

Water loading: a neglected factor in the analysis of piezometric time series from confined aquifers (Note)

W.E. Bardsley and D.I. Campbell

*Department of Earth Sciences
University of Waikato
Hamilton
New Zealand*

Abstract

Seasonal changes in the volume of near-surface water cause synchronous changes in the piezometric head of any deeper confined aquifer exhibiting a barometric response. Such loading-induced head changes occur independently of recharge effects. Time series models applied to confined-aquifer piezometric sequences may give erroneous results unless prior data adjustment is made to allow for water loading effects.

The analysis of long records of piezometric water levels by time series techniques is a standard approach to understanding the water balance of confined aquifers. The time-series models are usually straightforward, requiring little more than inputs, outputs, and lag effects. A component of barometric "noise" is likely to be present in the recorded water levels but this is usually insignificant relative to seasonal piezometric fluctuations.

There is, however, another "noise" factor which cannot be so easily dismissed in time-series models. We refer to the quantitative increase or decrease in confined aquifer water pressures created by the loading effect of changes in near-surface water mass. An increase in water loading may arise from rainwater accumulating in the soil profile or water table. The result (in the absence of other effects) is a progressive increase in pore water pressure in the confined aquifer. Conversely, decreases in water loading will occur whenever there is a reduction of near-surface water mass due to evaporation or net lateral groundwater export from an unconfined aquifer. These loading effects are independent of any head changes associated with recharge to the confined aquifer.

Water loading tends to be cumulative and hence may have a significant effect on seasonal time scales. For example, the water accumulated from

individual winter rainfalls may cause a loading increase of magnitude and duration greater than any barometric effect. For example, recall that the change of piezometric head in response to water loading is given by $(1-B)L$, where L is the depth-equivalent of accumulated near-surface water and B is the barometric efficiency of the confined aquifer. A barometric efficiency of 0.2 combined with 50cm of accumulated water would create a 40cm rise in confined-aquifer piezometric level.

Seasonal variation of water table levels represent an obvious indication of changes in near-surface water loading. It seems surprising then that there has been no prior recognition that these loading changes imply synchronous seasonal variation of piezometric head in any deeper confined aquifer. At least one major groundwater text even goes so far as to exclude the possibility of seasonal external loading (Freeze and Cherry, 1979, p.230).

It is possible that water loading has gone unrecognised for so long because piezometric data sequences often have time resolutions no better than a day, while hourly recordings of confined-aquifer piezometric levels are needed to show the near-instantaneous loading increments associated with individual rainfall events (Bardsley and Campbell, 1994).

Delayed water loading is another factor which may have hindered recognition of loading effects. Delayed loading will occur if the topography is such that a period of rainfall produces unconfined aquifer recharge, which in turn causes lateral groundwater convergence and consequent water table rise in the vicinity of a confined-aquifer recording piezometer. The delay here is a reflection of the time needed for the groundwater in the unconfined aquifer to migrate laterally to increase the water loading around the piezometer site. The time-lagged increase in confined-aquifer piezometric head could be easily misinterpreted as "delayed recharge to the confined aquifer". It would be quite possible for a recharge model to provide a good fit to such loading-induced increases in piezometric head even when there is no recharge at all to the confined aquifer.

Van der Kamp and Maathuis (1991) appear to have been the first to demonstrate the reality of seasonal surface loading effects on deep aquifers. We have recorded similar effects (Fig. 1) using high-resolution piezometric levels recorded from what is probably a fully-confined zero-recharge aquifer 40 metres beneath a land surface of low relief surface near Matamata. Further information about this experimental site is given by Bardsley and Campbell (1994).

Despite a few evident linear interpolations of missing data it is clear from Figure 1 that the seasonal variation of piezometric head and water table elevations are very similar. This suggests that water table fluctuations at this site give a good approximation to near-surface water loading, and the 40-metre seasonal piezometric changes are dominated by these loading effects.

What differences there are between the two time series probably reflect the fact that the water table observations are measured at a point while the 40-metre pore water pressures react in response to a spatial average of surface loading over a wider area. There will also be some loading component caused by water accumulation in the unsaturated zone. The evident difference between the water table and piezometric levels between November 1993 and May 1994 may reflect some loading reduction due to evaporative soil moisture depletion during the period of reduced rainfall associated with the Auckland water crisis.

