

Guidelines prepared by: Tim Ezzy and Matt Smith
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Guidelines for Reviewing Aquifer Tests for Proposed Consents or for Compliance with Consent Conditions

1 Introduction

Groundwater practitioners are often required to predict how an aquifer system will respond to a proposed or existing stress (e.g. groundwater abstraction). Current industry practice is to develop simplified conceptual models (CM) and to utilise a range of hydraulic parameter estimates. These CM are easily translated into analytical or numerical models, and can be conveyed to stakeholders.

The prediction of effects that are derived using models are inherently uncertain. The source of this uncertainty can largely be attributed to model error and to parameter error. Model error reflects the discrepancy between a simplified CM and the complex real world and can be evaluated by considering a range of alternative conceptual models. Parameter error, which reflects both measurement error and CM error, is best managed using a probabilistic framework which typically requires evaluation of a range of likely values rather than a single “best estimate”. An aquifer test is often the most effective method to constrain estimates of hydraulic parameters, while also providing an insight into the localised hydraulic performance of a given aquifer system (Kruseman and de Ridder, 1994). Because of the non-uniqueness of analytical solutions and the simple approximation of a real aquifer system, there is always an element of subjective judgement used when analysing an aquifer test. This subjective judgement may relate to selection of a likely CM for the site, or selection of the most appropriate solution to analyse the data, or which segments of the data should be considered more representative of the aquifer system.

Aquifer tests often result in drawdown responses that deviate from theoretically ideal responses as a result of one or more of the following factors:

- Fluctuations in discharge rate;
- Background trends in groundwater levels;
- Recharge boundary effects (including irrigation, rainfall, re-circulating pump-off water and presence of surface water bodies);
- No flow boundary effects;
- Barometric fluctuations;
- Aquifer heterogeneity and anisotropy not accounted for in the assumptions of the solution; and
- Superposition interference effects from other abstractions at the time of testing.

Correcting for interference and boundary conditions, and conclusively estimating a representative range of hydraulic parameters is a challenging and often debatable undertaking.

Acknowledging all of the uncertainty associated with aquifer test analysis should be the starting point when designing, analysing or reviewing tests to ensure that they are fit for a particular purpose. Aquifer tests are an important information source to support the AEE of proposed consents to take and use groundwater, as well as for demonstrating compliance with consent conditions. The hydraulic parameters estimated from the tests are typically used in analytical and numerical models to predict potential environmental effects as a result of pumping from a proposed well. The majority of predictions are for

assessing potential drawdown interference on neighbouring wells and stream depletion effects.

This guideline provides a benchmark for the review of aquifer test analyses. The guideline is intended to be a “living document” and we¹ encourage ongoing input and feedback on effectiveness and issues. The guideline provides details a set of analysis tools which can be used for both analysis and review. These tools have been provided to maintain a consistent review process between different reviewers. Again, we encourage you to provide feedback and ideas regarding these, and possible alternative, tools.

2 Up-Front Considerations

Aquifer tests for consent applications (or compliance) are generally undertaken to support an AEE. The key review question will be “Has the test provided results that ensure a reliable assessment of effects?” and ideally the review should also evaluate the AEE. In any case the review should consider the following questions:

- What is the purpose of the test?
- Did the test satisfy the purpose?
- If not, what are the limitations from the testing, and what are the consequences for any effects predictions?

It is important to recognise that not all tests will be used for the same purpose. The level of scrutiny placed on test analysis should match the significance of the AEE. For example, there is no point in arguing whether a barometric efficiency (BE) should be 30% or 50%, if the predicted drawdown interference using the WQN10 tool is below the minimum threshold in either case. Continuing with that example, if the consultant has not already provided WQN10 analysis scenarios using both 30% and 50% BE, the reviewer could prompt the consultant (via Matt Smith or Tim Ezzy) to provide those further predictions, rather than pushing for re-analysis of the barometric efficiency. If significant effects are likely to occur within that range of uncertainty, then further scrutiny of the aquifer test analysis is required. This “so what” type of approach to analysis and review has been promoted by the Canterbury Water Consultants’ Aquifer Test Sub-committee.

