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Investigations and Monitoring Group

# Aquifer test guidelines (2nd edition)

Report No. R08/25

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Environment Canterbury

Your regional council

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# Executive Summary

This report provides best practice guidelines for the design, analysis and reporting of aquifer tests and is a revision of the 1998 Aquifer Test Guidelines (Brooks).

Numerous analytical solutions exist that describe the response to pumping in the many hydrogeological settings found in aquifers. Generally these solutions describe three theoretical aquifer types; unconfined, leaky (semi-confined), and confined. Proper aquifer test design and analysis must take account of the aquifer conditions being tested or analysed.

Environment Canterbury actively compiles records of aquifer tests and well development. The reliability of an aquifer test is rated based on test type, duration, controls, data reasonableness, analysis method and corrections applied to datasets.

Aquifer tests which are submitted for consents or contract purposes which do not meet the criteria set out in these guidelines may not be accepted by Environment Canterbury.

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# 1 Introduction

## 1.1 Scope and structure

These guidelines update the first edition of the guidelines (Brooks, 1998) and cover:

- Designing aquifer tests;
- Undertaking aquifer tests;
- Analysing aquifer tests;

Additionally the quality of some aquifer test reports provided to Environment Canterbury requires improvement. These aquifer test guidelines aim to assist in improving data and report quality.

Aquifer tests which are submitted for consents or contract purposes which do not meet the criteria set out in these guidelines may not be accepted by Environment Canterbury.

## 1.2 Why aquifer test?

Aquifer testing[1] provides information on well performance and can be used to model aquifer response to groundwater abstraction. Testing assists owners to determine the performance and sustainability of their own well(s), and to determine the effects their pumping may have on neighbouring wells or streams.

Aquifer parameters are used to quantify pumping interference effects and to assist the management of the resource. Increasing competition for groundwater has developed to the extent that such testing is generally regarded as a prerequisite for resource consent applications.

A clear aim must be determined prior to the test, and the testing designed around this (rather than letting limitations of test design influence the aim). The aim should be clearly outlined in the aquifer test report. Issues that require specific test types are set out in Table 1.1:

**Table 1.1 Aquifer test purpose and design**

| Test purpose | Aquifer test design to include: |
|---|---|
| To determine an optimum pumping rate | Single well step-drawdown test |
| To estimate long-term pumping interference effect on a neighbouring well | An aquifer test with several observation wells (including neighbouring well) at a sufficiently high pump rate. |
| To estimate stream depletion effects | An aquifer test with observation wells and purpose-installed weirs in the surface water body. |
| Aquifer characterisation for general investigations to accompany a resource consent application | An extended pumping time with several observation wells in different aquifers, sufficiently close to pumping well |

[1] The term 'aquifer test' is used in this guideline as a generic term to encompass aquifer and pumping tests. The term 'aquifer test' more specifically refers to a test designed to estimate aquifer properties. A 'pumping test' is a broader term, which includes aquifer testing, but also testing of well performance, such as step-drawdown tests (refer to Section 1.3).

## 1.3 Types of aquifer test

Aquifer test types include:

- Single well tests - generally used to describe well performance; and
- Tests with observation wells - which best describe aquifer response to pumping.

A single well performance test (Section 4.4) is quick, relatively simple and relatively inexpensive to conduct. However, a well performance test, generally, does not describe aquifer parameters in detail and is of only limited use in determining the effects of a groundwater abstraction consent.

An aquifer test using both pumping and observation wells (Section 4.3) describes the response of aquifer pressures and levels to pumping. A test may determine how readily an aquifer can transmit water, release water, and, identify hydrologic boundaries. Aquifer parameters including transmissivity, storativity and leakage can be calculated from such a test, and these parameters can then be used to predict interference on neighbouring wells and streams.

## 1.4 Environment Canterbury regulatory requirements

Environment Canterbury's Proposed Natural Resources Regional Plan (NRRP) Rule WQN15 'Taking of water from groundwater for well development and pumping tests' makes aquifer testing a permitted activity provided that the prescribed conditions are complied with. The conditions require an extraction rate of < 100 L/s, test duration of < 72 hours, notification to Environment Canterbury one week prior to testing if the test is longer than one day, and the provision of any records and analysis to Environment Canterbury within one month of the test completion. The most current version of Chapter 5 of the NRRP is available on Environment Canterbury's website: http://www.ecan.govt.nz.

If the above conditions are not met then a Resource Consent is required from Environment Canterbury.

# 2 Designing aquifer tests

The design of an aquifer test is dependent on the purpose of the test and the hydrogeological conditions present at the test site. Optimal well location, depth, pump rate, test duration and analysis method are all dependent on these two factors. An aquifer test design plan should always be prepared for any aquifer test. Performing an aquifer test trial will also be very useful in determining final test design.

## 2.1 Aquifer test design plan

A test design plan will assist the aquifer testing to meet its objectives. The test design plan will also identify equipment and preparation required as well as possible eventualities. A checklist for an aquifer test design plan is included in Appendix A.

A test design plan should address:

- Purpose of test;
- Preliminary evaluation of hydrogeological conditions;
- Rationale for test design;
- Construction and location of the pumping and observation wells;
- Proposed method to pump and dispose of water;
- Estimated drawdown in monitoring wells.

Further factors to consider in test design are summarised in Table 2.1.

Standards Australia (1990) also establishes test standards and provides useful test considerations.

If the aquifer test is to be used in support of a resource consent application, it is recommended that a test design plan is submitted to Environment Canterbury to ensure that relevant data are being captured; however, any prior advice sought from Environment Canterbury on test design or analysis does not imply approval or acceptance of test results.

Table 2.1 Factors to consider in aquifer test design

| Factors to consider | Explanation |
|---|---|
| Hydrogeological conditions | Aquifer type and potential hydrological boundaries |
| Timing of testing | Aquifer tests are best undertaken outside the irrigation season because pumping from neighbouring wells is less likely. |
| Pumping of neighbouring wells | Wherever possible, neighbouring wells, especially those closest to observation wells, should not be pumped during an aquifer test. Alternative sources of water may be arranged for neighbours (such as tanks of water) to enable wells to be shut off. |
| Location of observation wells | The optimum location of observation wells is best determined by estimating potential drawdown within the pumped and adjacent aquifers for the type of aquifer. Guidelines for well spacing are outlined in Kruseman and de Ridder (1990). |
| Test duration | To determine later time drawdown parameters in leaky aquifers longer durations are often required. Longer duration tests are, however, more susceptible to atmospheric influences, pumping interference from neighbouring wells and other variations in groundwater levels not attributed to test pumping. |
| Data measurement | Method of measurement of pumping rate, depth to water, and barometric pressure. Additional measurement of tidal effects and stream flow may be required. |
| Discharge method | Pumped water must be discharged at sufficient distance and manner so that recharge to the aquifer will not occur and that flooding is avoided. |

## 2.2 Timing of testing

It is preferable that a test be conducted when there is minimal background interference in the water level data being collected. Sources of noise include pumping from other wells, atmospheric changes, and rainfall events. Testing should therefore be carried out during stable atmospheric conditions, preferably outside of the irrigation season. In some circumstances background pumping cannot be avoided, but will need to be accounted for in the analysis and will result in additional potential error.

If neighbouring well owners cannot interrupt their pumping schedules (especially in the case of domestic wells), then ensure that they start pumping several hours before the test pumping is started and continue pumping until after the test pumping is stopped (Standards Australia, 1990, section 4.5). Alternatively, flow rates should be measured and on/off times recorded. These can then be corrected for or included in the final aquifer test analysis. Neighbouring pumping will introduce additional sources of potential error and uncertainty into the test results.

## 2.3 Aquifer test trial

For pumping tests with observation wells, an aquifer test trial is highly recommended. This trial can be as simple as a step-drawdown test to determine an appropriate pumping rate, and to resolve any difficulties with establishing pumping rates prior to the test (e.g. through irrigation system controls, flow meters etc).

The trial can be of short duration (eg 2-4 hours), and observations of drawdown in the pumping and surrounding wells should be made. The absence of any drawdown may lead to a re-evaluation of the suitability of the aquifer test design and layout of observation wells to meet the aims of the test. As a guide, recovery to 95% of the initial depth to water is sufficient, but ideally, at least a day should separate a trial test and main aquifer test.

## 2.4 Aquifer type

There are three general aquifer types: confined, leaky (or semi-confined), and unconfined. Fully confined aquifers are very uncommon in Canterbury. Figure 2.1 shows schematic examples of these aquifer types, and sources of water to a pumping well, and Figure 2.2 shows log-log drawdown curves for the three aquifer types.

Most Canterbury aquifers are leaky. Leaky aquifers may display a variety of responses depending on the duration of the test and the amount of leakage from over, or underlying, layers.

The leaky response (middle curve in Figure 2.2) shows a flattening of the curve due to leakage. It is important to note that for the duration of the test there has been enough water coming into the pumped aquifer to match the pumping rate. However in reality leakage is often not infinite and some late drawdown is likely to occur (as in the bottom curve), especially when the effects over an entire irrigation season are to considered.

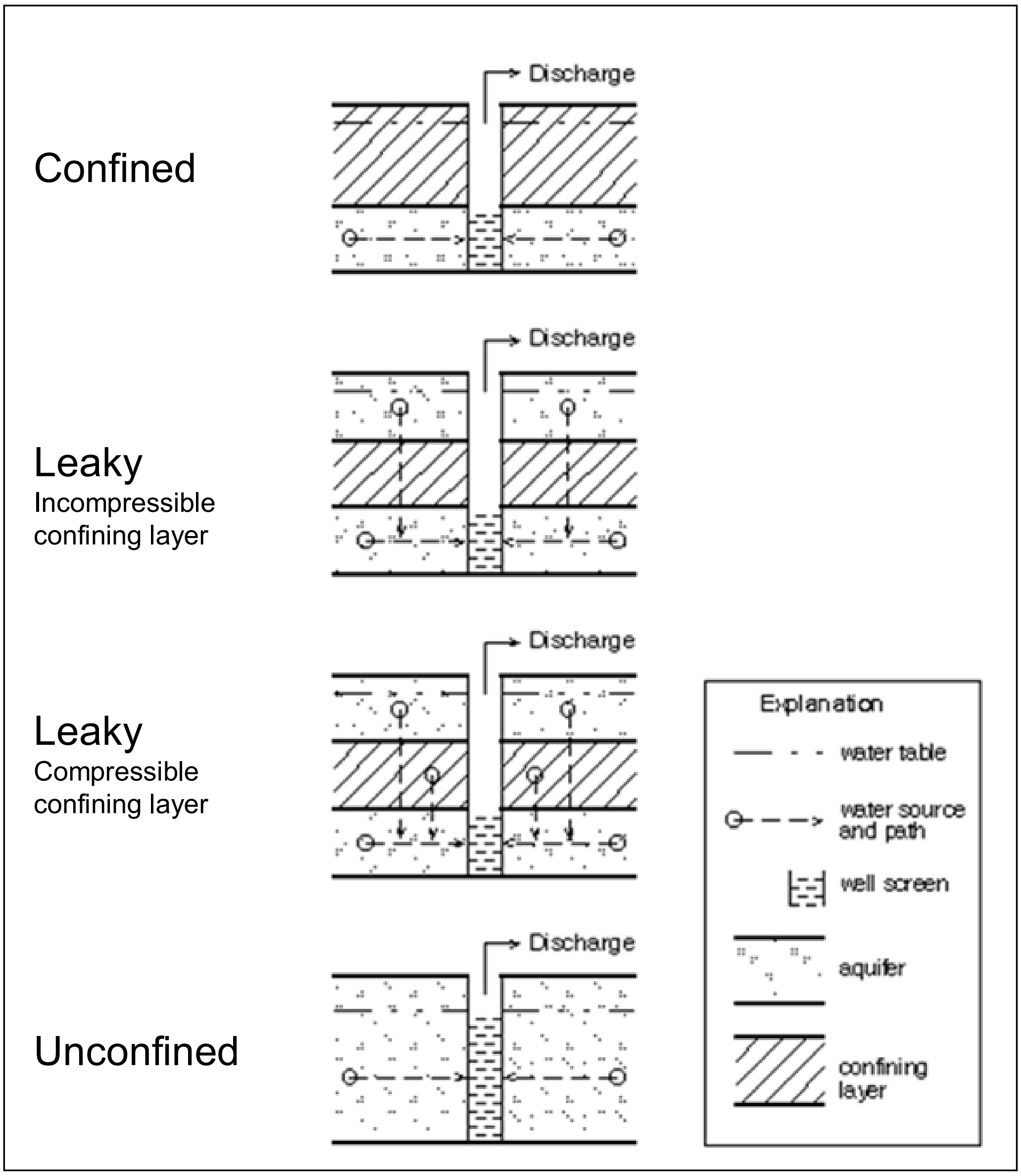
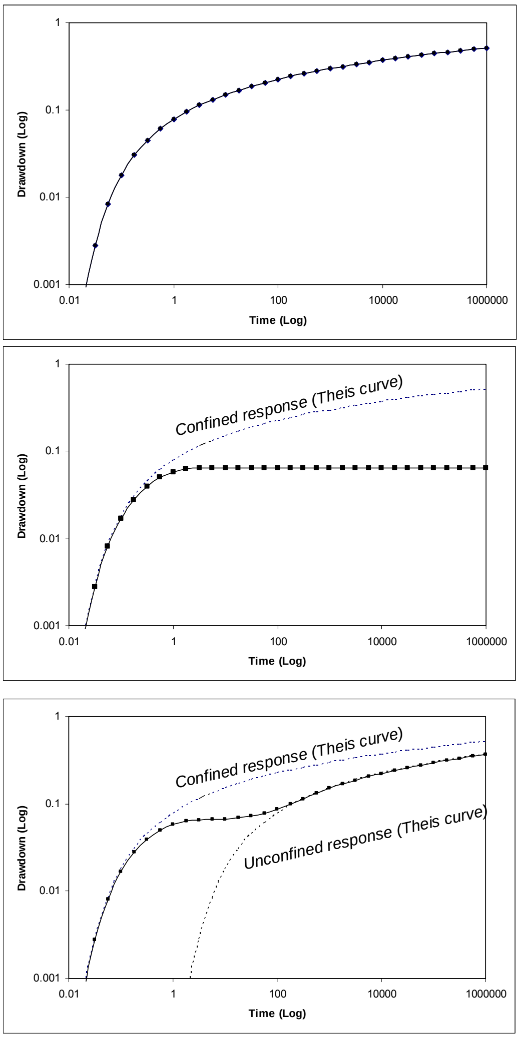



**Figure 2.1 Aquifer types and sources of water (Brooks 1998)**




Confined aquifer response

Semi-confined/ Leaky aquifer response (no delayed yield)

Leaky aquifer response (with delayed yield/late time drawdown) or Unconfined aquifer response

**Figure 2.2 Aquifer responses to pumping**

### 2.4.1 Hydrological boundaries

The presence of any hydrological boundaries should also be considered in test design and analysis. This includes no-flow boundaries due to geological constraints (i.e lateral limits to aquifer, changes in strata type and/or hydraulic conductivity, or geological faulting), and recharge boundaries such as streams, lakes and wetlands.

