Hydrogeol J (2017) 25:2207–2209
DOI 10.1007/s10040-017-1643-8

COMMENT

Comment on "Automatic estimation of aquifer parameters using long-term water supply pumping and injection records": paper published in *Hydrogeology Journal* (2016) 24: 1443–1461, by Ning Luo and Walter A. Illman

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Received: 28 February 2017 / Accepted: 6 July 2017 / Published online: 31 July 2017

Keywords Aquifer properties · Analytical solutions

The subject paper, Luo and Illman (2016), presents an analysis approach that has potentially wide application for the interpretation of data from municipal well fields and the management of groundwater resources. The paper concludes that long-term municipal water-level records are amenable to analyses using a simple analytical solution, but a caution is stated that the uniform parameters estimated with the analytical solution approach should be considered as "first rough estimates". This Comment examines the foundational aspects of the presented approach and the physical significance of the inferred parameter values.

The subject paper indicates that the starting point for the approach is the Theis (1935) solution. The drawdown predicted with the Theis solution at any elapsed time t at location P with coordinates (x,y) is:

$$s_P(x,y,t) = \frac{Q}{4\pi T}\,\mathrm{W}\left(\frac{\left[(x-x_w)^2+(y-y_w)^2\right]S}{4Tt}\right) \tag{1}$$

where x_w and y_w are the coordinates of the pumping well, Q is the pumping rate, and S and T are the storativity and the transmissivity, respectively.

For the case of multiple pumping wells with pumping histories defined as sequences of discrete steps, it can be shown through the principle of superposition that the drawdown predicted with the Theis solution is given by:

$$s_P(x,y,t) = \sum_{i=1}^{N}\sum_{j=1}^{M_i}\frac{Q_{i,j}-Q_{i,j-1}}{4\pi T}\,\mathrm{W}\left(\frac{\left[(x-x_{wi})^2+(y-y_{wi})^2\right]S}{4T\left(t-t_{Qi,j}\right)}\right) \tag{2}$$

where N is the number of pumping wells, M_i is the number of pumping steps in the record of the i-th pumping well up to an elapsed time t, x_{wi} and y_{wi} are the coordinates of the i-th pumping well, and $Q_{i,j}$ is the pumping rate of the i-th pumping well during the j-th pumping step.

The Theis solution is based on the assumption that the aquifer has uniform properties S and T and that this assumption is retained when the solution is generalized from Eqs. (1)–(2). In contrast, this assumption is not retained in the subject paper's analysis. Recalling Eq. (2) of the subject paper, each pumping well is associated with its own parameters S_i and T_i:

$$s_P(x,y,t) = \sum_{i=1}^{N}\sum_{j=1}^{M_i}\frac{Q_{i,j}-Q_{i,j-1}}{4\pi T_i}\,\mathrm{W}\left(\frac{\left[(x-x_{wi})^2+(y-y_{wi})^2\right]S_i}{4T_i\left(t-t_{Qi,j}\right)}\right) \tag{3}$$

Equation (2) in this Comment is the solution of a boundary-value problem that is developed from a statement of mass conservation and Darcy's Law. However, Eq. (3) is not the solution of a well-posed boundary-value problem. In

