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A statistical assessment of bore interference

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Abstract

Resource consent applicants and Regional Councils are required to assess the environmental impacts of groundwater withdrawals. Such impact assessments normally include a quantitative assessment of bore interference. Factors influencing interference include the size of the groundwater withdrawal, aquifer and bore characteristics, and distance from the groundwater abstraction. These parameters are normally obtained from the resource consent application and require aquifer tests that are costly and time consuming. The interpretation of hydraulic parameters is also uncertain. A simple method has been developed to assess bore interference for confined aquifers using some knowledge of hydrogeology and a statistical approach. The method also reflects the inherent uncertainty in interference estimation.

Introduction

The Resource Management Act (1991) requires consent applicants to submit an assessment of environmental impacts. An important factor in applications for groundwater allocations is bore interference i.e. the lowering of groundwater level in one bore due to groundwater withdrawal in another nearby. Such interference is the most common reason for submissions opposing groundwater withdrawal applications in the Manawatu region. To resolve disputes, therefore, it is essential that interference is reliably estimated.

Interference

In a confined aquifer interference, d, assuming several criteria are met, is described by the Theiss equation (Freeze and Cherry 1979) :

$$d = QW(u)/4\pi T \quad \text{where } u = r^2S/4Tt \qquad (1)$$

where Q is the discharge rate from the bore $[L^3/T]$, W(u) is the "well function", approximated by a Taylor series:

$$-0.5772 - \ln (u) + u - \frac{1}{2}\frac{u^2}{2!} + \frac{1}{3}\frac{u^3}{3!} - \dots,$$

r is the distance from the discharging bore [L],

S is storativity of the confined aquifer [1],

t is the time or duration of discharge [T], and

T is the transmissivity of the confined aquifer [L^2/T].

Q, t, and r are obtained from the consent application; T and S are normally determined from aquifer tests to solve equation (1). In general, T can be determined from aquifer tests from a single well; for S, however, data from observation bores are required. In the Manawatu region there are a number of practical constraints for using equation (1).

- Aquifer tests with observation bores are costly and time consuming.
- Data for bores drilled before the 1980s are often missing or not adequate.
- Very few bores have been drilled for observations only. Therefore data from privately owned water production bores replace "observation" bores.
- Privately owned bores are often not suitable for data collection.
- The construction details of older bores are unknown.
- Both transmissivity and storativity can change with location.
- Aquifer tests normally yield a range of these parameters, not fixed values.

Near Palmerston North many bores tap deep (>50 m), confined aquifers. These aquifers are characterised by moderate (10^2 to 10^3 m^2/day) transmissivity and a low (10^{-5} to 10^{-4}) storativity range. Interference is measurable in these aquifers at bores situated several hundred to a few thousand metres from the abstraction bore. Bore density is up to 10 bores/km^2, and cumulative groundwater use (125,000 m^3/day of groundwater is abstracted from confined aquifers within an area of 130 km^2) is very high. Groundwater level at a bore, therefore, may change due to groundwater abstractions from more than twenty nearby bores.

Statistical approach

Interference assessments are typically based on a deterministic method in which a single value is calculated using a set of fixed inputs. We argue that the parties involved in disputes are more interested in a range of predicted interferences rather than a fixed value. This approach addresses the difficulties in determining component drawdowns from many bores in a small area, as is common around Palmerston North. The inherent variability of aquifers is also reflected in the choice of randomised parameters. The same approach was used for estimating rainfall recharge to groundwater in the Manawatu area (Bekesi and McConchie, 1999).

We have developed a simple, easy-to-use add-in for Excel, that estimates a range of interferences, based on a range of transmissivities and storativities. The method uses the principles of Monte Carlo modelling. A random value is drawn for some input variables (T_i, S_i). These random values, combined with fixed variable inputs (Q, t, and r), compose a set that defines one scenario, producing a model output, d_i. The model is rerun n times producing a set of interference (d_1, d_2,...d_n) values. The output values constitute a random sample reflecting the probability distribution of the input variables (Q, t, r, T_i, S_i). The degree of uncertainty can be estimated from the variability of the output (d_1, d_2,...d_n) using standard statistical methods (Morgan *et al.*, 1990).