## 2.5 Location of pumping and observation wells

Ideally, an aquifer test site would be selected and purpose-drilled pumping and observation wells installed at appropriate spacing and depths. However, in reality due to the expense of well drilling, aquifer test sites often use existing wells. Unfortunately this has led to many aquifer tests in Canterbury where observation wells are located too distant from the test well to measure any significant drawdown (drawdowns of less than 0.05 m are common in reported tests). Wells should only be screened in the aquifer where drawdowns are to be measured – this includes the pumped aquifer, as well as over and underlying aquifers where leakage is involved. Wells with multiple screens in different aquifers will affect the validity of test results and analyses.

The optimum location of observation wells is best determined by estimating potential drawdown within the pumped and adjacent aquifers for the type of aquifer. Guidelines for well spacing are outlined in Kruseman and de Ridder (1990).

## 2.6 Duration of pumping

Without a trial test, predicting the ideal number of hours to pump a well during an aquifer test is always difficult. This is because the optimum period of pumping depends on the type of hydrogeological setting as well as the purpose of the test.

At the beginning of a test, the cone of depression develops rapidly because the pumped water is initially derived from the aquifer immediately adjacent to the well. As pumping continues, the cone expands and deepens more slowly because of the increased volumes of stored water becoming available, proportional to the radius of the cone. The cone of depression will continue to expand until the recharge into the aquifer equals the pumping rate.

Although it is not necessary to continue pumping until steady state conditions have been reached, under steady state conditions additional analyses can be carried out to verify the accuracy of unsteady flow analyses.

In some tests, steady-state or equilibrium, conditions may occur only a few hours after the start of pumping; in others, they occur within a few days or weeks, if at all. Kruseman and de Ridder (1990) state that in their experience: "…under average conditions, a steady state is reached in leaky aquifers after 15 to 20 hours of pumping; in a confined aquifer, it is good practice to pump for 24 hours; in an unconfined aquifer, because the cone of depression expands slowly, a longer period is required, say 3 days." In Canterbury, most well performance tests are carried out within a day, while more complex testing, such as constant discharge tests, are carried out for 1-3 days.

Additional pumping can indicate the presence of boundary conditions and in leaky aquifer situations extended pumping is particularly important to determine any delayed yield effects that may occur. Under these conditions a pseudo steady state may set up rapidly, but under additional pumping aquifer response will continue to be unsteady when aquitard storage (or other source of leakage) is exhausted or rate limited.

However, longer duration tests are also susceptible to noise from atmospheric changes, rainfall events, and pumping interference from neighbouring bores. 2-3 days of pumping should provide adequate observation data in most circumstances.

Pre-testing will provide an insight into aquifer response and type. Alternatively plotting of drawdown data during the test is useful to show what is happening and can be used to determine how much longer the test should continue.

## 2.7 Discharge of water

Consideration of where the water produced during an aquifer test will be disposed of must be made. Particularly in the case of testing an unconfined aquifer, the water must be discharged at sufficient distance and manner so that recharge to the pumped aquifer cannot occur. Care should be taken that the discharged water does not become a hazard to people or their property (i.e. flooding). Water race operators and district councils may need to be contacted if any problems are envisaged.

# 3 Undertaking aquifer tests

There are three important variables for which accurate records must be kept during an aquifer test: pumping rate; depth to water; and time. All may be measured manually or electronically, and accurate records should be retained to allow future analysis and interpretation of test data. To help determine if the duration of the test should be altered (for example to determine if a boundary condition has been met or if leakage or delayed yield responses are evident) it is useful to graph observation data as the test progresses

Examples of standard data collection forms are presented in Appendix B.

## 3.1 Pumping rate

The pumping rate may be measured in a variety of ways, depending on flow and test requirements. The frequency of measurement is important and must be often enough to allow any changes in pumping rate to be corrected for in the final analysis. Table 3.1 sets out some methods of measuring pumping rates currently in use in Canterbury.

**Table 3.1 Methods of measurement for pumping rate**

| Method of Measurement | Comments |
|---|---|
| Stopwatch and container | Excellent for low pumping rates, impractical for larger rates. Labour intensive if constant measurement of rate is required. |
| Orifice meter | Good measurement accuracy if installed correctly. Disposal method needs to be considered as the orifice can't always be installed into irrigation works. |
| Sharp-crested weir | Good measurement accuracy if installed and designed correctly. Another physical device and limitation of use as per orifice. |
| In-line flow meter | Accuracy will vary according to installation and meter specifications. Simple to use, especially if already installed. May require a data logger, which older meters may not be compatible with. |
| Acoustic flow meter | Portable versions can measure to a high accuracy, but are dependent on knowledge of pipe material and dimensions |

Ideally an aquifer test trial will have established an appropriate pumping rate that can be sustained throughout the test and not result in the test having to be cut short, due to excessive drawdown in the pumping well.

Although most analysis programs do not rely on a constant pumping rate, in some circumstances a constant discharge is the preferred option, such as when the test is intended to look at boundary/recharge or delayed yield effects.

## 3.2 Depth to water measurement

Depth to water measurements should be recorded for the pumped well and all observation wells before pumping starts to determine the static depth to water. Ideally water depth in wells should be monitored for a period of a least 24 hours, preferably several days, prior to pumping to establish background trends. Monitoring of groundwater in a well not affected by the test should also be carried out in order to allow correction for regional effects.

The most frequent measurements should be at the test start, when the change in depth to water is most rapid. Measurements can then lessen in frequency as the test continues. Table 3.2 and 3.3 outline measurement frequencies suggested by Kruseman and de Ridder (1990).

**Table 3.2 Range of interval between water-level measurements in the pumping well (Kruseman and de Ridder, 1990)**

| Time since start of pumping | Time interval |
|---|---|
| 0 to 5 minutes | 0.5 minutes |
| 2 to 60 minutes | 5 minutes |
| 60 to 120 minutes | 20 minutes |
| 120 minutes to shutdown of the pump | 60 minutes |

**Table 3.3 Range of interval between water-level measurements in observation wells (Kruseman and de Ridder, 1990)**

| Time since start of pumping | Time interval |
|---|---|
| 0 to 2 minutes | Approx 10 seconds |
| 2 to 5 minutes | 30 seconds |
| 5 to 15 minutes | 1 minute |
| 50 to 100 minutes | 5 minutes |
| 100 minutes to 5 hours | 30 minutes |
| 5 hours to 48 hours | 60 minutes |
| 48 hours to 6 days | 3 times a day |
| 6 days to shutdown of the pump | once a day |

The similar frequencies should also be followed from the time the pump is switched off when recording data during the recovery portion of the test.

Depth to water is commonly measured manually using electrical ‘dippers’, but can also be measured by transducers connected to data loggers which measure the pressure of the water column. If data loggers are used, the readings should always be verified with a number of manual depth to water measurements. Loggers are advantageous as they allow tests to be conducted with minimal personnel and also allow frequent measurement.

## 3.3 Time measurement

Time measurements should be kept as precise as possible. When data loggers are used for flow or depth to water measurement, the times should be synchronised. Whether data are New Zealand Standard Time (NZST) or Daylight Savings Time (NZDT) should be recorded.

Manual time measurements should also be made using GPS time to ensure that comparisons can be made between sites.

## 3.4 Other measurements

### 3.4.1 Rainfall

Any rainfall events during an aquifer test should be recorded. As a ‘unique’ fluctuation a rainfall event can mean that the test is rendered worthless and will need to be repeated. The weather forecast should be consulted before undertaking an aquifer test, as changes in barometric pressure can also affect depth to water. A test is preferably undertaken in stable weather conditions.

### 3.4.2 Barometric pressure

Barometric pressure should be measured prior, during and after testing to correct for the effects of barometric pressure changes on water levels and aquifer pressures, and to calculate the barometric efficiency of an aquifer well (Section 4.2.1). If a sealed (non vented) water level logger is to be used, barometric data will be required to correct the transducers readings to give actual depth to water readings.

### 3.4.3 Stream flow

Flow in a nearby stream should be measured during an aquifer test, particularly if the test is undertaken in an aquifer hydraulically connected to the stream. Measurements of stream flow should only be via weirs or flumes. The weirs/flumes should be placed outside of the zone of influence of pumping in order to measure the full stream depletion effect. Flow measurements should be taken at an upstream and downstream site to determine any change in flow.

Such a test must be carefully controlled. However, in some cases, the results may still prove inconclusive due to the relatively large margin of error inherent in flow measurements compared to the flow depletion over the relatively short duration of the test, and also due to any antecedent trends in stream flows and adjacent groundwater levels.

In most situations the maximum stream depletion rate is not reached during an aquifer test as stream depletion rates can develop over long pumping durations. The time it takes for the maximum stream depletion rate to develop depends on the separation distance between the well and the stream and the hydrogeological setting. The test can still, however, yield parameters that can enable a prediction of the longer-term stream depletion.

Refer to the most up-to-date version of “Guidelines for the assessment of groundwater abstraction effects on stream flow’’ for more in-depth information on stream depletion and stream depletion assessment techniques.

# 4 Analysing aquifer tests

## 4.1 Introduction

Kruseman and de Ridder's *Analysis and evaluation of pumping test data (2nd Ed,* 1990) is a very comprehensive text that describes aquifer test analysis for several hydrogeologic conditions. This text gives descriptions and practical field examples and is recommended as further reading. *Analysis and evaluation of pumping test data* can be downloaded from:

http://www.alterra.wur.nl/NL/publicaties+Alterra/ILRI-Publicaties/Downloadable+publications/

Others useful texts describing aquifer test analysis include:

| Title | Author |
|---|---|
| Applied Hydrogeology | Fetter, C.W. |
| Physical and Chemical Hydrogeology | Domenico, P. A., and Schwartz, W. |
| Aquifer testing, Design and analysis of pumping and slug tests. | Dawson, K.J., and Istok, J.D. |
| Aquifer-test design, observation, and data analysis. | Stallman, R.W. |

A paper by Hunt and Scott (2007) also describes a leaky aquifer solution, applicable to many Canterbury aquifers.

## 4.2 Data correction

Prior to analysis of drawdown data from an aquifer test it may be necessary to correct the datasets for external effects, or effects induced by the test. External effects include groundwater level changes due to barometric pressure variations, tidal fluctuations, and other recharge or discharge sources such as rainfall or river flow. Effects induced by the test may include the unintentional recharge of the aquifer from the inappropriate discharge of pumped water. To determine if corrections are required, trends in background water levels need to be analysed. Background trends may be measured in an observation well that is distant to the test site, or be inferred from water levels measured at the test site prior and post test.

Full details of any type of data correction applied, along with copies of the original and corrected data, should be included in the aquifer test report.

### 4.2.1 Barometric pressure

Water levels from leaky and confined aquifers can be affected by changes in atmospheric pressure, where a rise in pressure can result in a fall in water levels and vice versa. Barometric efficiency is calculated from the ratio of the change in water level in a well to the corresponding change in atmospheric pressure.

### 4.2.2 Tidal fluctuations

As with barometric pressure, water levels in leaky and confined aquifers can also be affected by tides Where tidal effects are likely, then a record of tidal effects on groundwater prior to and after the test, and tide tables for the period of the test, are both necessary to enable corrections to be made.

#### 4.2.3 Unique fluctuations

Events such as heavy rain or sudden river flows may cause a unique fluctuation in groundwater level. Typically groundwater level data cannot be corrected for a unique event, and the test should be repeated.

#### 4.2.4 Saturated thickness

For most analysis solutions, the aquifer is assumed to be of constant thickness. In an unconfined aquifer, this condition is not met if the drawdown is large compared to the aquifer's original saturated thickness. Where this occurs, the Jacob (1944) correction may be applied:

$$S_{corrected} = s - s^2/2D$$

Where $s_{corrected}$ is the corrected drawdown, s = observed drawdown and D is the original saturated aquifer thickness.