3 Verification of Data and Corrections

The first stage of review is to verify the data and analysis within the report. This is an important step to detect data transfer and data handling errors. Environment Canterbury will provide the processed datasets (usually in Microsoft Excel format) to the reviewer. We recommend an audit approach, rather than a comprehensive parallel assessment. Things to consider when auditing must include:

- Do drawdown measurements start at logical times after pumping has commenced?
- Does the aquifer recover to near pre-test levels, if not why not?
- Are any changes in pumping rates or pumping times described and accounted for?
- Are the corrections appropriate?
- Is the discharge location appropriate?
- Are the well numbers and well depths consistent between the report and the analysis?
- Are the monitoring wells screened at appropriate depths with respect to the pumped well?
- Are the test details within the report consistent with the data and appendices?
- Is the CM defensible and representative of the local aquifer system, or is there another CM that makes more sense?
- Are the groundwater-level measurements in the pumping well and the observation wells measured at reasonable time intervals? (see Section 3.2 of R08/25)

4 Analysis

The analysis should be reviewed after the data and corrections have been verified. The analysis should be logical, thoroughly explained and justified, and the detail should match the scale and significance of the potential effects. As mentioned in Section 2 above, a reviewer must consider the purpose of the test, and whether that purpose has been

¹ Contact Tim Ezzy (tim.ezzy@ecan.govt.nz) [03.363.9357] or Matt Smith (matt.smith@ecan.govt.nz) [03.364.9848]

achieved. The primary task of the reviewer is to determine whether the hydraulic parameter estimates are defensible and can be used to make appropriately conservative predictions of effects.

A robust analysis will have provided the following:

1. A clear description of the parameter thresholds for effects-based predictions (e.g. $T < 250 \text{ m}^2/\text{d}$ and $S < 0.00001$ will cause neighbouring wells to be affected). This type of screening assessment can be done efficiently using Environment Canterbury's online analytical calculators²;
2. A suitable range of parameter estimates based on conservative drawdown curve matching analysis (e.g. T is likely to be between $800 \text{ m}^2/\text{d}$ and $1,200 \text{ m}^2/\text{d}$, and S is likely to be between 0.0001 and 0.00001); and
3. A direct comparison of parameter thresholds and parameter estimates from drawdown curve matching. (e.g. A comparison of T and S thresholds indicate that the aquifer hydraulic parameters are not breaching the thresholds required to cause effects).

Note that the approach to aquifer test analysis described above is not mandatory. An aquifer test analysis should provide sufficient information about the likely range of parameter values to allow a reliable AEE. Non-uniqueness may mean that different parameter combinations may be possible; particularly for the more complex CMs. This complexity may need to be described.

5 Guidelines for Consideration

Section 4 of the Environment Canterbury aquifer test guidelines (Aitchison-Earl and Smith, 2008³) provides a good introduction to our expectations regarding analysis of aquifer tests. We also endorse Kruseman and de Ridder (1994) as a comprehensive text that describes aquifer test analysis in most aquifer types (e.g. unconfined, leaky, confined) and geological settings (e.g. bounded aquifers).

There is a practice note available on the Environment Canterbury website⁴ that outlines an approach for correcting groundwater level data for barometric fluctuations and barometric efficiency. A main recommendation of that practice note is that aquifer tests be designed to achieve more than 0.2 m of pumping induced drawdown at the observation well(s).

6 Aquifer Test Quality Rating

All tests maintained in Environment Canterbury's archives are rated for data reasonableness, analysis method validity, model fit and corrections. The rating system is outlined in Appendix C of the aquifer test guidelines. The reviewer shall use the rating form to assess a quality rating for each test that is reviewed. The quality form is a simple ranking exercise that generates a rating for both the test and for the estimated parameters.

7 Documentation of the Review

The reviewer shall prepare a brief written report (approximately 1-2 pages) outlining the major findings of the review. The report should focus on any issues or irregularities in the analysis. The issues should be separated into three clear categories:

1. Positive aspects of the test and/or analysis that were better than the "standard practice". This is an important and often overlooked part of the review that will allow the industry to learn and improve from each other;
2. Negative aspects of the test and/or analysis that could be improved upon in future tests. These are issues that may not be critical to the outcome of this particular test, but may be in future tests; and
3. Negative aspects of the test and/or analysis that have an influence on the effects predictions.

² <http://ecan.govt.nz/services/online-services/tools-calculators/Pages/groundwater-tools.aspx>

³ <http://ecan.govt.nz/publications/Reports/AquiferTestGuidelines2008plusReportExample.pdf>

⁴ <http://ecan.govt.nz/publications/General/Practice%20note%20-%20Barometric%20pressure%20correction.pdf>

8 Checklists

There are a series of checklists within the aquifer test guidelines, which may be useful while reviewing test analyses:

- Appendix A contains equipment considerations and test design checklists; and
- Appendix B contains test data sheets and summary sheets for constant discharge and step drawdown tests.