As the actual distributions of T and S cannot be reliably estimated for aquifers within the Manawatu region (T could be assumed to be log normal, but insufficient data exists to test this assumption), the most conservative uniform distribution was adopted to describe these parameters. For each scenario, transmissivity was randomly chosen as an integer using m^2/day units. Because storativity for Manawatu confined aquifers is in the range 10^{-4} to 10^{-5} it was multiplied by 10^6 prior to random selection then divided back to the original range.

For each scenario an output is calculated as shown in Figure 1, as a function of t, the time of discharge from the bore. Figure 2 shows the distribution of interference at a fixed time value. Figures 1 and 2 are based on a real set of data taken from a consent application for an average-sized abstraction.

Naturally the usefulness of this method will depend on how realistic the estimates of hydraulic parameters are, and the resultant uncertainty in the interference estimates. To estimate even *ranges* of aquifer parameters, actual aquifer test data and interpretation of hydraulic parameters are required. Thus we do not suggest this method as a substitute for aquifer tests, rather, as a simple tool to estimate interference for minor groundwater abstractions in areas where ranges for aquifer parameters are known.

Uncertainty

Uncertainty of the interference estimation can be quantified using percentiles of Monte-Carlo simulation outputs. In this example we have chosen the difference between 90 and 10 percentiles: $d_{90} - d_{10} = 1\ m - 0.54\ m = 0.46\ m$. This value can then be compared with uncertainties from other tests.

As Figure 2 indicates, interference predictions based on the actual pump test data (0.83 and 0.95 m) fall on the 71 and 85 percentiles respectively. These values are both above d_{50} because the actual storativity, $6 \cdot 10^{-5}$, is close to the minimum of the storativity range in this example.

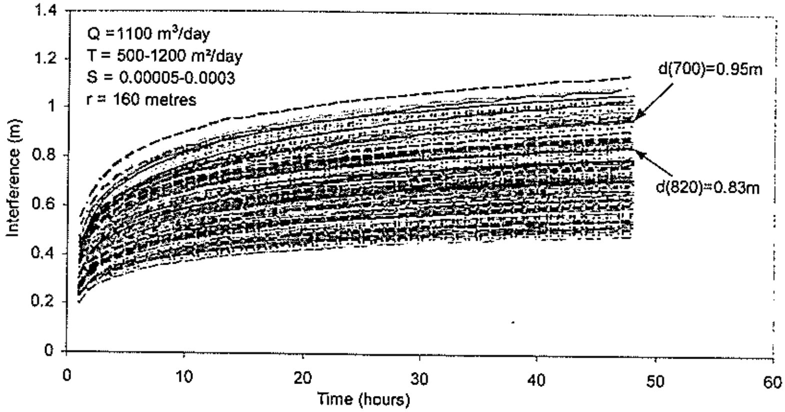

Figure 1 – Interference predictions using a range of input parameters for storativity (S) and transmissivity (T), and fixed values for Q (abstraction rate) and distance from groundwater abstraction (r). Arrows indicate "fixed" (interpreted from actual aquifer test) interference at 700 and 820 m²/day transmissivities and $S=6\cdot10^{-5}$.