#### 4.2.5 Partially penetrating wells

Corrections may also be required to account for partially penetrating pumping wells. In these circumstances flow in the vicinity of the pumped well will be higher than a fully penetrating well and can result in additional head loss. This effect decreases with increasing distance from the pumping well, and no corrections are required at distances greater than 1.5 to 2 times the saturated thickness of the aquifer. Methods to correct data are outlined in more detail in Chapter 10 of Kruseman and de Ridder (1990).

### 4.3 Aquifer testing with observation wells

There are numerous methods to analyse aquifer test data from multiple wells. The methods that are most accessible for analysis, and currently most used by Environment Canterbury as suitable for Canterbury aquifers, are described in this section and summarised in Table 4.1.

To determine the most appropriate analysis method:

1. Determine from the well or drill log(s) whether the hydrogeologic condition is likely to be unconfined, leaky or confined. For example, a gravel overlain with clay is likely to be leaky or confined.
2. Do an aquifer test to confirm the aquifer test condition. For example, the plotted test data as shown in Figure 2.2 should help distinguish whether the conditions are unconfined, leaky, or confined.
3. Analyse the test with the most appropriate method, considering both the hydrogeological conditions and observed aquifer response.

Other conditions such as hydrogeological boundaries (e.g. recharge or barrier boundaries) may influence the shape of a drawdown curve, and should be accounted for in analysis. Fetter (Section 5.9) and Kruseman and de Ridder (1990) provide an explanation of the effects of hydrogeological boundaries.

Traditional analysis involved hand-plotted data and fitting of type curves requiring a constant pump rate. Computer programs use iterative curve fitting methods, and allow analysis of variable pump rates, as well as very large datasets. It is essential to be aware of the limitations of an analysis method as it is possible to have a good fit of data but assume unreasonable hydrogeologic conditions.

Many software packages are available that allow analysis for various aquifer conditions, varying flow rates, multiple pumping and observation wells, partial penetration and a variety of analysis methods. Additionally, the Hunt 'Function.xls' Excel spreadsheets[2] include analysis options for the Hunt and Scott (2005, 2007) solution as well as other analysis options.

**Table 4.1 Aquifer tests with observation wells**

| Condition | Confined | | Leaky | | Unconfined | |
|---|---|---|---|---|---|---|
| Assumptions[1] | 1-6; | 1-6 | 1-7 | 1-8 | 1,3-6 | 1-6 |
| Analysis method[3] | Cooper - Jacob (1946) | Theis (1935) | Hantush Jacob (1955) | Hunt and Scott (2005, 2007) | Neuman (1975) | Theis (1935) with correction 4.2.4 |
| Solves for[2] | T | T,S | T, S, K′/B' | T, S, K'/B', $S_y$ | T,$K_h$,$K_v$,S,$S_y$ | T,$S_y$ |

[1]**Assumptions**
1. The aquifer has a seemingly infinite areal extent
2. The aquifer is homogeneous and isotropic
3. Uniform aquifer thickness over the area influenced by the test
4. Prior to pumping, the piezometric surface is horizontal (or nearly so) over the area influenced by the test.
5. The wells fully penetrate the aquifer, ie flow to the pumped well is essentially horizontal.
6. The volume of water in the pumping well is small cf the pumped volume(i.e well storage can be neglected)
7. Vertical leakage occurs through the confining layer, into the pumped aquifer
8. The elastic storage co-efficient of un-pumped layers are smaller than the porosity or specific yield of the top unconfined layer

[2]**Properties**
K = hydraulic conductivity (aquifer thickness required = KB)
T = transmissivity
S = storativity
K′ = vertical hydraulic conductivity of semi-confining layer
B' = confining layer thickness
S′ = storativity of the semi-confining layer
$S_y$ = specific yield
$K_h$ = horizontal hydraulic conductivity (aquifer thickness required)
$K_V$ = Vertical hydraulic conductivity (aquifer thickness required)

## 4.3.1 Confined aquifers

### *4.3.1.1 Theis (1935)*

This classic analysis method is the basis for several other more complex analysis methods, described by Fetter (2001, Section 6.3) and Kruseman and de Ridder (1990, p. 61-65). This method yields the following aquifer characteristics:

- Transmissivity [$L^2$/T].
- Hydraulic conductivity (where aquifer thickness is known) [L/T].
- Storativity (with an observation well).

[2] Available on the University of Canterbury web site.

#### *4.3.1.2 Cooper-Jacob (1946)*

The Cooper and Jacob method is based on the Theis formula, but uses a straight line approximation assuming that u ($u=r^2S/4Tt$) is small. This method is described by Fetter (2001, Section 6.3) and Kruseman and de Ridder (1990). The Jacob method is a suitable method for verification of other analysis results by combining the final drawdowns in one plot for a number of observation wells

The Jacob method yields the following aquifer characteristics:

- Transmissivity [$L^2/T$].
- Hydraulic conductivity (where aquifer thickness is known) [L/T].
- Storativity.

### 4.3.2 Leaky aquifers

When pumping a leaky aquifer, changes in hydraulic head will create change in the hydraulic gradient of the pumped aquifer and in the overlying aquitard. Water pumped from the aquifer is sourced from storage within that aquifer, while water contributed by the aquitard comes from storage within the aquitard and/or leakage through it from over or underlying layers.

When testing in a leaky aquifer, it is important to pump for sufficient time to estimate long-term leakage rates. This is particularly important for calculating the effects on over and underlying layers and for determining the effects of finite delayed yield.

#### *4.3.2.1 Hantush-Jacob (1955)(Walton's method)*

The Walton method assumes an incompressible aquitard, or rather that the changes in aquitard storage are negligible, and that the hydraulic head in the un-pumped aquitard remains constant during the test, providing an infinite source of leakage. The method is described in Fetter (2001, Section 6.4) and Kruseman and de Ridder (1990, p 81-84).

This method yields the following aquifer/aquitard characteristics:

- Transmissivity [$L^2/T$].
- Hydraulic conductivity (where aquifer thickness is known) [L/T].
- Storativity (with an observation well).
- Hydraulic resistance of the aquitard and leakage factor.

#### *4.3.2.2 Hunt and Scott (2005, 2007)*

The Hunt and Scott (2005) solution (an extension of Boulton's delayed yield solution) takes account of a reduction in hydraulic head in the un-pumped aquitard, resulting in a 'delayed yield' type response, similar to that seen in unconfined aquifers. Hunt and Scott (2007) build on this solution by considering a two-aquifer system with flow to a well in an aquifer overlain by an aquitard and a second un-pumped aquifer containing a free surface.

The 2007 solution provides for the more general case where the pumped aquifer is bounded by any number of aquitard and aquifer layers, and is able to simulate the Theis, Hantush-Jacob or Boulton delayed yield responses, depending on what parameters are used in the analysis. The Hunt and Scott solutions are the preferred solutions for analysis of Canterbury leaky aquifers where the test has been conducted long enough to observe late-time drawdown.

The method yields the aquifer/aquitard characteristics:

- Transmissivity [$L^2/T$]
- Hydraulic conductivity (where aquifer thickness is known) [L/T]
- Storativity (with an observation well)
- K'/B' (ratio of aquitard hydraulic conductivity and saturated thickness) [1/T] (Also the inverse of hydraulic resistance)
- Specific yield (σ) of the aquitard or of overlying layers.

### 4.3.3 Unconfined aquifers

Pumping from an unconfined aquifer leads to dewatering of the aquifer. Analysis must therefore consider saturated thickness reduction and vertical flow.

When unconfined aquifer test data are plotted on log-log paper, the data show an early (initial) Theis curve, a flattening of data along a horizontal line (delayed yield), then data evolve to a late (second) Theis curve (Figure 2.3).

The initial Theis curve in early time occurs within the first minutes of the test for a permeable aquifer and within the first hours for a less permeable aquifer. Canterbury's unconfined gravel aquifers typically are very permeable and the initial Theis curve may be observed within a few minutes (Kruseman and de Ridder, 1990)

Unconfined aquifer test analysis may be undertaken using the more accurate, comprehensive, and involved Neuman method that uses all test data, or by the simpler Theis method that uses only late data (excluding delayed yield data).

#### *4.3.3.1 Neuman (1975)*

The Neuman (1975) analysis method can determine vertical – horizontal anisotropy and storativity by using data from early and late time. For Canterbury's permeable aquifers, the method requires very early depth-to-water measurements in the first seconds of the test, such as every 15 seconds.

The Neuman method is described by Fetter (2001) and Kruseman and de Ridder (1990).This method yields the following aquifer characteristics:

- Transmissivity [$L^2/T$]
- Storativity for early time (with an observation well)($S_A$)
- Specific yield for late time (with an observation well) ($S_Y$)
- Isotropy ($K_h/K_v$) (where the saturated aquifer thickness is known)
- Vertical hydraulic conductivity (where the saturated aquifer thickness is known) [L/T]
- Horizontal hydraulic conductivity (where aquifer thickness is known) [L/T]

#### *4.3.3.2 Theis (1935)*

The Theis (1935) method may also be used for the analysis of unconfined data, but is typically associated with confined aquifer analyses, and corrections to the observed data need to be applied (Section 4.2.4). Though the Theis method is relatively simple to apply, care must be taken when considering early time data as the apparent Theis storativity can change due to elastic storage. See (Boulton 1973)

This method yields the aquifer characteristics:

- Transmissivity [$L^2/T$].
- Specific yield (with an observation well).

### 4.3.4 Hunt (2003) analysis for stream depletion effects

The Hunt (2003) solution is based on the hypothetical model of a stream that partially penetrates a leaky aquitard, which forms the top boundary of the pumped aquifer. The solution accounts for recharge to the pumped aquifer from stream depletion and from vertical drainage of the overlying aquitard. The solution models effects on stream flow as well as drawdown in the aquifer. A full description of the solution is given in Hunt (2003) and PDP and ECan (2005), and Figure 4.1 illustrates the typical drawdown response.

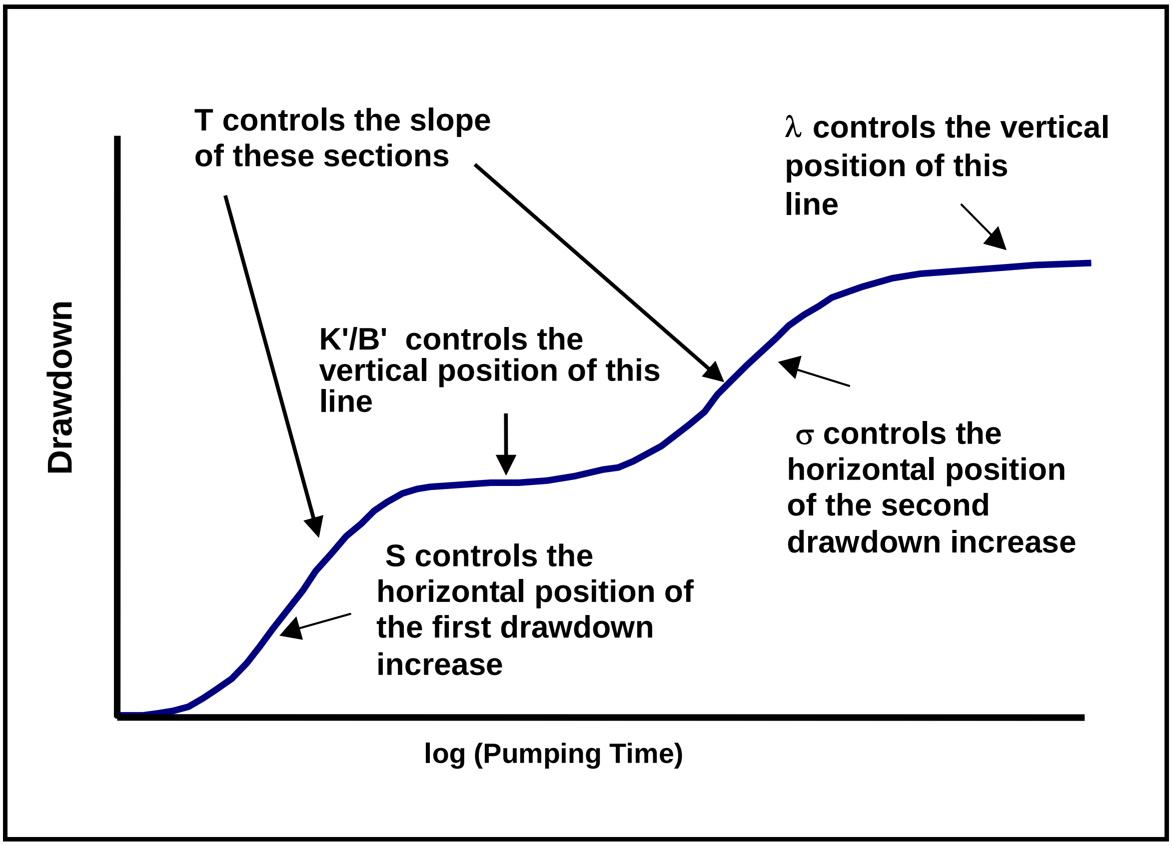



**Figure 4.1 Characteristic drawdown curve for a well screened in a leaky confined aquifer with stream depletion effects (adapted from PDP and ECan, 2005)**

This method yields the aquifer/aquitard characteristics:

- Transmissivity [$L^2/T$].
- Storativity.
- Hydraulic conductivity/thickness of the aquitard (K'/B') [T].
- Specific yield of the aquitard (σ).
- Stream-bed conductance (λ) [L].

