

Interactive comment on “Screening of sustainable groundwater sources for integration into a regional drought-prone water supply system” by T. Y. Stigter et al.

T. Y. Stigter et al.

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We thank the Referees and the Editor for all their suggestions and would like to inform that we have written a revised version of the manuscript, taking into account all your remarks. We do not consider that these changes were necessary in order to 'raise the paper to a quality as expected by readers of HESS', but rather that the revision clarifies the aspects of model validation and reliability, which are now dealt with in large detail, as requested. This makes the paper more technical.

Regarding the comments of Referee 1:

We took out subsection 1.2, so that the Introduction has been shortened 25 percent. We also shortened sections 2.2 on Hydrogeology (35 percent) and 3.2 on Results and

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Discussion of the SVI (25 percent).

In sub-section 2.3 it has been clarified that the created MPWSS does not include irrigation, through the following added sentence:

"The MPWSS does not supply water for irrigation of agricultural land; though several surface irrigation districts exist, irrigation continues to rely largely on groundwater."

The discussion on the natural recharge evaluation has been expanded, as follows:

"Annual recharge rates, depicted in Fig. 2, were determined as the fraction of deep infiltration of the precipitation, considering: (i) the Kessler method (1965) in areas of carbonate rock outcrops and (ii) the semi-empirical formulae of Thornthwaite (1948), Coutagne (1954) and Turc (1954) that calculate real evapotranspiration in areas of sedimentary deposits. During the implementation of regional flow models in the Algarve, the accuracy of these recharge estimates, first performed in the 1980s (Almeida, 1985) was improved, due to: i) the improved accuracy of the geometric representation of the lithological outcrops, based on more recent available information of geologic maps; ii) the improved accuracy and spatial resolution of rainfall, through the implementation of advanced methods, namely kriging with external drift on an orthogonal grid with a resolution of 1 km², with elevation proving to be the most representative auxiliary variable (Nicolau, 2002). The new recharge estimates were validated with the FAO dual crop coefficient method (Allen et al., 1998), taking into account parameters such as daily precipitation, soil texture, moisture content and vegetation cover (Oliveira et al., 2006, Monteiro et al., 2007a) and resulting in a three percent higher estimated recharge."

The discussion and validation of the delineation of homogeneous T-zones has also been performed in more detail, as follows:

"This scenario was based on the highest observed water levels in the past 20 years and used for inverse calibration of T, using the Gauss-Marquardt-Levenberg method, implemented in the nonlinear parameter estimation software PEST (Doherty, 2002).

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Although based on an automated procedure, calibration was not straightforward and involved a dozen of different zonation schemes before reaching the final configuration with 23 T zones presented in Fig. 5, where the behaviour of piezometers allowed a reasonable fitting of field data using a single value of T. This configuration corresponds to an accurate representation of the actual knowledge of the aquifer regarding its hydraulic behaviour in both natural conditions and in response to extractions in wells. Additional constraints were defined during the calibration process, in order to avoid unrealistic conceptualisations of the flow domain. Values of T in each zone are always higher than the maximum individual values of this parameter calculated from pumping tests, as T results from the multiplication of aquifer thickness by hydraulic conductivity (K), a parameter whose value tends to increase with scale (Király, 1978; Sauter, 1992). This constraint is very important because in some cases a good fit between observed and calculated heads can be obtained with unrealistic T values. In these cases the model will probably present very poor results in stress conditions different from the ones used in calibration (for example in drought conditions)."

"Regarding the most transmissive area of the aquifer (western sector) T values determined from pumping tests reach values as high as 30000 m²/d (0.347 m²/s), often determined in wells supporting yields of over 100 l/s and attaining maximum depths of 400 m. However, the thickness of the carbonate formations supporting the aquifer system in the south is in the order of 600 m or more. A realistic representation of the aquifer at the regional scale in this sector is based on zones with T values higher than 1m²/s (see Fig. 5). In this sense, the limits of T values defined during inverse calibration of the model can be characterized as limits of parameter-value acceptability and thus considered as 'soft data' that cannot be directly incorporated into the model, but can be of great importance to improve model quality."

