Improved calculation of groundwater heads for environmental management in the Great Artesian Basin, Australia

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Abstract

Accurate knowledge of groundwater head or groundwater level is critical for most hydrogeological investigations, including the assessment of environmental consequences of groundwater abstractions for mining. For groundwaters with unit density, measured groundwater elevation is equal to the head, and can be calculated for artesian wells as the sum of reference elevation head and pressure head.

In the Great Artesian Basin (GAB) of Australia the combination of high temperatures and deep wells make the precise calculation of groundwater heads challenging. In this environment, the pressure measured at the wellhead does not follow the same trend as head. Once a well is shut-in for measurement, the wellhead pressure decreases as the water column cools. Through analysis of extensive monitoring data from the South Australian portion of the GAB, it is apparent that temperature has an influence on the measured pressures.

Through improving the calculation of groundwater heads by accounting for variations in temperature, better outcomes for the management of the GAB can be achieved. The objective of this study is therefore to improve the calculation of temperature-inclusive groundwater heads to sub-metre precision.

A methodology to calculate temperature-inclusive head using well depth, elevation, pressure and both near-surface and bottom-hole temperature has been developed. The method assumes a linear temperature distribution between near-surface and bottom-hole temperatures.

Results indicate that calculated temperature-inclusive heads, unlike measured pressures, match the typical recovery patterns for artesian aquifers. We conclude that for deep and hot aquifers disregarding the effect of temperature may overestimate heads, and heads calculated from maximum pressures (the current practise in the GAB) may underestimate heads by not allowing for adequate recovery times.

Keywords: groundwater head, pressure, groundwater temperature, Australia, Great Artesian Basin

Introduction

Groundwater head (short for potentiometric head) is the main focus of most hydrogeological investigations. Sub-metre accuracy is not normally expected from artesian heads but in the GAB regulatory requirements for monitoring the impacts of mining-related extractions set small (~few metres) drawdown exceedance conditions. The objectives of this study are to improve the calculation of temperature-inclusive groundwater heads to sub-metre precision and, perhaps more importantly, analyse the implications on groundwater management in the GAB.

For groundwater with constant and unit density, groundwater elevation can describe the head (Oberlander, 1989). In the GAB, groundwaters with temperatures exceeding 50 ºC are common, some ranging to 100 ºC with aquifer depths to 2000 m (Habermehl and Lau 1997; Habermehl and Pestow 2002). The combination of high temperatures and deep wells require the inclusion of temperature-dependent groundwater density to head calculations.

Throughout the GAB, wellhead pressure, at or close to ground level, is monitored typically through a network of both dedicated monitoring sites and pastoral wells. To measure wellhead pressure, most GAB wells are shut-in and wellhead pressure is measured after a predetermined wait/recovery time.

Groundwater Head and Wellhead Pressure

Head (short for potentiometric head, H) at a given location and time, and in most ordinary artesian aquifers (containing cold and fresh water) is calculated as:

$$H = E + P_W/\rho_f g = E + P \qquad (1)$$

Where E is the elevation (of the reference, normally wellhead) P_w is the wellhead pressure, ρ_f is the density of freshwater and g is the gravitational acceleration. The second term in the right-side of Equation 1, P is referred to as pressure head (above the wellhead). Implicit in Equation 1 is the assumption that the water column, between the base of the well and the elevation of the reference is filled with groundwater with a unit density. Drawdown is calculated as the difference between the contemporary pressure and an agreed reference pressure judged to pre-date any effects of Olympic Dam water supply abstractions.

Methods

In the GAB, WMC (1998) used the following temperature correction:

$$H = P + D\times\rho_S(T)/\rho_F + E - D \qquad (2)$$

where ρ_S is in-situ density of water and *T* is the temperature. Density and temperature are related inversely; it follows that if H is constant P should increase with increasing temperature while the second term, $D\times\rho_S(T)/\rho_f$, should simultaneously decrease. Observations in several deep and hot wells in the GAB confirm that if the water is “heated” by allowing the well to flow, the wellhead pressure actually increases despite the flow. Wellhead pressure has also been observed to decrease in several (but not all) wells in the GAB after shut-in with corresponding cooling of the wellhead. It is clear that changes in wellhead pressure in these wells do not follow the patterns in groundwater head observed and explained elsewhere.

Head, wellhead pressure, and temperature characteristics in GAB wells is schematically illustrated in Figure 1. Subscripts H and C denote heated and cooled conditions, respectively.

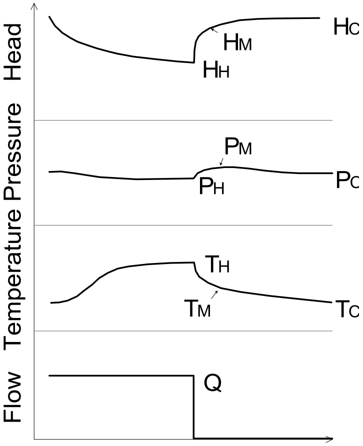

Figure 1 *Head, Wellhead Pressure and Temperature in GAB wells. H and C denote heated and cooled conditions, respectively; M the current practise of maximum pressure measurement*

Equation 2, in principle, would allow the calculation of head from temperature if the temperature in the water column was constant. WMC (1998) and Walsh (2000) both assumed a constant (or average) temperature in their calculations. We suggest that assuming an increasing temperature with depth profile may considerably improve the outcome of calculating heads, particularly for deep and hot wells.