## 4.4 Single well tests

Single well tests are more common than aquifer tests using monitoring wells due to the obvious advantage that only one well is needed. However, in practice, only transmissivity can be estimated, due to the high sensitivity of the (effective) well radius.

Some of the disadvantages of single well tests are:

- Well construction (e.g. partial penetration) can lead to an underestimation of aquifer transmissivity.
- Storativity cannot be reliably determined; and
- Single well test analyses typically make no allowance for leakage, or other recharge/no-flow boundaries.

### 4.4.1 Step drawdown tests

A step drawdown test provides a measure of well performance that can be used to estimate a well's efficiency and determine an optimal pumping rate for the well, as well as provide an estimate of maximum yield under various water level conditions.

Water levels in a pumping well decrease with pumping duration as well as increased pumping rate. This water level decrease, or drawdown, is made up of two components: aquifer loss and well loss.

a) *Aquifer loss* is head loss caused as water flows towards a well screen. Here the flow is assumed to be laminar, and the loss is proportional to the resistance provided by the material forming the aquifer.
b) *Well loss* is often associated with non-linear head loss where water flow is turbulent. Turbulent flow occurs when water passes rapidly through the well screen, and can occur in parts of the aquifer immediately adjacent to the screen. Additional turbulent losses can occur in the pump and rising column. The higher the flow the more turbulence and so the percentage of non-linear well losses increases with pumping rate.

In a step drawdown test, water is initially pumped at a known, low rate and water levels and time recorded until drawdown begins to stabilise. The pumping rate is then increased and water levels are again recorded until the drawdown again begins to stabilise. A step test should have at least three steps that cover a wide range of flows, preferably matching or exceeding the proposed design flow.

Step drawdown test data can be analysed with the Eden-Hazel (1973) method, which is based on the Jacob straight line method to give an estimate of transmissivity.

### 4.4.2 Specific capacity tests

Specific capacity is the ratio of the sustained pumping rate divided by the drawdown generated by that pumping rate, and can be determined from a single pumping step. Note that in most cases, specific capacity reduces with increasing pumping rate and extended duration.

### 4.4.3 Slug methods

For a slug test, a volume of water or solid is quickly added to, or removed from a well, and the response in water level is measured. From these measurements, transmissivity can be estimated. Slug tests are relatively straight forward and become statistically more significant when several wells in an aquifer or area are tested in a similar way. To achieve a reliable calculation of aquifer transmissivity, it is recommended that the slug test is repeated 3–5 times for each well.

Slug tests have the same disadvantages as other single well tests (step tests and specific capacity tests) in that the results are dominated by the well construction and lithological variation of the aquifer directly around the well. The short test duration and small water volumes involved mean that only very localised estimates of transmissivity may be made, and the tests are more useful in low transmissivity aquifers (where $T < 250$ $m^2$/d), because water levels can recover too quickly for manual measurements in aquifers with higher transmissivities.

Slug tests may be used in confined and unconfined aquifers and are described in Kruseman and de Ridder (1990). Fetter (2001) describes the Hvorslev slug test.

Slug tests yield the following aquifer characteristics:

- Transmissivity [$L^2$/T]].

### 4.4.4 Recovery tests

A recovery test is undertaken to determine aquifer characteristics, based on rising water levels (recovery) after the pump is turned off after a constant discharge test. A recovery analysis uses the average pumping rate during the pumping period and, therefore, the recovery data are unaffected by short period flow variations during the pumping period. It is a useful check of aquifer test parameters derived from the pumping period. A recovery test starts at the moment the pump is turned off and continues until water levels recover to at least 80% of the initial static level. Water level measurements are made more frequently immediately after the pump is turned off and less frequently with time as for a constant discharge test.

A recovery test is particularly useful for the following reasons:

- Constant discharge during pumping is sometimes difficult to achieve, particularly during the first few minutes of pumping. Recovery occurs at a constant rate, and can be used to independently verify results from early time data.
- If the pump unexpectedly fails, the subsequent recovery data can instead be used for analysis, providing good records of the pumping rates are kept.
- If test results for the pumping period appear anomalous, a recovery test can independently verify aquifer characteristics.
- Single well tests suffer from turbulence in the pumped well and hence invalid water-level measurements. Recovery data may result in a better analysis.

Theis recovery tests may be used for confined, leaky, or unconfined aquifers and are described in Kruseman and de Ridder (1990, p. 194-197 and p. 232-233).

This method yields the following aquifer characteristics:

- Transmissivity [$L^2$/T].
- Storativity (in an observation well).

# 5 Aquifer test reporting

An aquifer test report is the archival record of what happened during the test period, and the subsequent consideration of the data. The record should be complete, clear, and accurate.

All aquifer test reports provided to Environment Canterbury must comply with the NRRP Rule WQN15 (see Section 1.4), and/or relevant consent conditions, and should include the information detailed in Section 5.1 below. An example aquifer test is provided in Appendix D.

Any test submitted to Environment Canterbury should include the items summarised in the ‘Checklist for Aquifer-Test Reports’ in Appendix B.

## 5.1 Aquifer test information

One purpose of an aquifer test report is to re-create the aquifer test conditions and events for a person who did not participate. It is to include all items that affected, or potentially affect, the test results (see appendix B). More generally, a test report should include:

- Specific design of the test including modifications from the planned original configuration and rationale for any deviations.
- Map of test location, GPS locations and depths of wells and other relevant features such as screens.
- Test date.
- Static water level in all wells before testing begins.
- Hydrogeological characteristics, including:
    - Descriptive lithology and hydrogeological setting based on current understanding and well logs.
- Test results, including:
    - Aquifer parameters (transmissivity, storativity, etc.).
- Test conditions, including:
    - Pumping rate and whether it was maintained, or flow record(s)
    - Details about the discharge of the pumped water.
    - Test duration.
- Analysis summary, including:
    - Aquifer type (unconfined, semi-confined, confined).
    - Data corrections.
    - Analysis methods used.
    - Plotted data and type curves used.
    - Detailed calculations leading to determinations of aquifer characteristics.
    - Discussion of data and analysis reliability.
- References for all cited information.
- Data records, including:
    - Data forms, including original and corrected interference, time, pumping rate, and antecedent recordings for any wells or other monitored variables (such as weirs).
    - Well construction (well logs, etc.) for each participating well.

## 5.2 Aquifer test and parameter rating

All tests maintained in Environment Canterbury's archives are rated based on:

- Test type.
- Test duration.
- Reported information.
- Data reasonableness.
- Analysis method validity and model fit.
- Corrections.

This rating system is included as Appendix C.

## Acknowledgements

Environment Canterbury would like to thank Paul White of Geological and Nuclear Sciences, and Helen Rutter and Julian Weir of Aqualinc Ltd, for their contributions to this report.

# 6 Glossary

**Aquiclude:** Low permeability geological unit that, although porous and able to absorb water and contaminants, is incapable of transmitting significant quantities of water. Note: aquicludes are very uncommon in real world situations – especially over significant distances.

**Aquifer:** Saturated, permeable geological unit that is capable of yielding economically significant quantities of water to wells and/or springs.

**Aquifer test:** Withdrawal or injection of measured quantities of water from or to a well and the associated measurement of resulting changes in head during and/or after the period of discharge or injection. Aquifer tests are performed to determine hydraulic properties of an aquifer

**Aquitard:** Low permeability geological unit that retards, but does not completely halt, groundwater flow through it. It does not yield water in significant quantities to wells and/or springs, but can be a significant source of groundwater storage.

**Area of influence;** Zone around a well in which hydraulic heads are altered due to fluid injection or withdrawal activity in that well.

**Cone of depression**: Depression of hydraulic heads around a pumping well caused by the withdrawal of water. It increases in depth and lateral extent with increasing time and pumping rate.

**Confined aquifer:** Aquifer bounded above and below by an aquitard or aquiclude. Water in a confined aquifer is under pressure greater than atmospheric pressure. Note that in reality fully confined aquifers are very rare. i.e. they tend to be recharged from somewhere, and therefore are not completely confined.

**Delayed yield:** **1** Concept describing the phenomenon that the apparent storativity of an unconfined aquifer changes over time, ultimately approaching a constant value which is the specific yield; or **2** Storage released from an adjacent aquitard (and aquifer) to a pumped aquifer that appears as leakage in the short term.

**Drawdown:** Reduction in hydraulic head, or water level, at a point caused by the withdrawal of water from an aquifer.

**Hydraulic conductivity**: Hydraulic conductivity is defined as the volume of water that can move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow.

**Hydraulic resistance (c):** Characterises the resistance of the aquitard to vertical flow. Reciprocal of the leakage coefficient (K'/B')

**Leakage factor (L):** The leakage factor is a measure of leakage through an aquitard into a semi-confined (leaky) aquifer, or vice versa. Large values of L indicate a low leakage rate through the aquitard, whereas small values of L indicate a high leakage rate.

**Partial penetration:** Where the intake (screened) portion of the well is less than the full thickness of the aquifer. This causes an additional loss of head due to vertical flow components. The effects are likely to be negligible at distances of greater than 1.5 to 2 times greater then the saturated thickness of the aquifer.

**Piezometric surface:** Imaginary surface coinciding with the hydrostatic pressure level of the water in the aquifer. Also Potentiometric surface

**Porosity:** The percentage of the bulk volume of a rock or soil that is occupied by pores (interstices), whether isolated or connected.

**Semi-confined (or leaky) aquifer:** An aquifer confined by upper and lower layers of low permeability (aquitard) that allow vertical leakage of water into or out of the aquifer.

**Specific capacity**: The rate of discharge of a water from a pumped well per unit of drawdown within the well. Specific capacity varies with duration of discharge and discharge rate.

**Specific yield:** Specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit change of the water table. Specific yield is sometimes called effective porosity, unconfined storativity or drainable pore space.

**Storativity**: The volume of water an aquifer releases from, or takes into, storage per unit surface area of a saturated confined aquifer per unit change in head.

**Transmissivity:** The rate at which water is transmitted though a unit width of an aquifer under a unit hydraulic gradient.

**Unconfined aquifer:** Aquifer with no confining beds between the saturated zone and the surface and in which water is free to fluctuate under atmospheric pressure. The top of the saturated layer is known as the water table in an unconfined aquifer and the bottom of the saturated zone is terminated by an aquitard or aquiclude.

**Water table:** The surface in an unconfined aquifer at which the pore water pressure is atmospheric.

**Well interference:** The lowering of the groundwater level in a neighbouring well from pumping a nearby well.

**Well screen:** A form of well casing used to stabilise the aquifer and/or gravel pack while allowing the flow of water into the well.

# 7 References

Boulton, N.S.,1963. *Analysis of data from non-equilibrium pumping tests allowing for delayed yield from storage* Proceedings Institution of Civil Engineers, v.26, p 469-482.

Boulton, N.S., 1973. *The influence of delayed drainage on data from pumping tests in unconfined aquifer.* Journal of Hydrology 19 (2) p 157-169.

Brooks, T., 1998. *Aquifer Test Guidelines*. Environment Canterbury Technical Report U98/10..

Cooper, H. H., and Jacob, C. E, 1946. *A generalised graphical method for evaluating formation constants and summarizing well field history.* American Geophysical Union Transactions, Volume 27, p 526-534.

Dawson, K.J., and Istok, J.D., 1991 *Aquifer testing, Design and analysis of pumping and slug tests.* Lewis Publishers, Chelsea

Domenico, P. A., and Schwartz, W., 1990 *Physical and Chemical Hydrogeology* John Wiley and Sons, New York.

Driscoll, F.G., 1986. *Groundwater and wells*: St. Paul, Johnson Filtration Systems, Inc.

Eden, R.N and Hazel, C.P, 1973. *Computer and graphical analysis of variable discharge pumping test of wells.* Institute of Engineers Australia, Civil Engineering Transactions, p 5-10.

Pattle Delamore Partners Ltd (PDP) and Environment Canterbury, 2000. *Guidelines for the assessment of groundwater abstraction effects on stream flow.* (1st Ed) Environment Canterbury Technical Report R00/11.

Fetter, C.W., 2001. *Applied Hydrogeology, 4th Edition*: Prentice Hall, Upper Saddle River, N.J.

Hantush, M.S., and Jacob, C.E., 1955. *Plane potential flow of ground-water with linear leakage.* Transactions of the American Geophysical Union, vol. 35., p20.

Hunt, B., 2003. *Unsteady stream depletion when pumping from semi-confined aquifer.* ASCE Journal of Hydrologic Engineering, Vol. 8 (1) p 12-19.

Hunt, B. and D. Scott 2005. *Extension of the Hantush and Boulton solutions.* ASCE Journal of Hydrologic Engineering, Vol. 10 (3), p 223-236.

Hunt, B. and D. Scott 2007. *Flow to a well in a two-aquifer system*. ASCE Journal of Hydrologic Engineering, Vol. 12 (2), p 146-155.

Jacob, C.E., 1944. *Notes on determining permeability by pumping tests under watertable conditions.* US Geological Survey Open File Report.

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

Neuman, S.P., 1975. *Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response.* Water Resources Research, vol. 11.

Porges, R.E. & Hammer, M. J., 2001. *The Compendium of Hydrogeology*. National Ground Water Association.

Stallman, R.W., 1971. *Aquifer-test design, observation, and data analysis*. U.S. Geological Survey Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter B1.

Standards Australia, 1990. *Test pumping of water wells*: North Sydney, New South Wales, Standards Association of Australia publication AS 2368:1990.

