Authors' responses to reviews for hess-2014-444

Groundwater surface mapping informs sources of catchment baseflow

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We thank Anonymous Referees #1 and #2 and Professor Ian Cartwright for their considered and insightful reviews of our paper. Their helpful comments and suggestions have been addressed below with responses to each individual comment. The page number and line number of changes made in the revised manuscript are provided for each comment.

Anonymous Referee #2

General Comments

Most of my comments echo those of the previous reviewer, for example I question how well this method would work with fewer data points, and I also question why the authors didn't use heterogeneous subsurface properties provided they were present.

Authors' response

Please see responses and changes made to General Comments 1 and 2 of Referee #1

Specific comments

1. Following the usefulness of this method with reduced data points, were any of the kriging parameters varied to determine the uncertainty relative to these parameters?

Authors' response

Further information is provided in the Methods section for how the kriging parameters used in the groundwater mapping were calibrated. Essentially, the parameters were optimised to reduce the variance in the mapped surfaces. The increase in the variance between the potentiometric and water table sets of maps (see response to comment 1 of Referee #1) shows that using fewer data points does result in increased uncertainty and changes in the Kriging parameter values.

Section 2.2 (Methods), P7, L14-32, P8, L1-20.

" In order to construct groundwater surface maps for specified dates, the periodic (generally monthly) water level observations of the bore data were first modelled using the nonlinear transfer-function-noise time-series modelling methodology of Peterson and Western (2014). Water level estimates for the start of each month were then derived by adding the time-series simulation, interpolated to the required data, to a univariate oridinary kriging estimate of the timeseries model error at the required date, which ensured a zero error at dates with a water level observation. groundwater surface maps were then produced for the first of each month for the years 2007 to 2010 using the Kriging with external drift (KED) method (Peterson et al., 2011). In applying the KED, the external drift term was the land surface elevation (Shuttle Radar Terrain Model (SRTM) 30 m dataset). A model variogram was derived for the component of the groundwater elevation not explained by the external drift. The KED approach requires the estimation of three parameters for the residual model variogram and a parameter for the maximum search radius during the mapping. Considerable effort was taken to reliably calibrate the variogram parameters and set a search radius producing cross-validation residuals that are approximately first-order stationary. The Kriging variance (see example in Fig. 6) does provides an indicative estimate of the map reliability for the given parameter set and the available water level observations. However, the density and location of observations also influences the variogram parameters and the maximum search radius parameter. Accounting for this parameter uncertainty in the groundwater mapping is not trivial and future work is required to explore methods that account for variogram uncertainty (Ortiz et al., 2002) and localised estimation of the search radius (Abedini, 2012). This groundwater level component was first estimated using ordinary least squares regression and then minimised by repeatedly fitting an isotropic exponential variogram, using multi-start Levenberg-Marquardt optimization and re-derivation of the water level component, until a stable model variogram was achieved. The depth to groundwater was calculated by difference from the SRTM representation of the ground surface and used to measure changes in the percentage of the catchment with very shallow groundwater surfaces (nominally "saturated" within the uncertainty range of the groundwater surface position) over the period of mapping. This was done for the parts of the catchment with an elevation of <100 m in order to analyse changes in the saturated area around the valley floor and lower slopes of the catchment where most monitoring bores were located and hence confidence in the groundwater surface mapping was highest."

2. Was any consideration given to whether the saturated areas fell in regions where surface water was present (i.e. within the streambed) given that these areas would vary with stream stage? For groundwater discharging to regions with little to no surface water present, was ET taken into consideration?

Authors' response

The measurement of saturated areas within the catchment was used as a first-order approximation of the interaction of the groundwater with the land surface. As such, we did not consider how much of the saturated areas fell within the streambed and neither was ET taken into consideration. Stream stage could result in local reversals in gradient between groundwater and streamflow but could not be accurately determined at the scale of the 30 m DEM used in the water table mapping. These aspects are addressed in Section 3.4 and 4.2.

Section 3.4 (Results), P14, L32-33, P15, L1-9.

" We use a range of realistic but relatively high (Nwankwor et al., 1984) specific yield values from 0.05-0.3 for the different geological units within the <100 m elevation mask for the groundwater surfaces (see Fig. 1). The estimates of the ratio of monthly baseflow (from Eckhardt filter) to monthly mapped volume change, shown in Table 2, are generated using the same specific yield values across all geological units and also by varying the values consistent with expected hydrogeological properties (i.e. specific yield of alluvium > Wangerrip Group > Heytesbury Group). We consider that this range of estimates based on these specific yield values provides an upper bound to the groundwater discharge, particularly since any phreatic evapotranspiration flux, which would also account for some of the volume changes, is not considered."

Section 4.2 (Discussion), P19, L1-7.

“ Fluctuations in the water table remain a relatively coarse measure and provide only a first-order estimate of possible groundwater discharge patterns. For instance, the mapping does not have the resolution to identify the fine detail of channels and near-stream zones. Stage variations in channels will have local effects on groundwater recharge and discharge that are not captured by the groundwater mapping. Likewise, capillary fringing effects in near-stream zones could lead to rapid increases in the water table with a small rise in water content in the unsaturated zone (Gillham, 1984).”

3. Both references used on page 12407 lines 4 & 10 were found to contain significant content that was improperly cited from other sources. It is recommended that the authors find the original sources of the information in this work and cite those instead.

Authors’ response

The original references have been deleted or replaced by the Bredehoeft et al. (1982) reference.

Section 1 (Introduction), P2, L14-17.

“ It has been long recognised that over-extraction from aquifers may result in significant long-term declines in groundwater levels resulting in decreases in baseflow in rivers (Bredehoeft et al., 1982).”

4. Page 12419 Lines 7-10 are a little redundant.

Authors’ response

These lines have been removed.

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