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Interactive comment on "Error in hydraulic head and gradient time-series measurements: a quantitative appraisal" *by* Gabriel C. Rau et al.

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This paper provides a good review of many of the factors that can influence hydraulic head measurements and it is nice to see increased focus on such a fundamental measurement. There are three areas in the paper where we feel further clarification is warranted: time-lag of the monitoring well; calculation of hydraulic gradient; and the comparison of vented and non-vented transducers. Our comments address relatively subtle points and not intended to detract from the overall emphasis of the paper.

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1 Time-lag

It should also be emphasized that while the equivalent freshwater water level (corrections for density) or equivalent piezometric level (for shut in measurements) are often used to infer flow directions and calculate hydraulic gradients, the water level elevation in an open well is not the fundamental parameter of interest. The hydraulic head in the formation is what drives flow. A key distinction is that often a monitoring well or piezometer requires groundwater flow between the formation and monitoring well to record a change in water level surface. This flow is not instantaneous and is commonly referred to as time-lag (Hvorslev, 1951). This time-lag is different than the time-lag associated with the propagation of barometric pressure through the vadose zone mentioned in the current paper. The length of the time-lag is dependent on well-bore storage and formation properties; the water level measured from an open monitoring device (or even a grouted transducer to a much smaller extent) will incorporate the effects of antecedent changes in formation pressure. Monitoring wells do not all have the same time-lag associated with them, which also adds temporal uncertainty when comparing measurements. As monitoring frequency increases the uncertainty associated with variable time-lags will become more important and apparent.

2 Hydraulic gradients

The locations of the monitoring wells play a very important role in the calculation of the hydraulic gradient, not only the knowledge of their true position (x and y, z, and time coordinates) but how the wells are oriented in relation to each other. For example, it is worth mentioning that for calculating a planar hydraulic gradient from three wells in the same hydrogeologic unit the optimal arrangement is in the form of an equilateral triangle. As the locations deviate further from an equilateral triangle the uncertainty of water level measurements plays an increasingly important role in gradient calculations.

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Gradients vary in space and time, so with increasing monitoring distances the spatial confidence of the calculated gradient actually declines (i.e., uncertainty around the representativeness of the gradient). We are limited by our devices but we strive to get gradients across appropriate scales. It should be mentioned in the discussion on vertical gradients that avoiding blending of distinct hydrogeologic/hydrostratigraphic units is critical to accurately calculating meaningful vertical gradients.

3 Vented and non-vented transducers

One of the main arguments against non-vented transducers is that you need to convert these values to an open hole water level measurement. While this may be the case when you want to compare the value to a manual measurement in a conventional piezometer, in many cases this is not necessary. For example, if you are trying to calculate a horizontal gradient between three wells in the same aquifer, and all of the transducers deployed are non-vented, there is no need to first remove the barometric component from the results if the elevations of the sensor of each transducer are known. Converting to an equivalent water level may just add uncertainty that is not necessary. Another example is for calculating barometric/loading efficiency. The main issue is related to time shift between equipment, which affects both methods similarly. Given the same transducer specifications, a similar uncertainty will be associated with the result.

Figure 5 is particularly damning for non-vented transducers and we think that it needs the raw data and transducer specifications to be provided as well, or the data should not be included at all. This figure runs counter to our experience with hundreds of transducers, both vented and non-vented. It may be that you are comparing differences in full-scale, transducer type, transducer location, or perhaps the barometric compensation procedure could be improved to account for temporal offsets. Likely it is a full-scale or transducer type issue given the smoothness of the barometric pressure data. Care needs to be taken with a figure like this to be as transparent as possible in what is being compared to not overemphasize a preference or mis-interpretation of the cause/effect.

Both vented and non-vented transducers exposed to large temperature changes will have increased uncertainty about their measurements; non-vented should not be singled out in section 6.4.1 line 21. This is more a question of deployment location (protected vs. unprotected) and less of a vented, non-vented issue. If possible, both transducer types should be deployed in protected environments that minimize the effect of the external environment while still capturing the measurements of interest (i.e., adherence to data quality objectives).

While we agree that the smaller full scale (and thus typically better accuracy and resolution) of vented transducers is a key preference and leads to some simplified calculations, the vent tube and increased cabling, particularly for even moderately deep applications, is a major downside that should be considered when selecting the optimum transducer type. We would suggest not having such a conclusive recommendation of one transducer type over the other.

4 Other comments and specific notes

1) We feel that there is little reason to record with such an infrequent or low monitoring frequency as 1 hour given current technology. The optimal monitoring frequency is dependent on the device hardware and the tools available for the analysis of the data. With improved tools, the hope is that monitoring at higher frequency becomes more common so that more complete water level histories are obtained. While you say that it is the maximum monitoring frequency, should this paper suggest a higher frequency of monitoring to push the profession forward?

2) The HEADCO manual by Spane 1985 also provides a thorough review of many of

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the common issues related to hydraulic head measurements and should be cited as an excellent reference for the readers of this manuscript.