Theis, C.V., 1935. *The lowering of the piezometric surface and the rate and discharge of a well using ground-water storage.* Transactions of the American Geophysical Union, vol. 16.

Walton, W.C., 1962. *Selected analytical methods for well and aquifer evaluation*. Illinois State Water Survey Bulletin 49.

# Appendix A: Aquifer Test Design

**Equipment Considerations for Pumping Tests**
**Pumping Test Design Plan Checklist**

# Equipment Considerations for Pumping Tests

**At pumping well**

- ☐ Pump with a non-return valve. It is important when the recovery starts that no water from the irrigation system or connected pipes flows back into the pumped well when water level measurements are taken at the pumped well.
- ☐ A flow meter close to the pumped well so the person adjusting the pump valve can immediately see the effect of adjustment on the flow rate.

**At the discharge point**

- ☐ Water chemistry sampling bottles and supplies (if required).
- ☐ Anti-scour materials to prevent erosion while discharging test water.

**At each observation well**

- ☐ Water-level probe (each well to have its own) or other water-level measuring device (Standards Australia, 1990, section 3.3.4.4). Transducers and data loggers are excellent for recording but ideally will be checked with regular manual measurements. Data loggers should all be synchronised with GPS time.
- ☐ Record keeping materials, if measurements are taken manually at each site.
- ☐ Label the measuring point on every measured well.

**Other**

- ☐ Location sketch of the test layout including wells, discharge point and any other important surface features (e.g. streams).
- ☐ Camera
- ☐ GPS
- ☐ Field communications: 2-way radios for communicating between sites and agreed hand signals, if required
- ☐ Laptops for logger download.
- ☐ Copy of relevant health and safety guidelines.

# Pumping Test Design Plan Checklist

A pumping test design plan should cover the following:

- ☐ **Test Purpose**

- ☐ **Expected hydrogeological environment**
    - Potential boundary conditions (streams/geological boundaries).
    - Existing pump/step test information

- ☐ **Map of test site** including pumping well, observation wells, discharge point, and surface water bodies.

- ☐ **Well Details** (pumping observation and background)
    - GPS location
    - Depth, screen placement, bore-log
    - Static water level range
    - Distance to pumping well

- ☐ **Proposed test duration**

- ☐ **Proposed Pumping rate(s)**

- ☐ **Estimated drawdown at monitoring wells** based on proposed pumping rate(s) and estimated parameters and model.

- ☐ **Methods of measurement**
    - **Pump rate measurement**
        - Proposed frequency and Method (e.g. orifice meter).
    - **Depth to water level measurement**
        - Proposed frequency and Method

- ☐ **Other measurements**
    - Barometric pressure, Location, frequency and method
    - Rainfall, Location, frequency and method
    - Stream Flow, Location, frequency and method

- ☐ **Discharge of water**
    - If discharge is to a stock/irrigation water race or stream, is water body capable of receiving the water? (i.e., will flooding be an issue).
    - Does local District Council need to be informed of discharge?
    - Is discharge of water likely to cause aquifer recharge that will affect testing results (i.e. if test is in same aquifer or a highly connected aquifer)?

- ☐ **Legal requirements**
    - Does pumping test meet relevant Regional Plan (NRRP) requirements? (i.e. duration, pumping rate).

Does test design meet requirements of any relevant consent conditions?

# Appendix B: Example Aquifer Test Forms

**Constant Discharge Aquifer Test Data** (2 sided form)

**Step Drawdown Aquifer Test Data** (2 sided form)

**Constant Discharge Aquifer Test Summary**

**Step Drawdown Aquifer Test Summary**

**Checklist for Aquifer Test Reports**

## Constant Discharge Aquifer Test Data

**Observation well number** ..........................................
Pumping well number ..........................................
Persons measuring ..........................................
.........................................................................................

Distance from pumping well ....................................m
Pumping rate (average).........................................L/s
Initial depth to water.................................................m
Measuring point description .....................................

Page ____ of _____ pages

| Date | Clock time (24-hour) | Time into test (min) | | Depth to water (m) | Uncorrected drawdown (m) | Drawdown correction (m) | Corrected drawdown (m) | Pumping rate (L/s) | Person measuring (initials) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pumping | Recovery | | | | | | | |
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# INSTRUCTIONS
# Data pages for *Constant Discharge* Aquifer Test

General Instructions
1. Each well (pumping or observation) has its own unique sequence of data pages.

Specific Instructions:

I. Unit definitions: L, litre; m, metre; min, minute; s, second

II. Observation well number Well number for the data recorded on the page
  - A. A data record the pumped well will record the same well number in this space as in the next line for Pumping well number.
  - B. A data record for a non-pumping well will record its own well number here.

III. Pumping well number: The well number for the well that is being pumped.

IV. Persons measuring: Record last name and first 2 initials of those recording data at this observation well.

V. Measuring point description: Brief description, such as "top of casing" or "white paint on casing." *Here and elsewhere, depths below datum are without sign or are negative (-), above datum are positive (+)*.

VI. Page ___ of ___ pages Record sequential page numbers as pages are completed; then add the total pages at test completion.

VII. Date It is sufficient to record the date at the start of the test and with the start of each new day's date.

VIII. Clock time Record the real time, as you see on your watch during the test at each measurement time.

IX. Time into test
  - A. Record as minutes. If you record the first several measurements as seconds, clearly label the values in seconds (label with "s") in the upper half of the box and later convert to minutes in the lower half of the box.
  - B. Examples
    1. "-10" indicates a measurement at 10 minutes before the pump is scheduled to be turned on, this may be used when establishing the Initial depth to water.
    2. "0" is the moment the pump is turned on.
    3. "10" is ten minutes after the pump was turned on.
  - C. Pumping Times recorded while the pump is pumping
  - D. Recovery Times recorded after the pump was turned off; "0" minutes at the moment the pump is turned off.

X. Uncorrected drawdown Determined from the following calculation: Depth to water - Initial depth to water.

XI. Drawdown correction Any and all corrections to raw test drawdown data, such as corrections for antecedent trends during test duration in which water levels have risen or dropped, regardless of the test occurring.

XII. Corrected drawdown Drawdown to be plotted for analysis, after corrections for antecedent trends, barometric efficiency, etc. Corrected drawdown = Uncorrected drawdown – Drawdown correction.

XIII. Pumping rate Complete this column only for the pumping well data form.

XIV. Person measuring Initials of person(s) making each measurement; record for every measurement or use ditto marks to indicate successive measurements by the same person(s).

XV. Comments Record any information that may later explain an anomalous measurement, such as "pump stopped," "odd, will re-measure," or "train passed."

**Step Drawdown Aquifer Test Data**

**Pumping well number** .............................................
Observation well number ............................................
Pumping rates: 1)......... 2) ......... 3)......... 4).......... 5)..........L/s
.............................................. Distance to pumping wel
Initial depth to water ... .......................................m
Persons measuring .....................................................
Measuring point description ...................................................................................................................................
Page ____ of _____ pages

| Date | Clock time (24-hour) | Time into test (min)<br>Pumping | Recovery | Depth to water (m) | Uncorrected drawdown (m) | Drawdown correction (m) | Corrected drawdown (m) | Pumping rate (L/s) | Person measuring (initials) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
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# INSTRUCTIONS
# Data pages for *Step Drawdown* Aquifer Test

General Instructions

1. Each well (pumping or observation) has its own unique sequence of data pages.

Specific Instruction

I. Unit definitions: L, litre; m, metre; min, minute; s, second.

II. Measuring point description Brief description, such as "top of casing" or "white paint on casing." *Here and elsewhere, depths below datum are without sign or are negative (-), above datum are positive (+).*

III. Persons measuring Record last name and first 2 initials of those recording data at this well.

IV. Page _____ of _____ pages Record sequential page numbers as pages are completed; then add the total pages at test completion.

V. Date It is sufficient to record the date at the start of the test and with the start of each new day's date.

VI. Clock time Record the real time, as you see on your watch during the test at each measurement time.

VII. Time into test

  A. Record as minutes unless you label as seconds, such as within the first few minutes of the test where measurements may be in seconds. Where you record seconds, write the values in seconds (label with "s") in the upper half of the box and later convert to minutes in the lower half of the box.

  B. Examples

    1. "-10" indicates a measurement at 10 minutes before the pump is scheduled to be turned on, may be used to establish Initial depth to water.

    2. "0" is the moment the pump is turned on.

    3. "10" is ten minutes after the pump was turned on.

  C. Pumping Times recorded while the pump is pumping.

  D. Recovery Times recorded after the pump was turned off; "0" minutes at the moment the pump is turned off.

VIII. Uncorrected drawdown Determined from the following calculation: Depth to water - Initial depth to water.

IX. Drawdown correction Any and all corrections to raw test drawdown data, such as corrections for antecedent trends during test duration in which water levels have risen or dropped, regardless of the test occurring.

X. Corrected drawdown Drawdown to be plotted for analysis, after corrections for antecedent trends, barometric efficiency, etc. Corrected drawdown = Uncorrected drawdown – Drawdown correction.

XI. Pumping rate Complete this column only for the pumping well data form.

XII. Person measuring Initials of person(s) making each measurement; record for every measurement or use ditto marks to indicate successive measurements by the same person(s).

XIII. Comments Record any information that may later explain an anomalous measurement, such as "pump stopped," "odd, will re-measure," or "train passed."

# CONSTANT DISCHARGE AQUIFER TEST SUMMARY

| | | | | | | |
|---|---|---|---|---|---|---|
| **Report number:** | **Well numbers** | | | | | |
| **Town:** | | | | | | |
| **District:** | | | | | | |
| **Grid reference:** | **Pumping** | **Observation** | | | | |
| **Test date:** | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Test results** | | | | | | | |
| | Reported | Individual | | | | | |
| Aquifer | | | | | | | |
| Transmissivity ($m^2$/d) | | | | | | | |
| Storativity | | | | | | | |
| Specific yield | | | | | | | |
| Hydraulic conductivity (m/d) | | | | | | | |
| Vertical hydraulic conductivity (m/d) | | | | | | | |
| Specific capacity ((L/s)/m) | | | | | | | |
| Confining Layer | | | | | | | |
| Leakage (m) | | | | | | | |
| K'/B' | | | | | | | |
| **Supplemental information** | | | | | | | |
| Distance from pumping well (m) | | | | | | | |
| Aquifer saturated thickness (m) | | | | | | | |
| Confining layer thickness (m) | | | | | | | |
| Average pumping/discharge rate (l/s) | | | | | | | |
| Final depth-to-water (m) | | | | | | | |
| Initial depth-to-water (m) | | | | | | | |
| Maximum drawdown (m) | | | | | | | |
| **Analysis methods (Tick applicable methods)** | | | | | | | |
| Confined | Theis | | | | | | |
| | Jacob | | | | | | |
| Semi-confined | Walton | | | | | | |
| | Hunt and Scott | | | | | | |
| Unconfined | Neuman | | | | | | |
| | Theis | | | | | | |
| Other: ................................................................ | | | | | | | |
| **Data corrections (Tick applicable corrections)** | | | | | | | |
| Tidal | | | | | | | |
| Antecedent trend | | | | | | | |
| Barometric efficiency | | | | | | | |
| Jacob correction for unconfined | | | | | | | |
| Boundaries | | | | | | | |
| Well interference | | | | | | | |
| Other: ................................................................ | | | | | | | |

Duration: pumping ..................min; recovery...................min

Water chemistry collected: □field values □lab analysis

Test commissioned by .............................................................

Test undertaken by ..................................................................

Test analysed by ......................................................................

**Comments**

……....................................................................................
..........................................................................................
..........................................................................................
..........................................................................................
………..................................................................................
..........................................................................................

**Reliability**:…… **Rated by/date**:……………………….…….….

| **Plan view of test site (wells, discharge, landforms, etc.)** |
|---|
| |

# STEP DRAWDOWN AQUIFER TEST SUMMARY

**Pumping well number** ........................................
Report number ........................................
Test date ......../......../.....................

Town ..........................................................
District ..........................................................
Grid reference ..........................................................

**Test results**

Transmissivity ....................$m^2$/d
Hydraulic conductivity ......................m/d
With observation wells:

| Well number | Distance from pumping well (m) | Storativity | Confining layer vertical hydraulic conductivity (m/d) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

Step-discharge test coefficients
Linear aquifer/well loss coefficient $B(r_{ew},t)$
....................d/$m^2$
aquifer loss $B_{1(rw,t)}$ .................d/$m^2$
well loss $B_2$ ....................d/$m^2$
Non-linear well-loss C ...................$d^2/m^5$

Well efficiency ..........................%
Maximum long term pumping discharge ......................l/s

**Supplemental information**

Aquifer saturated thickness ..........................m
Confining layer thickness ..........................m
Free flowing (artesian) discharge........................L/s
Water chemistry collection and analysis
- Field values
- Laboratory analysis

Test commissioned by .....................................................
Test undertaken by ..........................................................
Test analysed by:..............................................................

**Analysis method**

Confined
- Eden-Hazel
- Other

........................................................................

General
- Hantush-Bierschenk
- Rorabaugh
- Sheahan
- Other

........................................................................

- Other

.......................................................................................