In the transient model, new simulations were performed with increasing values of S, in order to avoid gradient inversion and consequent seawater intrusion at the end of the drought of 2005, as this in reality did not occur:

"Regarding S, trials were performed with different values; many of the runs provided relatively pessimistic scenarios when compared to observed data, simulating the inversion of the hydraulic gradient and consequent seawater intrusion from the Arade estuary in some periods. A final S of 0.05 was used, which provided reliable simulations for the entire period, including the long-lasting drought in 2005. For a fissured limestone matrix, the used S is relatively high, but not uncommon; moreover, the value is consistent from a theoretical point of view, as discussed by Monteiro (2002) and Reimann et al. (2008). S and T were validated with observed hydraulic head time series in several monitoring wells and observed spring discharge at the Arade estuary."

Figure 1 has a very high resolution, so that the map can be zoomed in to obtain great detail.

In Figure 3b the white dots have been removed (they indeed were confusing), as well as the blue circle (unnecessary)

Regarding the comments of Referee 2:

(1) Many of the referred aspects have been dealt with and discussed in the text above: the text on inventory and screening is shorter, whereas much more has been written about the model and its validation. Section 3 now has 1400 words (10 percent less), whereas section 4 has 2795 words (30 percent more). In the original manuscript already section 4 on sustainable yields and the model already had 500 words more than section 3 on screening and the SVI, so it is not entirely true that little space had been left for section 4. Though much text has been added to the model description and validation, the total length of the paper has not increased much (250 words), because we made an effort to reduce other sections accordingly.

Equations have been included in the model description.

(2) This issue has been dealt with during the discussion of the model and is partly illustrated in the following paragraph:

"SCENARIO 3: reducing natural groundwater recharge in the steady-state model by 40 percent, based on the predicted decrease in rainfall by 2100 (Santos and Miranda, 2006), while maintaining the groundwater withdrawal volumes for public supply and irrigation. A minor difference with the previous steady-state model is that besides the Water Utility wells only the screened wells are used, rather than the wells where groundwater withdrawal actually occurred in 05/06. As it was decided to maintain a constant public supply of 21.5 hm³, including screened and Water Utility wells, pumping rates were set at 66 percent of maximum rates. Naturally, this is a simplification of the reality, as it is difficult to predict if and how change in climate and water consumption will lead to a new steady-state situation. More accurate simulations can be provided by transient scenario modeling if climate change data are available with sufficient temporal resolution, which is currently being studied. The idea here is to obtain a general idea of the impact of a strong decline in recharge, which in part may also reflect an increase in water consumption by economic uses."

(3) We now refer that the transient model has been made in FEFLOW (Koskinen et al., 1996), so that the readers who are familiar with this software, know its routines.

(4) See (2). This is an assumed simplification, but the reduction in recharge can be seen to partly reflect the increase of groundwater consumption. In the discussion of Scenario 3, some sentences were modified:

"Hydraulic heads drop significantly in the entire area, up to 120 m or 60 percent in the northeast and 90 percent in the west, where the hydraulic gradient is extremely small. There are no signs of seawater intrusion, since the regional mean annual water budget continues to be positive, though it comprises only 6 percent (3.5 m³ yr⁻¹) of natural recharge. A simultaneous increase in water consumption could lead to a negative water budget, and in any case it would be extremely difficult to meet ecological demands for the groundwater dependent ecosystems, whereas the lowering of hydraulic heads would significantly reduce or stop spring discharge"

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(5) The first sentence of the last paragraph of the Conclusions was changed to:

"The results obtained from predictive modeling, though based on a simplified steady-state scenario that should be treated with caution, point out the need to prepare social and technical tools to alleviate the combined impact from future climate changes and water demand increases in the region."

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