Storativity) as these properties are then used to make predictions on future drawdown at specified locations and hence impacts on other water features.

The interpretation of pumping test data is based on mathematical or graphical models that relate drawdown response to discharge from the abstraction borehole. Models have been developed by a number of researchers that enable the derivation of aquifer characteristics from pumping test results for different aquifer types. The choice of aquifer type is therefore crucial to the process, as the wrong choice will potentially lead to incorrect estimation of aquifer characteristics, and thus lead to errors in impact predictions.

In order to minimise the risk of use of the wrong model and derivation of incorrect aquifer parameters the following procedure should be adopted:

1. Provisionally determine the aquifer type from the geological evidence (use of maps & borehole data) as described in *Section 4*.
2. Create diagnostic plots of pump test data. See *Section 5*.
3. Define flow regime and determine if the flow is steady or non-steady state and choose the appropriate analysis method. See *Section 6*.
4. Determine the aquifer parameters See *Section 6*.
5. Use the aquifer parameters to determine the drawdown in the aquifer at a certain distance to help predict the impacts on the water environment. See *Section 7*.

3. Step Drawdown Tests

In many cases a step drawdown test will have been undertaken in addition to the constant rate test. The step drawdown test provides information on aquifer yield and well losses. Applicants are advised to submit step test data where available as the information can be used to make corrections to certain constant rate tests. For advice on step drawdown test interpretation the reader is referred to Chapter 14 of *Kruseman and de Ridder*. Constant rate analysis without correction for well losses will make more conservative predictions of drawdown than where corrections are made.

4. Provisionally Confirming Aquifer Type

The usual classification for pump test analysis divides aquifers into two broad flow categories, intergranular and fractured. The former category includes such aquifers as river gravels and high matrix porosity, low fracture porosity sandstones (e.g. the Permian aquifer of Dumfries, the Knox Pulpit Formation in Fife). The latter category includes much of the Carboniferous and Devonian sedimentary aquifers of the central belt and the intrusive, extrusive and metamorphic aquifers of the Highlands and Islands and the Borders. Aquifers within each category are further divided into unconfined, confined or leaky.

The classification should begin by an examination of the geology, both of the aquifer material and the setting. Inspection of borehole logs can provide useful information. *Table 1* provides a summary of aquifer types

Table 1 Aquifer Types

Aquifer Type	Sub-Type	Example
Intergranular	Unconfined	River Terrace Gravels of Spey, Tweed, Dee etc.
	Confined	Parts of Knox Pulpit Fm, Fife
	Leaky	Parts of the Permian Sandstones, Dumfries
Fractured	Unconfined	Parts of Devonian Sandstones, Highlands & Islands, Borders
	Confined	Parts of Carboniferous, Middle and Lower Devonian, Highlands & Islands, Borders
	Leaky	Parts of Carboniferous, Middle and Lower Devonian, Highlands & Islands, Borders

5. Create Diagnostic Plots

5.1 Processing the Data

Before constructing diagnostic plots, and to get the best results, pump test data should be examined and corrected for variations in baseline conditions that occurred during the test and were recorded by the monitoring regime. Such variations include:

- Trends or cyclic variations in water level caused by natural recharge or discharge trends, tides, day night differences in evapotranspiration
- Non-cyclic variations in water level for example, changes in barometric pressure
- Isolated fluctuations such as significant rainfall events affecting recharge or river flows during the pump test. Where large unique fluctuations occur it is often difficult or impossible to make a correction.

5.2 Using Diagnostic Plots

The appropriate drawdown and time derivative plots should be drawn up for the most likely aquifer type, provisionally selected using geological data, using *Table 2*. In some cases (single horizontal or vertical fractures) more than one solution is possible for each aquifer type, depending upon the flow regime. In such cases further diagnostic plots will have to be drawn as identified in *Table 2*.

The standard approach is to plot drawdown versus time on log-log and semi-log axes.

In addition to these standard plots there are a number of others that can be studied to determine the aquifer type and flow regime including:

- Drawdown versus square root of time (*s* v. $t^{1/2}$)
- Drawdown versus the fourth root of time (*s* v $t^{1/4}$)
- The time derivative of the drawdown versus time in a log-log plot

Where the time derivative of drawdown is defined as:

$$\frac{\delta s}{\delta t} \cdot t = \frac{s_{i-1} - s_i}{t_{i+1} - t_i} \cdot \frac{t_i + t_{i+1}}{2}$$

and *si* and *si +1* represent the drawdown at two time steps *ti* and *ti + 1*

A combination of two, three or more plots may be needed to define both the aquifer type and the flow regime within that aquifer.