**Data corrections**

- Tidal
- Antecedent trend (natural water-level fluctuation)
- Barometric efficiency (confined analysis)
- Jacob modification of confined for unconfined
- Boundaries
- Well interference
- Other ..............................................................................

| Step number | Dis-charge (L/s) | Step duration (min) | Draw-down (m) | Drawdown increment (m) | Specific drawdown (d/$m^2$) | Specific capacity ((L/s)/m) | Plan view of test site (wells, landforms, etc.) Please attach as larger copy. |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

**Comments**

..........................................................................................................................................
..........................................................................................................................................

Reliability rating: .................................................. By: .................................................. Date: ..............................

## Checklist for Aquifer-Test Reports

*An aquifer test report is to re-create the aquifer test conditions and events for a person who did not participate, including all items that affect the test results. More specifically, a test report should include the items in the following outline.*

**Title page to include**

- ☐ Report title including locality and pumping well number.
- ☐ Author(s) and report date.

**Executive summary to include:**

- ☐ Test location, including the nearest town and district.
- ☐ Date and duration of the testing.
- ☐ Purpose of testing (Aquifer parameters, actual well interference etc.).
- ☐ Aquifer parameters value that represent the aquifer test results and the range of values.

**Report to include:**

- ☐ Hydrogeological summary.
- ☐ Map of test site including; pumping well, observation wells, discharge point, any recharge/no-flow boundaries, and surface water bodies.
- ☐ Dates and duration of pumping and recovery periods.
- ☐ Wells pumped and observed, with static water levels.
- ☐ Any data corrections applied (such as antecedent trends, barometric, etc.).
- ☐ Analysis method(s) applied to determine aquifer characteristics, along with solution assumptions.

**Discussion and analysis.**

- ☐ Data used to correct observed data.
- ☐ Plotted test data.
- ☐ Include all calculations that lead to the determination of aquifer characteristics.
- ☐ Discussion of reliability of data and analysis; aquifer test assumptions.
- ☐ Note any unmet or partly met assumptions.
- ☐ Note any other general factors that affected test or analysis results.

**Submit the final report to Environment Canterbury as:**

- ☐ Paper copy.
- ☐ Electronic copy.
- ☐ Please include a copy of all data electronically.

☐

# Appendix C: Aquifer Test Quality Rating

Well # _________   Test date___/___/___   Rated by________

**Environment Canterbury Aquifer Test and Parameter Rating Form**

## Preliminarily Check

| | |
|---|---|
| ☐ | Pumping Rate(s) |
| ☐ | Well Locations/ distances |
| ☐ | Data Sets |
| **If any of the above criteria are missing then test is considered to be unreliable** | |

## Test Rating:

### Type & Duration

| | |
|---|---|
| 1 | **Slug Test** |
| | **Step Test** |
| 0 | 1 step |
| 1 | 2 to 3 steps |
| 2 | 3+ steps |
| | Duration: |
| 0 | <0.5 hour per step |
| 1 | 0.5 to 1 hour per step |
| 2 | >1 hour per step |
| 3 | **Multiple Well** (with at least 1 observation well) |
| | Duration: |
| 1 | <24 hours |
| 2 | 1-2 days |
| 3 | >2 days |

### Well Details

| | |
|---|---|
| 0 | Depths unknown |
| 1 | All depths known (some screens known) |
| 2 | All screen locations known |

### Well locations

| | |
|---|---|
| 0 | No observation wells |
| 1 | Observation wells in overlying (or underlying) aquifer |
| 2 | Observation wells in pumped aquifer |
| 3 | Observation wells in pumped and overlying (or underlying) aquifer |

### Reported Info

| | |
|---|---|
| 1 | Static water levels Water level |
| 1 | GPS locations |
| 1 | Test date |
| 1 | Barometric data |

Test Rating
Total ____out of 15

| Score | Wells Database Rating |
|---|---|
| >5 | 3 |
| 5-10 | 2 |
| 10+ | 1 |

**Objectives** - Did testing meet design purpose?

| |
|---|
| No |
| Partially |
| Yes |

## Parameter Rating:

**Analysis method & Fit of model**

| | |
|---|---|
| 0 | Invalid analysis |
| 1 | Poor Fit of model to observations |
| 2 | Reasonable Fit of model to observations |
| 4 | Excellent Fit of model to observations |

**Boundaries**

| | |
|---|---|
| 0 | Not identified, but present |
| 1 | Identified and corrected for |
| 2 | Not present |

**Corrections**

| | |
|---|---|
| 0 | Required, but not applied |
| 1 | Required and applied |
| 2 | Not required |

**Drawdown** in observation well (max, non-pumping)

| | |
|---|---|
| 0 | Less than 0.1 m |
| 1 | 0.1 to 0.2 m |
| 2 | Greater than 0.2 m |

Parameter Reasonableness rating
Total ____out of 10

| Score | Wells Database Rating |
|---|---|
| >2 | 5 |
| 2-4 | 4 |
| 4-6 | 3 |
| 6-8 | 2 |
| 8+ | 1 |

**Comments:**

# Appendix D: Annotated Aquifer Test Report Example

# Pumping Test on WellXX/0001, Locality1

## Report Number XX/00X
## 1 September 20XX

## Prepared by LL Pump Co

## Summary

LL Pump Co conducted pump tests on bore XX/0001, owned by S and J Smith, located at Locality1 in August 20XX. An aquifer test with observation bores was conducted to provide aquifer characteristics, and a step-drawdown test to provide information on well efficiency.

Initially a variable-rate drawdown test utilizing 4 observation bores was conducted for a 2-day period pumping at 25 and 70 L/s. Drawdowns were only recorded in one observation bore, A35/0005 which was located in the same aquifer as the pumped well. No drawdown was observed in shallower (80-90 m) observation bores.

A Hantush-Jacob analysis of the drawdown data provided the parameters:

| | | |
|---|---|---|
| Transmissivity (T) | = | 4000 $m^2$/day |
| Storativity (S) | = | 0.00007 |
| Leakage (L) | = | 22,900 m |
| K'/B’ | = | 0.000008 $d^{-1}$ |

The lack of drawdown in shallower observation bores, combined with the leakage value (which indicates minimal leakage) indicates that the pumped aquifer is acting in a nearly confined manner, and there is little interaction over the pumped time period with overlying aquifers.

A step-drawdown test pumped at 5 rates of between 35 and 70 L/s yielded an estimated transmissivity (using the Eden-Hazel method) of 1800 $m^2$/day and a well efficiency of 31 – 42%.

# 1 Introduction

LL Pump Co was contracted by S and J Smith to pump test bore A35/0001 near Locality1. This report presents details and findings of pump testing which was undertaken from the 2nd to the 6th of August 20XX.

> Dates of testing included

## 1.1 Scope/Purpose of Testing

A variable-rate aquifer test was undertaken to provide aquifer parameters to better predict long-term interference effects to assist in a consent application to take water, as well as to add to hydrogeological understanding in the area.

A step-drawdown test was also undertaken to ascertain the hydraulic performance of the bore.

> Refer Section 2.1 – Purpose includes a clear aim for testing

## 1.2 Location

WellA35/0001 is adjacent to Railway Road, Ashburton and is owned by S and J Smith. A location map is provided in Appendix A showing the position of all bores used during testing. Accurate locations of all bores was obtained using a hand-held GPS unit.

# 2 Hydrogeology

The Locality1 area is characterised by a sequence of leaky aquifers, overlain by a shallow aquifer associated with the XXXX river. The shallow aquifer is typically less than 25 m deep, and occurs within a limited (1-2 km) extent of the river. The deeper leaky aquifer consists of coarse sandy gravels, and is overlain by a leaky confining layer of silty clay. A third aquifer is encountered at depths of greater than 160 m. Again these sandy gravel aquifers are ... in bore logs as 'clay'. Bore logs for all of the ... Appendix B.

> Description of hydrogeological environment and relation of aquifer tested to other aquifers. Refer to Section 2.2

Water levels in the deeper aquifers are typically lower than the overlying aquifers, and indicate a downwards hydraulic gradient. It is unknown how hydraulically connected the deeper aquifers are to each other, as no other aquifer testing at the depth of the subject bore (A35/0001) have been completed in this area. Previous tests in the shallow and second aquifer have indicated there is some limited connection between the shallow unconfined aquifer and the first leaky aquifer, with K'/B' values in the order of 0.01 – 0.001 $day^{-1}$.

# 3 Step-Drawdown Test

## 3.1 Test Details

A step-discharge test was undertaken on bore A35/0001 on 2nd August 20XX. Table 1 summarises bore details for A35/0001. The bore was pumped at 5 different rates between 40 and 70 L/s, for 60 minutes per step. and then recovery was measured (refer to Table 2 for details).

**Table 3.1 Details for A35/0001**

| | |
|---|---|
| Well Number | A35/0001 |
| Owner | S and J Smith |
| Grid Reference | A35:00011:00022 |
| Depth | 170 m |
| Diameter | 300 mm |
| Casing Material | Steel |
| Use | Irrigation and stockwater |
| Screen details | 160 - 170 m (stainless steel) |

Flow from A35/0001 was measured using the installed flow meter (type XXX), and was logged using a minitroll logger. Water was discharged into a stock-water race located 200 m from the bore (refer to site diagram in Appendix A).

Groundwater levels in the pumped well were logged automatically at 30 second intervals using a mini-troll diver. Manual measurements were also taken before, during and after the test to calibrate the recorder data.

Details of measurement method (refer to Section 3.2)

## 3.2 Analysis and Results

A summary of all data collected for the step-drawdown test is presented in Table 1. Raw data is included in Appendix C. Data collected from the step-drawdown test was analysed using the Eden and Hazel (1973) method to calculate aquifer transmissivity and bore efficiency. Figure C.1 in Appendix C shows the Eden-Hazel analysis, from which a transmissivity of 1800 $m^2$/day was derived.

Method of analysis listed (refer Section 4)

**Table 3.2 Summary of results from step-drawdown test on bore A35/0001**

| Step | 1 | 2 | 3 | 4 | 5 | Recovery |
|---|---|---|---|---|---|---|
| Pump time (mins) | 0 | 60 | 120 | 180 | 240 | 300 |
| Duration of step (mins | 60 | 60 | 60 | 60 | 60 | |
| Pump Rate (L/s) | 40 | 50 | 57 | [illegible] | 70 | |
| Maximum measured drawdown | 6.85 | 9.65 | [illegible] | 14.3 | 16.68 | |

All pump rates, durations and drawdowns recorded for step test

# 4 Variable Discharge Test

## 4.1 Test Details

A variable discharge test was undertaken on bore A35/0001 on 2nd August 20XX. The pump rate was 25 L/s for the first 566 minutes of the test, and then increased to 70 L/s for the remainder of the 3,043 minute test (just over 2 days to observe leakage). Recovery was measured over 1,322 minutes. Four [illegible] neighbouring bores at depths of 116 to 172 m and distances of 1,400 to [illegible] from the pumping bore were measured during the test. These [illegible] the closest bores to the subject pumping bore.

Justification made for test duration (refer to Section 2.6) and reasoning behind choice of observation bores.

[illegible] discharge aquifer test, and Table 4 summarises pumping details. Raw data is included in Appendix D (Figures D.1 to D.6).

**Table 4.1 Variable Discharge Test details**

| Well Number | A35/0001 | A35/0002 | A35/0003 | A35/0004 | A35/0005 |
|---|---|---|---|---|---|
| Well Use | Pumping | Obs | Obs | Obs | Obs |
| Easting | 240001 | 240xxx | 240xxx | 240xxx | 240xxx |
| Northing | 570001 | 570xxx | 570xxx | 570xxx | 570xxx |
| Depth (m) | 170 | 170 | 170 | 170 | 170 |
| Diameter | 300 | 300 | 300 | 225 | 300 |
| Radius from pump bore (m) | | 1450 | 3330 | 2930 | 2500 |
| Static water level at start of testing (m bgl) | 99.17 | [illegible] | 30.97 | 35.00 | 85.13 |
| Screen (m bgl) | 160-170 | 80-9[illegible] | [illegible]5-95 | 98-105 | 162-175 |

Details of all pumping and observation wells included.

**Table 4.2 Pumping Details**

| | | |
|---|---|---|
| Pump Bore | | A35/0001 |
| Pump Start (NZST) | | 2/8/XX 07:42 |
| Pump Stop (NZST) | | 4/8/XX 10:25 |
| Total pump time | hrs | 50.7 |
| | mins | 3043 |
| Pump Rate | 0 - 566 mins | 25 L/s |
| | 566 - 3043 mins | 70 L/s |
| Barometric Pressure at start (hPa) | | 985 |
| Barometric Pressure at stop (hPa) | | 992 |

All pumping rates and times recorded

## 4.2 Data Corrections

Barometric pressured varied throughout the test period (refer to Figure C.1, Appendix C), Rising in the first day from around 986 hPa to 993 hPa, then fluctuating slightly from 991 to 993 hPa over the remainder of the test. This change in barometric pressure has a moderate effect on groundwater levels measured in during the test – with all bores recording a similar magnitude [illegible]. Corrections were applied to account for this. Tidal effects also app[illegible] groundwater levels.

Appropriate data corrections applied (refer to Section 4.2)

WellA35/0003 did not record drawdown from the pumping test, and was used to correct for antecedent trend. Figure D.3 in Appendix D shows the water levels measured at this bore, which show a declining trend over the period of measurement.

## 4.3 Analysis

Once corrections were applied to the groundwater level data, drawdown was only apparent at one well, A35/0005. Table 4.3 details the drawdown response.