A loading-driven similarity between the piezometric and water table plots of Figure 1 implies a consistent porosity within the range of the water table variation. An estimate of this porosity is obtained from the ratio of the scales on the left and right axes. This yields a mean porosity of 0.48 - consistent with the loose sandy subsurface at this site.

The example of Figure 1 is a special case of a confined aquifer where recharge effects are likely to be negligible. In most confined aquifers seasonal piezometric variations will derive from both recharge and loading influences. Unfortunately both effects will tend to occur together. For example, a wet year is likely to produce greater recharge to a confined aquifer, but the water loading effect is also likely to be greater because of higher water tables.

It is important that a check be made to determine whether piezometric levels from confined aquifers require a loading correction prior to data analysis. Corrections can be made by using the aquifer barometric efficiency to adjust the recorded levels upwards or downwards after estimating surface water loading from water table variations. Failure to make a correction might result in over-estimation of aquifer recharge with possible consequences for resource allocation.

Whether or not water loading will have a significant effect in a given data sequence will depend on a number of factors including the magnitude of the surface loading variations, the barometric efficiency of the confined aquifer, and the location of the piezometer concerned with respect to distance from aquifer recharge and discharge boundaries. Any piezometric time series with variation of similar magnitude to water table fluctuations has the potential to have water loading as a significant component of the recorded variation. For example, the piezometric time series modelled by Fenemor (1989) has a seasonal range of less than three metres and it would be useful to check whether a loading correction might be applicable to that data. In contrast, the piezometric levels modelled by Bidwell *et al* (1991) varied over tens of metres - presumably well beyond the loading magnitudes which might be generated by local water table fluctuation.

This paper has been concerned with water loading only to the extent of pointing out its potential impact on piezometric time series and the need for pre-analysis corrections. Clearly there are many directions for further research

in this interesting subject area. For example, past time series analyses could be reworked with a loading correction to the data, and new analytical and numerical groundwater models could be developed which explicitly include water loading as a contributing factor to head variation in confined aquifers. There are also some qualitative field implications which could be worth further investigation. In particular, the loading effect of a significant rainfall event might be expected to induce a brief discharge increase in springs emerging from confined aquifers with high storativity. Any detectable "loading hydrograph" of this type will be synchronous with the initiation of rainfall, with the recharge hydrograph perhaps following later as a distinct second peak.

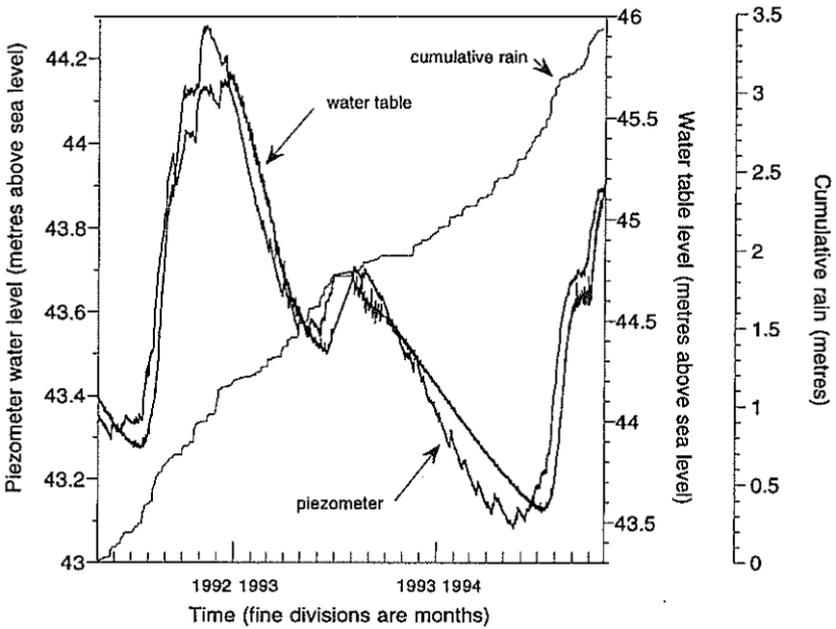


FIG 1 — Comparison of water table elevation and the piezometric head in a confined aquifer 40 metres beneath the surface, near Matamata, New Zealand. Water table elevations are data as recorded, the piezometric heads have been corrected for barometric pressure effects. The saw-tooth rises in the piezometer water levels are the loading impacts of individual rainfall events.

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