There is also a checklist for aquifer test reports.

A “Self audit check sheet” for aquifer test design is also available on the Environment Canterbury website⁵. The purpose of this checklist is to encourage aquifer test practitioners to minimise sources of external interference and maximise any observation response.

Finally, there is a checklist that will accompany any pre-application review request. This new pre-application review service was developed to align with the principles of the RMA Streamlining Act in 2009. We developed these forms to describe the minimum level of information that should be supplied to a reviewer in order to complete a review. There is a separate form for constant discharge tests⁶ and step drawdown tests⁷.

9 Set of Analysis Tools

We are providing access to a set of analysis tools which will be posted on our website and updated from time to time. These tools utilise the Microsoft Excel[®] “Function.xls” macro functions⁸ developed by Dr Bruce Hunt. We also recommend several software packages that we use internally on a regular basis to review tests.

The Excel spreadsheet tools developed using Bruce Hunt’s Function.xls include solutions for confined and leaky aquifer systems. The analysis tools we have developed include:

- A spreadsheet analysis tool that progressively locks down individual hydraulic parameter estimates using Theis, Hantush-Jacob, and Hunt and Scott solutions. The Theis solution is used first to resolve pumped aquifer T and S estimates; the Hantush-Jacob solution is then utilised to resolve K'/B'; and finally, the Hunt and Scott solution is used to estimate parameters in the overlying aquifer. The progressive use of these three solutions requires an iterative approach;. and
- A spreadsheet that utilises multi-parameter curve matching methods to solve for the Theis, Boulton, Cooper-Jacob and Hunt-Scott solutions.

We are also currently looking into developing an uncertainty analysis tool, which will provide a probabilistic description of estimated hydraulic parameters. This approach is currently being evaluated by Dr Catherine Moore using example datasets provided by the Water Consultants’ Aquifer Test Sub-committee.

The software packages that we use and recommend to reviewers include:

- AQTESOLV^{®9}: A comprehensive aquifer test analysis programme that handles constant-rate and variable-rate analysis; step drawdown analysis; type curve families; derivative analysis; and slug test analysis (including solutions for underdamped oscillatory responses in highly conductive confined and unconfined gravel aquifers); and
- Step Master[®]: a programme which solves Eden-Hazel and Bierschenk solutions for step drawdown test data (step tests).

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<http://ecan.govt.nz/publications/General/Aquifer%20test%20design%20Self%20audit%20check%20sheet.pdf>

⁶ <http://ecan.govt.nz/publications/General/aquifer-test-review-constant-discharge-test-form-110210.pdf>

⁷ <http://ecan.govt.nz/publications/General/aquifer-test-review-step-drawdown-test-form-110210.pdf>

⁸ <http://www.civil.canterbury.ac.nz/staff/bhunt.shtml>

⁹ <http://www.aqtesolv.com/>

10 Consistency

We are dedicated to providing a consistent review service to the Canterbury groundwater industry. To maintain a standard that is fair and equitable, we will need to occasionally audit the work of external reviewers. We consider this to be a three-part process:

1. An initial screening of the first review conducted by a new reviewer. This will include a brief audit of the review documentation;
2. An ongoing audit of review documentation (likely to be an annual check) to make sure that the industry standard is improving and that new processes are being applied; and
3. Feedback sessions with the Water Consultants' Aquifer Test Sub-committee to discuss ongoing practice and identify necessary improvements.

11 Environment Canterbury Support

If any major issues arise between the reviewer and applicant/consultant we will be available to provide input and advice. We advocate getting all parties together over a computer to discuss the issues and identify a clear and practical way forward. We can facilitate these discussions and provide advice, if necessary. Additionally, we will also provide access to any data/advice that is necessary to complete the review.

12 Timeframes

There are strict RMA timeframes that will need to be adhered to for each individual test review. These timeframes will be provided to reviewers before they make a commitment to complete each review. The timeframes will differ depending on whether the review is for a consent in process or if it is for compliance with a particular consent condition (e.g. Rakaia-Selwyn hearing).

13 References

Aitchison-Earl, P. and Smith, M. 2008: Aquifer test guidelines (2nd Edition). Environment Canterbury Technical Report R08/25, 53 p.

Kruseman, G.P. and de Ridder, N.A. 1994: Analysis and evaluation of pumping test data (2nd Edition - Completely Revised). Publication 47: International Institute for Land Reclamation and Improvement, Wageningen, the Netherlands, 377 p.