**Table 4.3 Maximum drawdown recorded in observation bores**

| Well | Depth (m) | Radius (m) | Max displacement (m) |
|---|---|---|---|
| A35/0002 | 96 | 1450 | 0.5 |
| A35/0003 | 95 | 3330 | 0 |
| A35/0004 | 105 | 2930 | 0.2 |
| A35/0005 | 175 | 2500 | 0.4 |

The corrected drawdown and recovery data for A35/0005 was analysed using the Hantush-Jacob (1955) method to determine aquifer transmissivity, storativity and leakage factor for the pumped aquifer. This method was chosen as appropriate for a leaky aquifer. No delayed yield response is seen in the drawdown curve for bore A35/0005, hence the Hunt-Scott model was not utilised. The analysis was undertaken using the AQTESOLV (Duffield, 1996) program. Figure D.8 in Appendix D illustrates the drawdown data and matched curve. Tabl[illegible] resulting aquifer parameters.

Justification for the analysis method chosen

**Table 4.4 Aquifer parameters for A35/0001**

| Bore | Radius from pumped bore (m) | Analysis Method | Transmissivity ($m^2$/day) | Storativity | K'/B' ($d^{-1}$) | Aquifer Type |
|---|---|---|---|---|---|---|
| A35/0005 | 2500 | Hantush-Jacob (1955) | 4000 | 0.00007 | 0.000008 | Leaky |

Summary of results provided.

## 4.4 Discussion

The K'/B' value indicates that little leakage is occurring, and the aquifer is acting in an essentially confined manner for the duration of the test. The test was 2 days long, and it is possible that with further pumping, a delayed yield response may have occurred. While the Hantush-Jacob method has been used to analysis the data, it is not recommended that this method be used to extrapolate longer term drawdown in neighbouring wells, because it does not take account of the delayed yield response that may occur. A more conservative estimate of long-term drawdowns can be obtained using the Theis model (based on the lack of leakage) or the Hunt-Scott model with an assumed aquitard specific yield.

# 5 References

Eden, R N and Hazel, CP (1973): Computer and graphical analysis of variable discharge pumping test of wells. *Civil Engineering Transactions Institute of Engineering, Australia: 5-10*

Hantush, MS and Jacob, CE (1955): Non-steady radial flow in an infinite leaky aquifer. *American Geophysical Union Transactions 36:95-100.*

Hunt, B., 2003., 'Unsteady stream depletion when pumping from semi-confined aquifer' Journal of Hydrological Engineering 8 (1) p 12-19.

G.M Dufffield, AQTESOLV v.3.01, Hydrosolv Inc.

# Example Appendix A: Site Plan and Well Locations

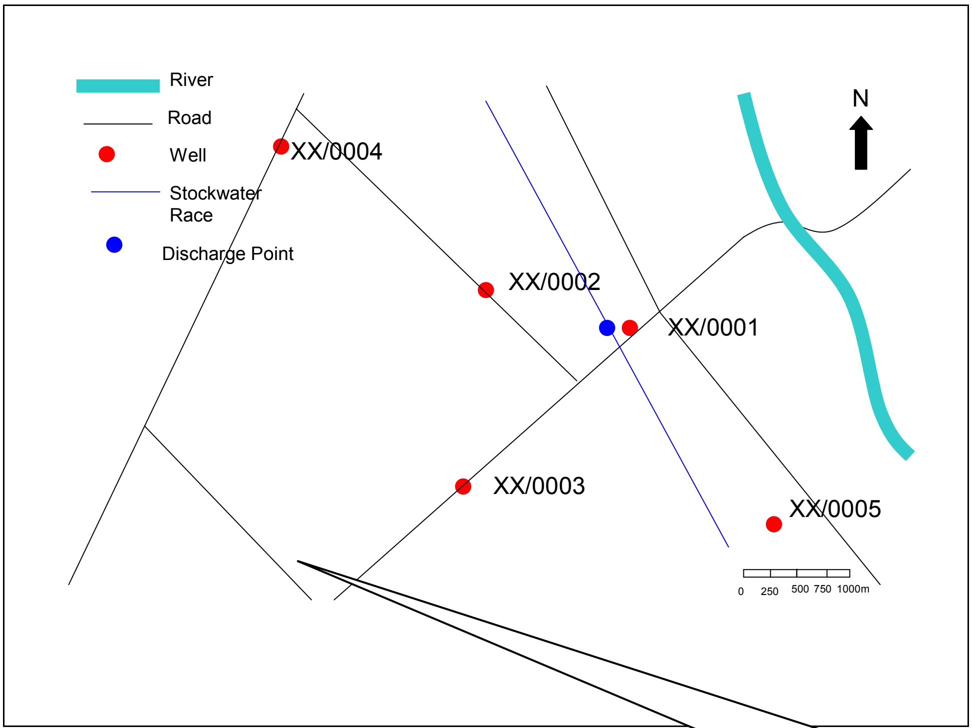
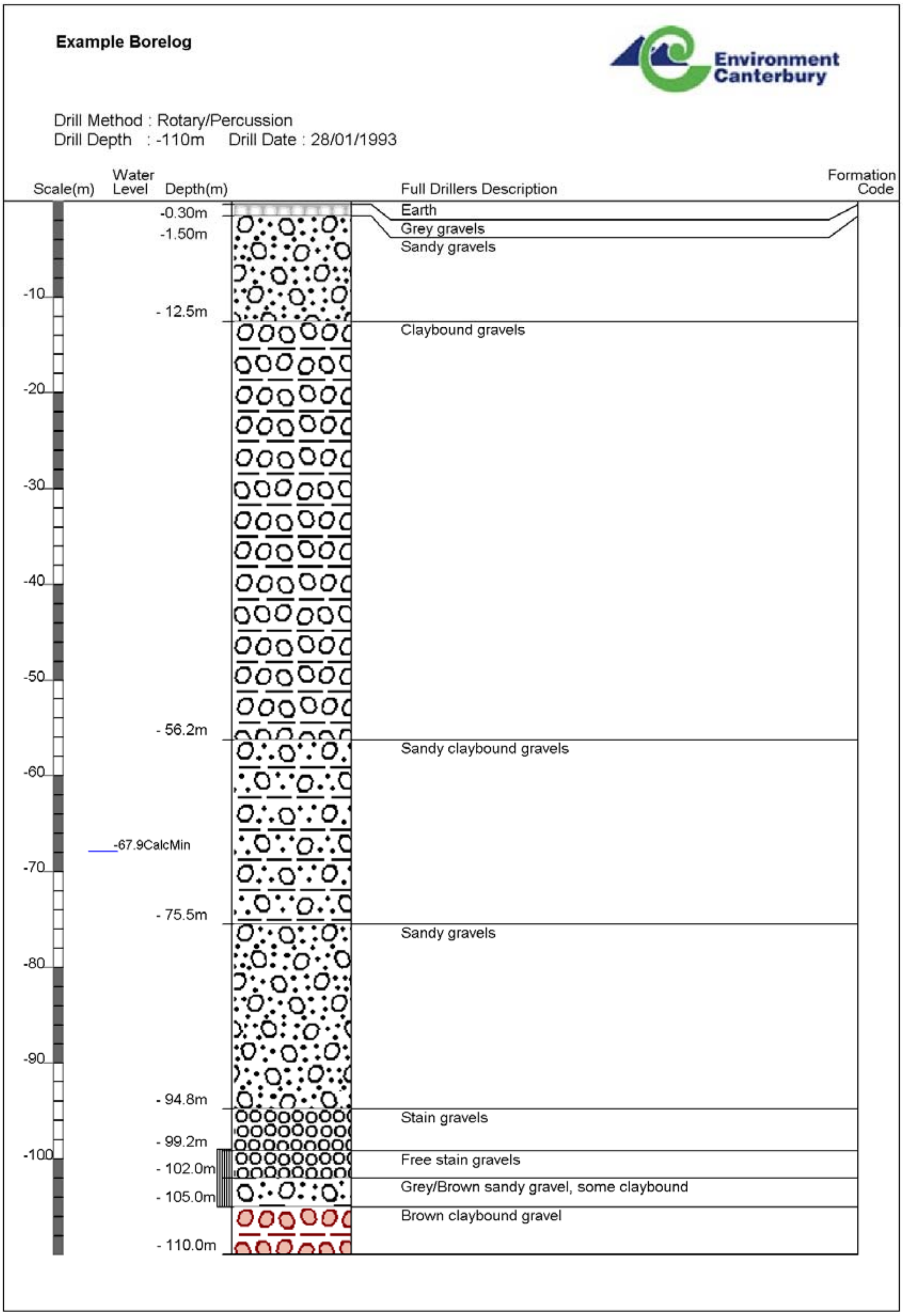


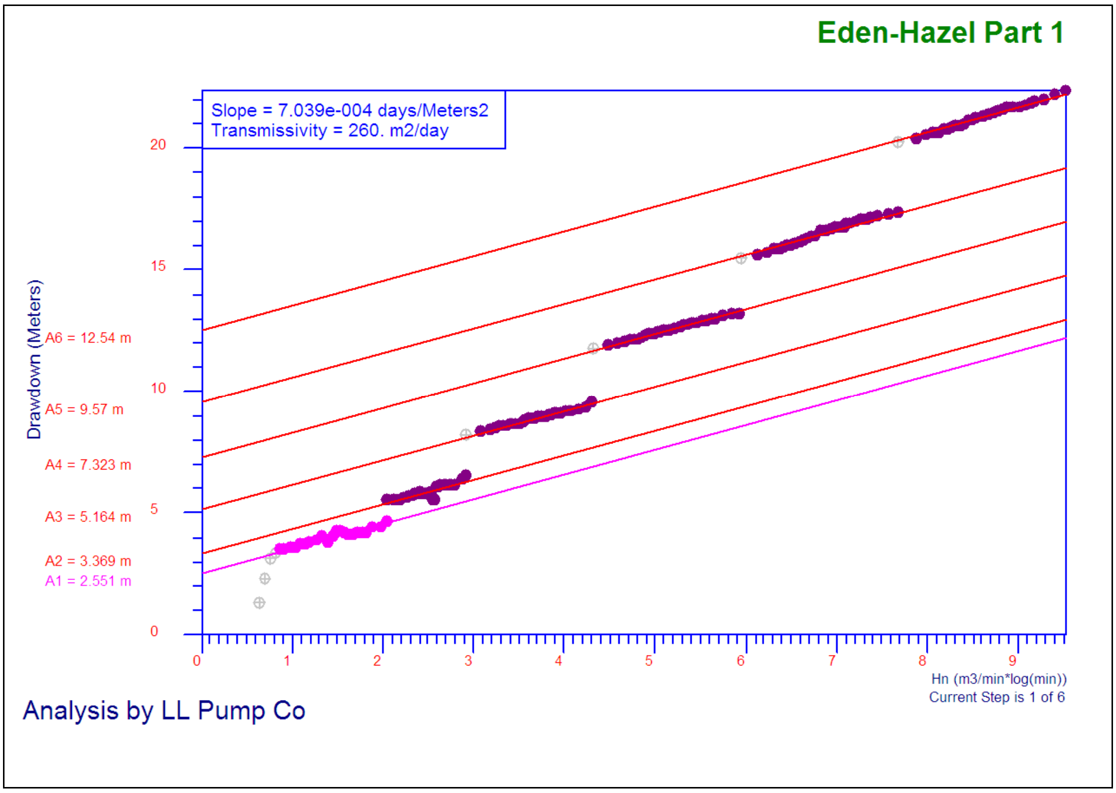

**Figure A 1 Location of Test Site**

Site plan includes all well locations, discharge point and relevant surface features.