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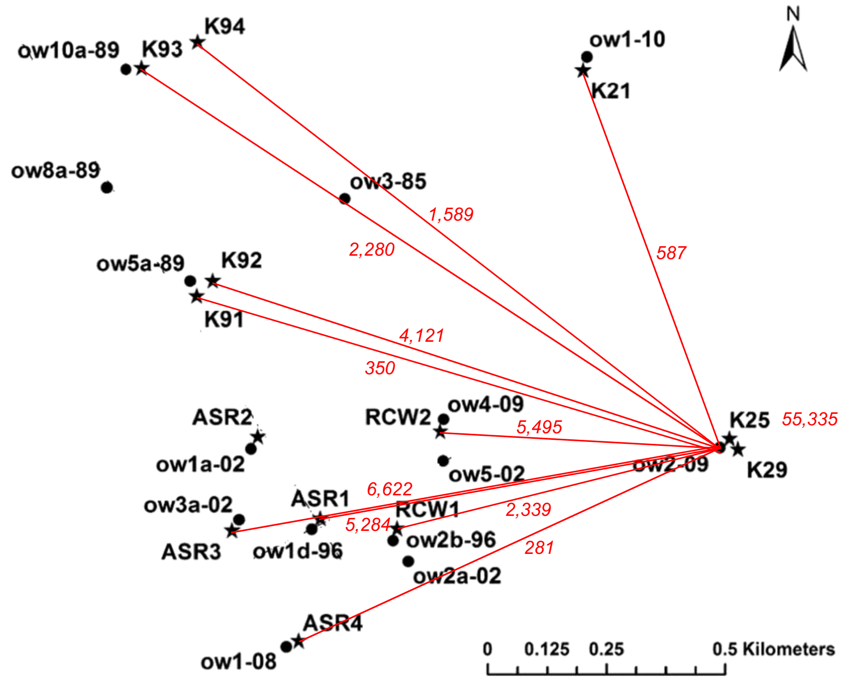
Fig. 1 Distribution of transmissivity estimates for observation well ow2–09. Transmissivity values are reported in m^2/day



heterogeneous aquifers, the objective is to estimate bulk-average parameter values rather than values associated with particular lines that connect pumping wells and observation wells.

Problems with the physical interpretation of the parameters S_i and T_i are highlighted by an examination of the results of the analyses. The transmissivity estimates inferred through the analyses are summarized in Table 5 of the subject paper. The transmissivity estimates range from 9 to 55,325 m^2/day. The subject paper noted that transmissivity estimates in excess of 10^5 m^2/day were inferred from the analyses but had been excluded from Table 5. The relatively wide range of reported transmissivity estimates point to complexity in the subsurface structure that is not captured in the Theis solution. Since all of the inferred estimates are assigned equal weighting, it is not possible to assess which values might be more representative. Experience at other sites suggest that unrealistically high transmissivity values are frequently characteristic of the responses of observation wells located in zones that are not well connected to the pumping well with which they are paired.

The storativity estimates inferred through the analyses are summarized in Table 6 of the subject paper. The reported estimates range from 0.002 to 0.736; however, the subject paper noted that values of storativity up to 10 were obtained in the analyses. The lowest values are significantly larger than typical literature values for confined aquifers (see for example Lohman 1972; Boonstra 1989), while several of the higher values exceed a likely upper limit of about 0.3 for the specific yield of unconfined aquifers (Johnson 1967). None of the storativity values reported in the subject paper appear to be physically realistic.

The true test of any approach developed to infer aquifer properties lies in comparing predicted and observed drawdowns at a location that was not considered in the original analyses. Is it possible to apply such a test to the results of the subject paper? In Fig. 1, the estimated transmissivities for one of the observation wells, ow2–09, are superimposed on the site map adapted from the subject paper's Fig. 1c. The transmissivity values along each ray correspond to the 14th column of Table 5 in the subject paper. As shown in Fig. 1, the transmissivity can apparently take on a wide range of values between the rays, from 281 to 55,335 m^2/day. There is no discernible spatial pattern to either the transmissivity or the storativity values inferred from the analyses. Viewed from this perspective, the analysis of the subject paper's approach has no predictive power in the setting for which it has been applied.

Although the transmissivity and storativity values inferred from the subject paper's analyses are not physically meaningful, they do have diagnostic value. A model that is invoked to interpret the data represents a working hypothesis of the structure of the groundwater system. When an analysis yields results that are in clear violation of the fundamental assumptions underlying the model, there is a clear demonstration that the conceptual model underlying the analysis is inappropriate. This is the only conclusion that can be drawn from the analyses. The parameter values in Tables 5 and 6 of the subject paper should not be regarded even as "first rough estimates."

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