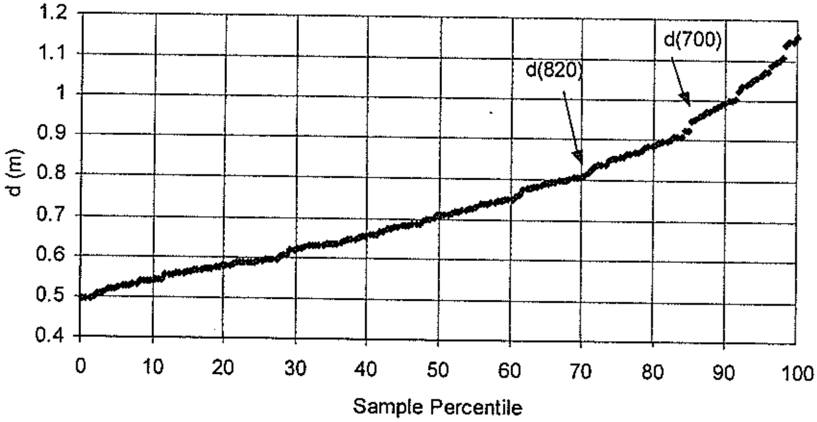

Figure 2 – The distribution of interference (d) at t=48 hours, based on 200 simulations. T varies between 500 and 1200 m²/day; and S varies between 0.00005 and 0.0003. Arrows indicate "fixed" (interpreted from actual aquifer test) interference at 700 and 820 m²/day transmissivities and $S=6\cdot10^{-5}$.

Sensitivity

The Monte Carlo analysis enables the use of a regression technique to calculate sensitivity. A least-squares regression model can be fitted to estimate the output, d, as a linear function of inputs, T and S:

$$d = b_0 + b_1 T + b_2 S \qquad \text{or in this example:}$$

$$d = 1.518 - 0.00078\, T - 685.5\, S \tag{2}$$

$$r^2 = 0.951$$

where b_0 is the regression intercept, b_1 and b_2 are the linear regression coefficients for variables T and S, and r is the correlation coefficient measuring the strength of the linear regression. Regression coefficients b_1 and b_2 measure the linear sensitivity of the output to the input variables. The meaning of b_1 is that, for a unit increase (m^2/day) of transmissivity, there is an average 0.00078 m decrease in interference. Similarly, a unit increase in storativity would cause an average 685.5 m decrease in interference. In reality, however, variations in transmissivity are larger, and in storativity are much less, than a unit. To overcome the unit dependent regression coefficients, standardised regression coefficients (U_T and U_S) can be used as a more useful measure of linear sensitivity (Morgan *et al.*, 1990):

$$U_T = b_1\, stdev(T) \,/\, stdev(d)$$

$$U_S = b_2\, stdev(S) \,/\, stdev(d)$$

where *stdev* represents the standard deviation of the variable.

Given:

$$stdev(d) = 0.17$$

$$stdev(T) = 200.8$$

$$stdev(S) = 0.0000712$$

with b_1, b_2 from equation (2):

The results are:

$$U_T = -0.921$$

$$U_S = -0.287$$

The standardised regression coefficients measure the sensitivity of input variables over their entire range. For Manawatu conditions, the absolute value of U_T is larger than U_S, indicating that the linear sensitivity to transmissivity is the crucial factor in estimating interference. For the Manawatu, efforts should therefore concentrate primarily on obtaining transmissivity through single well tests (these tests are also cheaper to run). In the Manawatu area, transmissivities are available for only 2.7% of bores—other regions of the country have similar, or lower, data availability (Table 1).

Table 1 – Pump test data, for various regions of New Zealand. Transmissivity and storativity are only available for a small fraction of all bores.

Region	% of bores for which data are available Transmissivity	Storativity	Source (pers.comm., 2001)
Manawatu/Wanganui	2.7	0.5	
Waikato	3	0.4	Hadfield
Canterbury	1	0.25	Ettema
Taranaki	1–2	1–2	Stevens
West Coast	0	0	James
Southland	<0.6	<0.1	Hughes
Gisborne	2.3	1.15	Reid
Hawke's Bay	<1	<1	Brooks
Nelson	3	1.25	Thomas

Conclusions

A simple method has been developed to assess bore interference for confined aquifers using some knowledge of hydrogeology and a statistical approach. The add-in for Excel estimates a range of interferences based on a range of transmissivities and storativities. The method quantifies the inherent uncertainty in interference estimation. A sensitivity analysis indicates efforts should be concentrated on single well tests, to acquire transmissivity values confined aquifers in the Manawatu region.

References

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