3) For the grouted-in application, would you still recommend vented transducers?

4) Page 2: “This is by no means trivial, and certainly much more complex than collecting manual measurements”. Understanding what a manual measurement represents is also quite complex, in part because we are often missing the appropriate additional information necessary for their interpretation. Manual measurements, tend to have increased temporal uncertainty and also lack an associated barometric pressure value taken at the same time.

5) Page 4: “The hydraulic head is defined as (e.g., Freeze and Cherry, 1979)”. Consider citing the original work here (Hubbert, 1940) rather than an introductory level textbook.

6) Page 6-7: “Air pressure changes act differently on the water column in open GMI than on the groundwater, because in the open GMI the air pressure change is transmitted instantaneously to the water, whereas the groundwater pressure response is more complex and can be delayed.” We disagree with this statement. The air pressure changes result in formation pressure changes that are reflected in the open hole water level measurement, just perhaps at a later time period. We would argue that the water level response in an open hole would be more complex than the actual formation head. This is because open hole response contains both the formation response in addition to the responses resulting from the direct atmospheric connection and well-bore storage.

7) Page 12: “Vertical head gradients in an aquifer tend to be small under natural (i.e., not pumped) conditions, often less than 10^{-3}”. Followed by “this can be taken as an indication of the maximum head error for a typical piezometer caused by uncertainty about the elevation of the point of measurement”. Given that this reasoning is used to quantify one of the forms of uncertainty based on standard practice, some basis for the gradient of 10^{-3} should be provided. Also, it seems very limiting to constrain

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this discussion to ‘aquifer’ units in non-pumped systems. Larger vertical gradients should be expected across units with lower bulk vertical hydraulic conductivity and in recharge areas of a flow system or where units are being pumped (which is often the case). There are examples in the literature that show vertical gradients larger than 10^{-3} (see references provided in Meyer et al. 2014). Also, blending of distinct hydrostratigraphic/hydrogeologic units in a single well screen seems like an important but neglected aspect of this discussion.

8) Page 14: “In layered aquifer systems, the water level in wells with long screens was found to depend on the transmissivities of the layers intersected by the wells (Sokol, 1963)” This is the key point! This can have a dramatic influence on the head recorded even for short screens if cross-connecting the system. The measured head value becomes biased toward the highest transmissivity intersected and much of the earlier text on the monitoring point tends to confuse this issue. For a monitoring well the head is representative of the open interval and assigning the location to a point is inappropriate.

9) Page 21 Figure 6 caption: “Note that the manual dips confirm that there was no diurnal variability in the water levels (blue dots).” With the sparsity of measurements we don’t think this statement is justified.

10) Page 26 Line 3: “Clock stability is an important consideration when using multiple instruments. Examples include the barometric correction of absolute pressure measurements from a non-vented transducer, or the calculation of hydraulic gradients using two different time series.” Barometric correction requires the calculation of the barometric efficiency. You need barometric pressure measurements to do this calculation and therefore both non-vented and vented transducers will be affected.

11) Page 33 Line 7: Probably should site some earlier works here - for example Jacob 1940, Rojstaczer et al. 1988.

12) Page 35: “Because vented PTs measure a relative pressure instead of an abso-

lute pressure, they have a smaller range and do not require a separate instrument to simultaneously record the atmospheric pressure." We should encourage barometric pressure to be monitored at every site. In addition, recording barometric pressure at a higher frequency can provide certain advantages related to barometric response function calculation as a more complete barometric history is obtained.

13) Page 35: "For reliably resolving head gradients and flow direction at small vertical distances, for example when assessing surface water-groundwater interactions, we recommend the use of wet/wet differential pressure sensors (e.g., Cuthbert et al., 2011)." We don't think "wet/wet differential pressure sensors" were discussed in the body of the manuscript. If not, this comment is out of place in the conclusions section. Consider adding a brief discussion to the main body of the paper or removing from the conclusions.

Thank you for this important paper,

Regards, Jonathan Kennel, Jessica Meyer, Christopher Neville, Beth Parker

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References

Hvorslev, M.J., 1951. Time lag and soil permeability in ground-water observations.

Jacob, C.E., 1940. On the flow of water in an elastic artesian aquifer. Eos, Transactions American Geophysical Union, 21(2), pp.574-586.

Meyer, J.R., Parker, B.L., and Cherry, J.A. 2014. Characteristics of high resolution hydraulic head profiles and vertical gradients in fractured sedimentary rocks. Journal of Hydrology, 517, 493-507.

Rojstaczer, S., 1988. Determination of fluid flow properties from the response of water levels in wells to atmospheric loading. Water Resources Research, 24(11), pp.1927-

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1938.

Spane Jr, F.A. and Mercer, R.B., 1985. HEADCO: A program for converting observed water levels and pressure measurements to formation pressure and standard hydraulic head (No. RHO-BW-ST–71-P). Rockwell International Corp.

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