Table 2 Diagnostic Plot Analysis

Aquifer Type	Flow Regime	Diagnostic Plots		Refs
		Drawdown	Time Derivative	
Homogenous Isotropic	Radial Symmetric	Semi-log: straight line	Log-log: horizontal line	1
Double Porosity	Radial Symmetric	Semi-log: two parallel straight line sections		2
Single Vertical Fracture or Dyke	Fracture Linear Flow[a]	Log-log: straight line with ½ slope	Log-log: straight line with ½ slope	3
	Bilinear Flow[b]	S vs $t^{1/4}$: straight line Log-log: straight line with ¼ slope	Log-log: straight line with ¼ slope	3
	Formation Linear Flow[c]	S vs $t^{1/2}$: straight line Log-log: straight line with ½ slope	Log-log: straight line with ½ slope	4
	Pseudo Radial Flow	Semi-log: straight line	Log-log: horizontal Line	5
Single Horizontal Fracture	Storage Type Flow[d]	Log-log: straight line with 1/1 slope		6
	Linear Flow	Log-log: straight line with ½ slope	Log-log: straight line with ½ slope	6
	Pseudo Radial Flow	Semi log: straight line	Log-log: horizontal Line	6

a Flow to a well along a fracture only
b Flow to a well from fractures and matrix (dual porosity aquifers are a special case within this category)
c Flow to a well from the matrix through a fracture of infinite conductivity
d Flow to a well where release from storage may be delayed, e.g. recharge to an aquifer from a less permeable confining layer

1Thiem (1906); Cooper Jacob (1946)
2 Warren and Root (1963); Kazemi (1969)
3 Cinco-Ley et al. (1978); Cinco-Ley & Samaniego (1981); Boonstra & Boehma (1986); Boehma & Boonstra (1987)
4 Gringarten et al. (1974); Jenkins & Prentice (1982); Bardenhagen (1999)
5 Theis (1935); Cooper Jacob (1946)
6 Gringarten & Ramey (1974)

6. Confirmation of Aquifer & Flow Type, Calculation of Aquifer Parameters

Confirmation of the aquifer type and flow regime by diagnostic plots forms the most important part of the work needed to allow the appropriate analytical solution to be identified. Once the flow regime has been identified and the appropriate analytical solution chosen then simple curve matching and calculations can be carried out to determine values of Transmissivity and Storativity.

If different flow regimes can be identified during a test, each section should be evaluated using the appropriate method. For long term extrapolation only the late time data solution should be used.

Analytical solutions for fractures may contain more than two fitting parameters. The analysis of different sections of the time – drawdown data can allow the flow equation to be solved for the different parameters by using one time section, where two parameters control the shape of the plot (the curve), to determine other parameters which control the curve shape over a different time section.

The only thing that is missing is to decide if the groundwater flow regime was in a steady state at the end of the test pump. This is best accomplished by examination of the late data from the pump test. If the time-drawdown curve becomes a straight horizontal line the flow regime can be assumed to have achieved steady state. The appropriate analytical solution can now be chosen.

A number of computer software programs are available for curve matching that can significantly simplify and speed up the process. Aquifer Win 32 provides a comprehensive curve analysis package which includes derivative curves and is the preferred software for SEPA use.

In addition, to the above the hydrogeologist should be aware that:

- Analysis of late-time drawdown may be essentially unrelated to the region of the aquifer that is of interest
- Well bore storage can mask the effects of important heterogeneities such that semi-log analysis of drawdown in the well may lead to underestimates of transmissivity
- Local transmissivity heterogeneities can produce apparent anisotropic behaviour in the drawdown responses in observation wells

The installation of wells can connect previously unconnected fractures and create short-circuit pathways.

7. Extrapolation or Modelling

The derived values of Transmissivity and Storativity are used in the solution equation to derive values for drawdown at the appropriate distance and time. For example, if the aquifer were of the unconsolidated, confined type and it was decided that the Cooper-Jacob solution was appropriate, values of S and T would be derived from:

$$s = \frac{2.3Q}{4\pi KD} \log \frac{2.25KDt}{r^2S}$$

this can be resolved to:

$$S = \frac{2.25KDt}{r^2} \quad \text{and}$$

$$KD = \frac{2.3Q}{4\pi\Delta s}$$

Where:

Q = the pump discharge, in m3/day

S = the drawdown measured in a piezometer at a distance r from the well, both in metres

KD = the Transmissivity of the aquifer, in m2/day

S = the Storativity of the aquifer, unitless

t = the time since pumping began, in days

The values can then be used to derive drawdown for times exceeding that of the pump test and/or at other distances from the pumping well. Alternatively, if a model has been submitted these values can be checked against those used in the model.

The calculated, or modelled, drawdown at any point of interest can be used in the impact assessment. Details of assessment techniques and thresholds are given in *WAT-RM-16: Groundwater Abstraction - Hydrogeologist Impact Assessment*.

Annex 1: Solution Methods

Much research has been done in this area and a number of solutions are compatible with Scottish aquifers. Refer to the following documents for a more detailed examination of pump test data analysis and solution derivation:

- *Baumle* (hydraulic testing is considered in Chapter 2)
- *Manual on Pumping Test Analysis in Fractured–Rock Aquifers*
- *Kruseman and de Ridder*

For most situations more than one solution method exists. In addition, analytical solutions assume that a number of conditions are satisfied. Readers should carefully examine the pumping test and hydrogeological conditions to ensure that, whichever solution is chosen, if the conditions are met.

References

NOTE: Linked references to other documents have been disabled in this web version of the document.

See the Water >Guidance pages of the SEPA website for Guidance and other documentation (*www.sepa.org.uk/water/water_regulation/guidance.aspx*).

All references to external documents are listed on this page along with an indicative URL to help locate the document. The full path is not provided as SEPA can not guarantee its future location.

Regulatory Methods

WAT-RM-11: Licensing Groundwater Abstractions including Dewatering

WAT-RM-16: Groundwater Abstraction - Hydrogeologist Impact Assessment

External References

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