# Example Appendix B: Bore Log Details



# Example Appendix C: Step-Drawdown Test Analysis



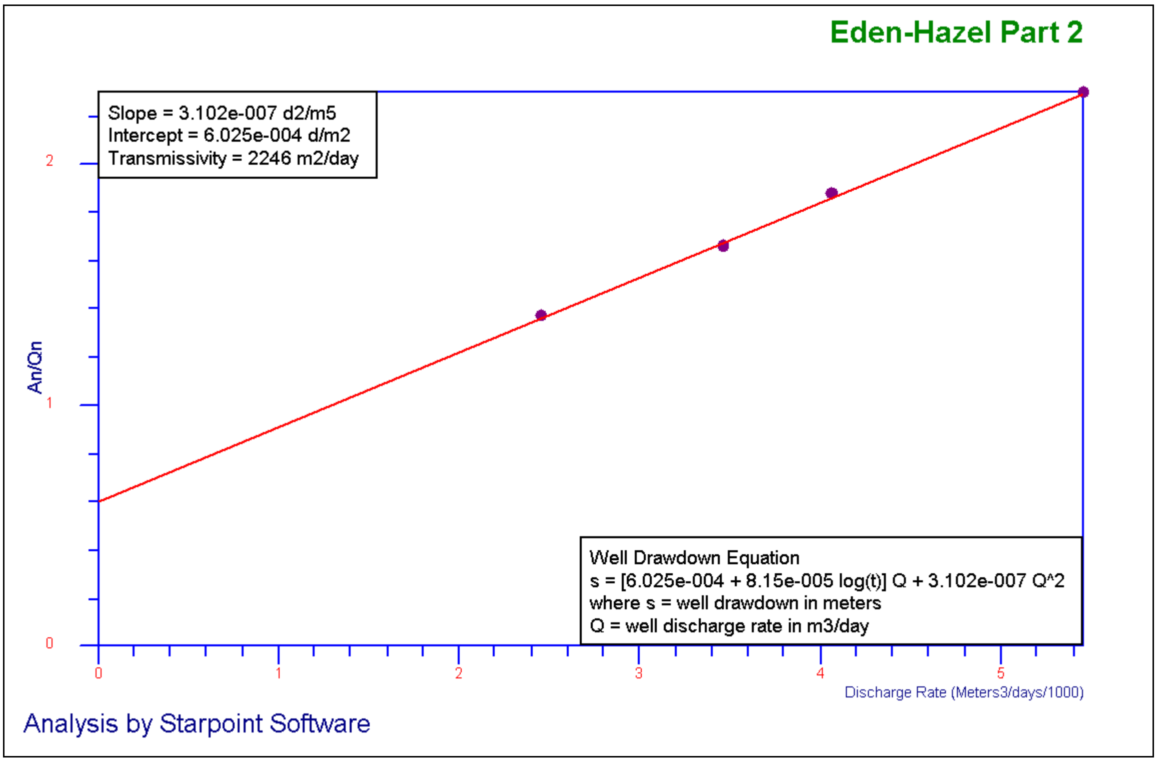




**Figure C 1 Step Drawdown Analysis – Curve fits**

# Example Appendix D: Variable-Rate Test Analysis

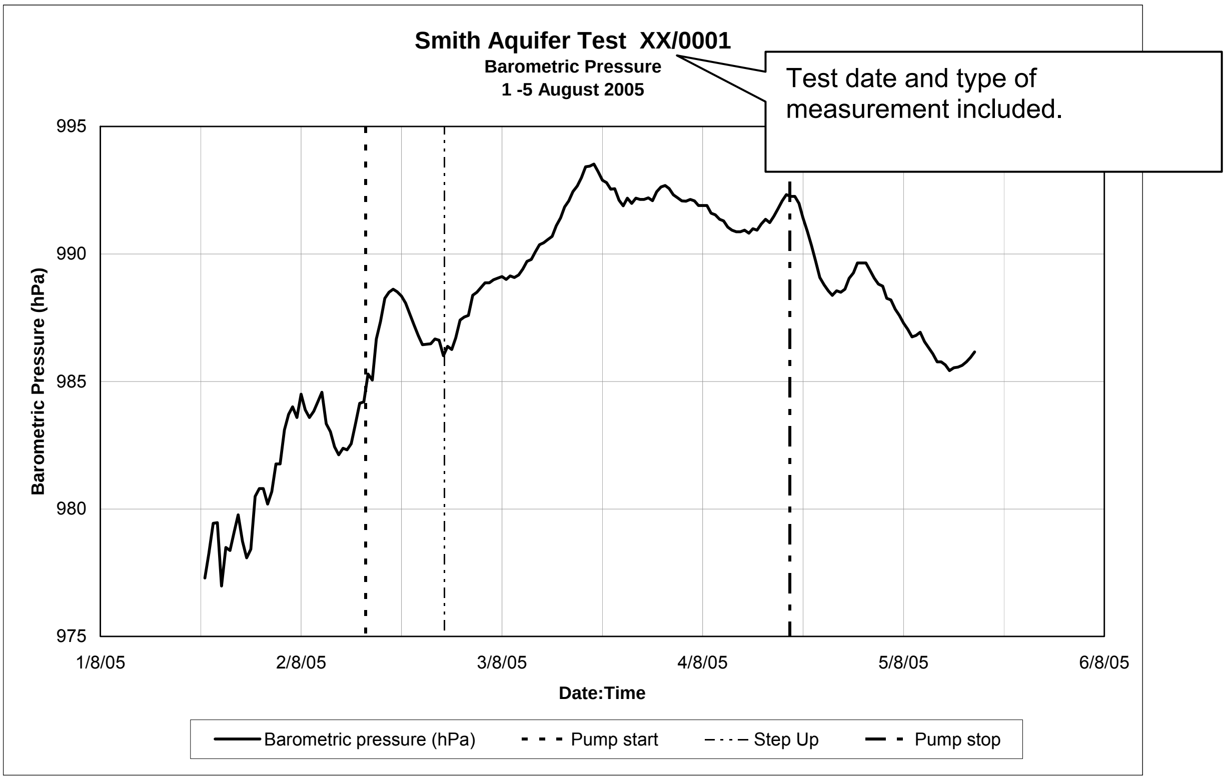



**Figure D 1: Barometric Pressure over Aquifer Test Period**

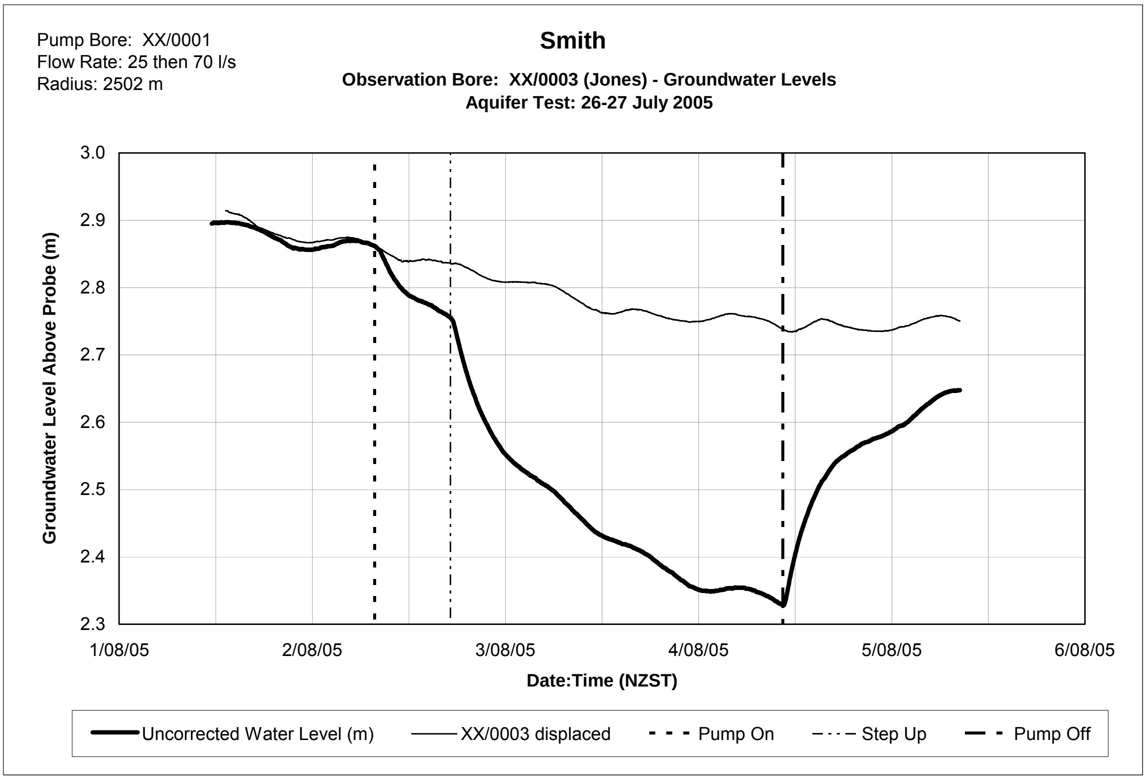



**Figure D 2: Hydrograph of observation bore A35/0005 and antecedent trend shown in A35/0003**

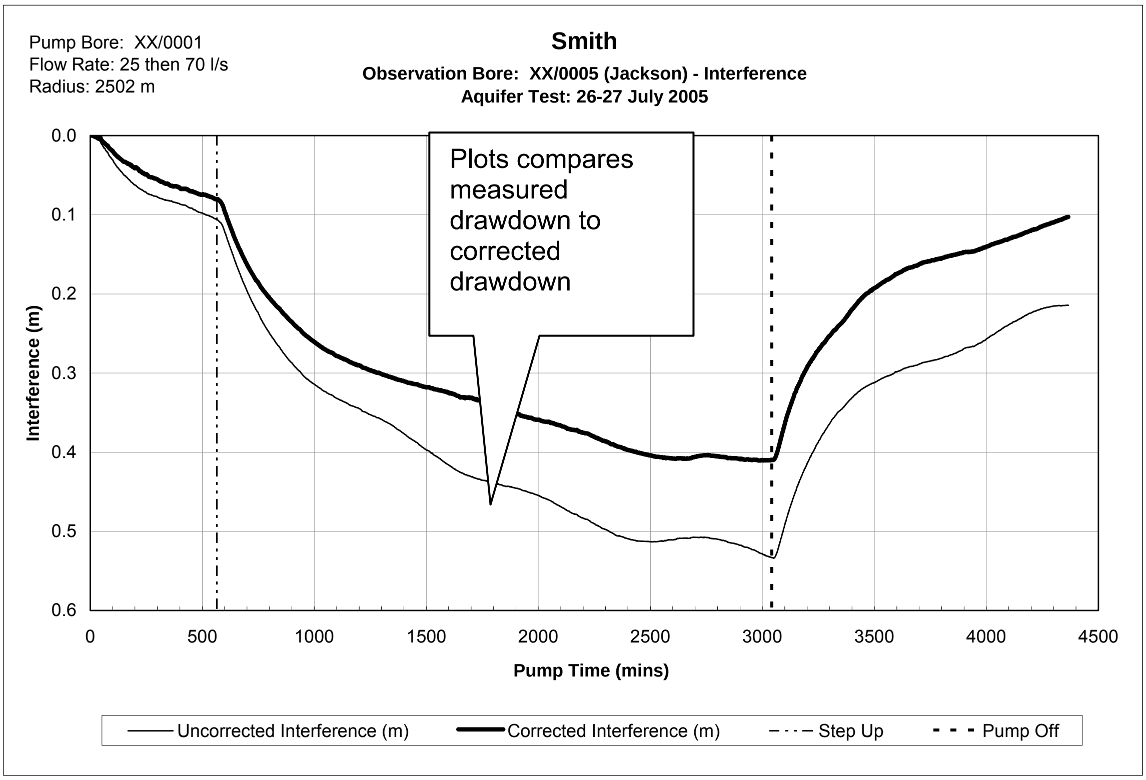



**Figure D 3: Drawdown and corrected drawdown hydrograph for observation bore A35/0005**

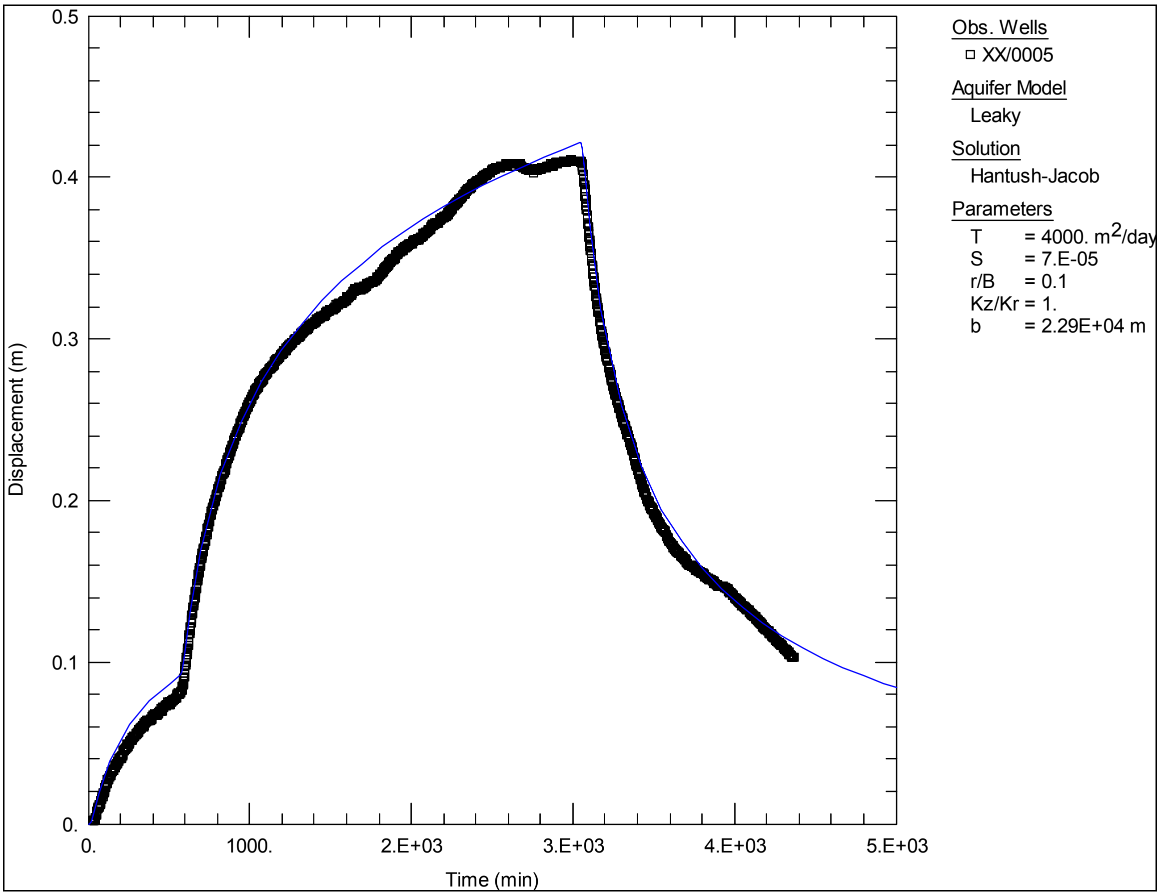



**Figure D 4: Hantush-Jacob Drawdown analysis of observation well A35/0005**

Analysis plot includes well number, analysis method used, resulting parameters, raw data and type curve.

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