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Hydrology and Earth System Sciences
Discussions

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

Anonymous Referee #2

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The authors of "Error in hydraulic head and gradient time-series measurements: a quantitative appraisal" provide interesting discussion of a fundamental concern in evaluation of field hydrogeologic data. As such, the paper has potential to make a significant contribution to the hydrologic literature. In presenting the following comments, I should note that I am principally an academic with substantial field experience. I believe that I may have approached review of this manuscript from a different viewpoint than did the other referee and the other reviews already received. I hope that this difference in viewpoint is useful to the authors.

In this vein, one overall comment that I would introduce beyond those comments already provided by Kennel and the other reviewers is that it is somewhat unclear whether this paper is intended to be a basic discussion for those working in the field

(in which case some of the additional sources of error suggested by the other reviewers might be considered) or a more theoretical analysis to help inform further study for improving estimation of hydraulic gradients and fluid fluxes in complex groundwater systems (for example, use the sources of error identified by these authors, but place them into a random numerical analysis in an effort to provide more insight into the most important errors within multiple field scenarios such as local, three-dimensional flow versus regional flow). Specifically, in reviewing this manuscript, I found that the discussion of the details of the field technologies (tapes, transducers, dip instruments) was quite fundamental (e.g., discussing the increment of measurement on a depth-to-water tape) without discussion of possible improvement, while the discussion of the magnitude of errors (and lack of discussion of interaction among errors) involved a number of assumptions. The paper has potential to be a valuable contribution, but I believe that it would benefit substantially through a bit more clarity on the intended audience (e..g, field technician versus more theory-based hydrologist) and a bit greater effort to more thoroughly understand the interplay in the identified errors. I also believe that this suggestion is reflected in some of the comments of the other reviewers (e.g., interplay of errors as suggested by Fang, the suggestions for additional types of errors by Rosenberry, the comments by Kennel et al that the example magnitude of errors should be based on a broader range of field experience and placed within context of reasonable error expectations).

More specific comments:

For many of the conclusions put forward by the authors, it might be beneficial to both suggest the implications for measurement precision in the field and avoid comparisons / generalizations that cover only a partial range of field experiences. For example, the abstract suggests that uncertainty in the hydraulic gradient "magnitude can have as great an effect on the uncertainty of flow rates as the hydraulic conductivity". I would note that these two aspects of groundwater flow analysis are fundamentally different in terms of impact on flow rates, flow direction, and response to hydraulic stimuli. I

might avoid this simplification of error comparison as it will require substantially great discussion in terms of impact on the type of final analysis desired. Further, the authors suggest that 170 meters measurement point separation is required to achieve an estimate of 10^-4 in the field. Note that this implies (in perfectly one-dimensional flow) an error in differential head measurements of approximately 1.7 cm. The authors might be direct about this allowable error and briefly discuss whether this is a reasonable field result.

As noted by the other reviewers, situations in which gradients in vertical flow are of interest will often involve impact of geologic heterogeneity, natural transients (e.g., due to precipitation), and anthropogenic impacts (e.g, pumping from wells or differential densities near contamination sources). Clarification of concerns, and where those concerns are important, need to be clarified in terms of vertical gradients / vertical flow. Once again, the authors are encouraged to avoid making generalizations. This is particularly of concern in that suggestions from this manuscript might be adopted by field technical staff without careful review of the field conditions assessed by the authors and applied under conditions that are not appropriate.

I would agree with comments in one of the other reviews regarding the authors' suggestion that complexity in automated water-level measurement is significantly more complex than manual measurements. Specifically, this is perhaps inappropriate and likely ignores the complexities involved in making repeated manual measurements.

After equation 6, the authors state that del(H) is continuous. In the presence of any type of heterogeneity, this is not necessarily the case (think for example, about the instantaneous change in del(H) in the vertical direction as we move from a high K to a low K material). This statement should be corrected. More importantly, as noted in one of the other reviews, heterogeneity makes the discussion of errors in the hydraulic gradient far more complicated than even presented in this manuscript. Well geometry, well screen length and location relative to changing hydrologic units in the subsurface, screen clogging, regional variation in pumping (other wells not part of a given study),

the distance of well separation relative to the scale of heterogeneity, are all errors that make this analysis far more complex than presented here.

There is substantial concern that the authors have artificially separated "horizontal" from "vertical" gradients (e.g., equations 6-9). Certainly at the lengths scales for which errors in water levels have substantial, negative impact on our field analysis, there is no reason to make an assumption in advance that the flow field can be separated into horizontal and vertical flow and that such analysis does not vary rapidly in space. Why not base the discussion in the paper on analysis of the error in the direction and magnitude of the three-dimensional hydraulic gradient?

On page 15, the authors make some strong, sweeping conclusions about non-verticality of wells. I agree with one of the other reviewers that the authors could assist the reader by providing a bit more insight here. For example, for what minimum depth of well and in what geologic conditions will this error be most likely to impact field analysis? Further, the suggestion to use geophysical measurements to measure vertical deviation in all wells in all projects is likely beyond the financial capacity of many field efforts.

Starting on page 17, the authors make several assumptions regarding the error in the measurements of pressure transducers. As noted in at least one of the other reviews, the precision and time drift in a pressure transducer is strongly dependent on a number of factors including the type of transducer, the maximum range, and quality of construction. A bit more discussion of the range of likely precisions to be observed in the field and, as suggested by Rosenberry, careful field design can provide an opportunity to optimize field instrument design to minimize instrument errors.

I would prefer if figures 10a and 10b were presented on the same vertical scale (with some data in figure 10b shown as off range on the graph) so that the reader can actually compare the majority of the data presented.

Page 28 - I agree with the other review comment that the sampling interval of 1 hour

seems arbitrary and too long. Perhaps reconsider this suggestion.

Again, I believe that there is a potentially valuable paper presented here. I would, however, encourage the authors to consider the comments of the other reviewers as well as the comments presented here as an opportunity to substantially increase the applicability and value of the discussion presented.

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