The relationship between temperature and depth is essentially linear, indicated by the coefficient of determination being very close to unity for BHP Billiton's MB7 monitoring well that has six vibrating wire sensors installed, set at 110, 265, 395, 460, 580 and 618 m depth below ground level (Figure 2). Most of the temperature profiles published by Habermehl (2001) for nearly 800 wells also indicate that temperature can be reasonably approximated by a linear distribution.

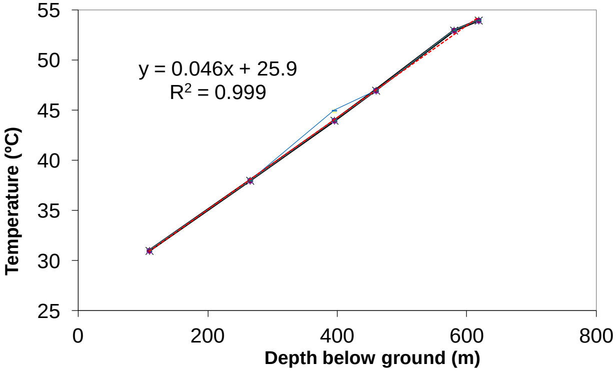

Figure 2 *Temperature in MB7 Monitoring Well. Most of the 54 time-series plotted are obscured because the data overplot.*

Temperature in the well may be discretised to i layers, each with constant temperature and hence water density:

$$H = E - D + P + \Sigma(\rho_i(T_i)\times b_i)/\rho_f \quad \text{and} \quad \Sigma b_i = D \qquad (3)$$

Where $\rho_i(T_i)$ is the density of the i-th discretised layer with temperature T_i and thickness b_i. Of the independent input variables of Equation 3, E, D, and P are known from measurements or well-logs. The measurement of the temperature profile, Ti, is not possible in every well. It may be more practical to estimate T_i from linear interpolation between the bottom-hole or aquifer temperature (T_{AQ}) and near-surface temperatures (T_{NS}) observing that temperature changes linearly in the well column.

Results

Table 1 indicates, using examples that depict real wells in the GAB, significant differences between heads calculated for temperature exclusive (head= elevation+wellhead pressure head), constant temperature and linear temperature scenarios.

The differences are small for shallow and comparatively cold wells (S1) and very large when considering deep and hot wells (P3). Groundwater in the GAB moves in the general direction from P3 towards S1 therefore the changes in head (and hydraulic gradient) will also change significantly.

***Table 1** Calculated Heads for GAB Wells*

Well	**Method**	**Assumed Temperature**	**S1**	**JB**	**D2**	**P3**
Depth (m)			280	488	762	2692
Elevation (m AHD)			38.53	22.25	24.13	31.15
Temp(near surface, ºC) T_{NS}			17.5	29.2	44.1	25
Temp (bottom-hole, ºC) T_{AQ}			43	57	78	100
Wellhead Pressure Head (m)			32.6	64.1	77.4	113.5
Groundwater Head (m AHD)	Temp-Exclusive		71.1	86.4	101.5	144.6
	Constant Temp(Eq.2)	T_{AQ}	69.4	80.4	83.7	52.6
		$(T_{AQ}+T_{NS})/2$	70.6	83.4	90.7	116.7
		T_{NS}	71.4	85.8	97	158
	Linear Temp(Eq.3)		70.6	83.4	90.4	112.9

Other Examples of Results – Head During Recovery Tests

Groundwater head follows a well established pattern during recovery: for homogeneous, isotropic confined aquifers of uniform thickness and of infinite extent heads should plot along a straight line on a semi-logarithmic plot (Kruseman and de Ridder, 1994). As Figure 4 indicates, heads calculated using the linear temperature distribution from both tests (Test No.2 shown in grey box) plot approximately along a straight line in sharp contrast to the decreasing trends in the other curves.

Conclusions

We conclude that groundwater heads in deep and hot aquifers should be calculated using both pressure and temperature measurements. Not considering temperatures may results in significantly overestimated heads. Heads calculated from maximum pressures may not allow for adequate recovery times and are therefore lower than those calculated from cooled, shut-in conditions. Heads calculated at constant temperatures may be underestimated because they do not consider the additional hydrostatic pressure represented by the colder water towards the upper parts of the well. Only the temperature-inclusive heads follow the recovery pattern expected from confined aquifers.

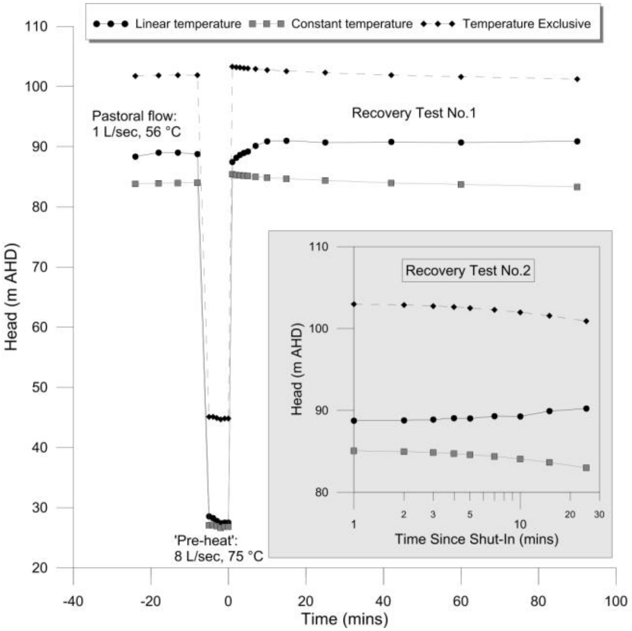

Figure 3 *Groundwater Head in Well D2 during Testing*

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