Tide cleaning of heads in unconfined coastal aquifers via processing of signal wave components

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ABSTRACT

An effective method to remove the tide effects from head data at different depths has been developed. The method has been applied in the discharge zone of Motril-Salobreña coastal aquifer (South Eastern Spain) for two time intervals (one month and one year). It consists in handling the groundwater head like a wave, which is defined in terms of amplitude, frequency and phase. These significant tide components are extracted from the original tide-perturbed head by low and high pass filters of frequency applying software tools of signal processing. The obtained signal represents the non-perturbed head level, which allows to delve into the non-tide water head affections that can be detected in the discharge zone of coastal aquifers.

INTRODUCTION

Tidal perturbation in groundwater head measurements near the coastline is, in principle, an issue with two principal faces. It is possible to create analytical and numerical models to derive aquifer parameters via relationships between tide and groundwater head. Secondly, the tide oscillation and consequent the gradient variability at discharge zone produce an enhanced of mixing zone due to an increase in local dispersivity values (**Cirpka and Atting 2003; Guarracino et al. 2012**). The changes in groundwater heads associated with changes in recharge, pumping and modifications of the aquifer conditions would represent a third face that can be achieved through the study of the groundwater head without tidal oscillation, The present study has the aim of obtaining a simple but efficient method for filtering data of tidal oscillation considering only the principal tide components detected on monitoring groundwater. Then, the method will be applied in two different time intervals of data and at two different depths

Background

Several studies proposed different equations to eliminate the tide oscillation in monitoring wells close to the sea, but they only accounted mathematics approximations of head fluctuation with higher or lower accuracy. **Nielsen (1990)** developed a mathematical model based on Boussinesq's equation and different analytical solutions, and the comparison of these with measurements presented greatest discrepancies meanly due to seepage face formation. **Erskine (1991)** derived transmissivity/storage ratio based on time lag and tidal efficiency factor values and performed a filtering of groundwater head data using these two factors, and the results showed imperfections owing to non-tidal effects. **Trefry and Johnston (1998)** applied least-square techniques to eliminate tidal oscillation from a pumping test data, but applied on more than one day period the results do not show a good fit or completely clean up. In any case, these methods are applied to a time interval comprising no more than several days or one month, and always in relatively shallow aquifers (tens of meters) and specific coastal morphologies or multi aquifer systems. **Li and**

Jiao (2003), Zhou et al. (2013) and **Bye and Narayan (2009)** proposed methods focused on the effects of tide on the saltwater-freshwater interface configuration and water table predictions, but not on cleaning groundwater head measurements.

METHODS

The study is based on the processing signal via frequency and amplitude detection of the different harmonics components of the tide observed in the measured groundwater head. Tide data with hourly time resolution has been used from *Puertos del Estado* (*Spanish Ministry of Development*). Head data were monitored with hourly resolution in two piezometers (P1 and P2) 300 meters from coastline and screened at -128 m and -34 m in depth respectively (relative to mean sea level). They are closed one to each other (3 m) so we can treat them as a single point where the groundwater head is recorded in two different depths.
First step of the filtering process consist to calculate principal harmonic components in terms of frequency, amplitude and phase in tide and head data in both points, which allows recognizing all the tidal components that affect to the latter. It has been carried out by applying a modified script based on T_TIDE (**Pawlowicz et al., 2002**). The outputs are frequency, amplitude, phase and *snr* factor (*"signal to noise ratio"*), indicating the most significant tidal constituents from the analyzed signal (when *snr >2*).
Next steps consist to isolate those constituents by filtering the original groundwater head signal through the application of low and high pass filters, based on the *Fourier Series Development*. Density spectral analysis for both groundwater head signals is used to confirm the principal tidal frequencies on that, compared with T_TIDE output frequencies. These harmonics of different frequencies are removed from the original data by filters based in different wavelets families. The derived signals represent the non-tide perturbed groundwater head.

RESULTS AND DISCUSSION

Principal results have been obtained for two different time intervals (a month and a year). The adjustment of the significant tidal components was performed on the largest time interval, with the aim to obtain all possible or detectable harmonics of tide. Filtering of data and cleaned up the signals was performed separately viewing thus the possible inconsistencies due to the selected time interval.

TIDE							P1						
Tide ID	F (h^-1)	P (h)	A (m)	A_Err (m)	Pha (°)	snr	Tide ID	F (h^-1)	P (h)	A (m)	A_Err (m)	Pha (°)	snr
SA	0.0001	8764.24	0.0594	0.013	359.38	22	SSA	0.0002	4382.12	0.0636	0.03	119.17	4.5
SSA	0.0002	4382.12	0.0192	0.012	40.41	2.5	K1	0.0418	23.93	0.012	0.001	182.02	150
MF	0.0031	327.86	0.0059	0.009	352.96	0.4	N2	0.0790	12.66	0.0109	0.001	118.63	160
O1	0.0387	25.82	0.0199	0.001	121.98	210	M2	0.0805	12.42	0.0529	0.001	122.42	4000
P1	0.0416	24.07	0.0115	0.001	151.07	89	S2	0.0833	12.00	0.0163	0.001	105.54	340
K1	0.0418	23.93	0.0324	0.001	155.94	610	P2						
N2	0.0790	12.66	0.032	0.002	31.87	230	Tide ID	F (h^-1)	P (h)	A (m)	A_Err (m)	Pha (°)	snr
M2	0.0805	12.42	0.1573	0.002	48.62	410	SSA	0.0002	4382.12	0.052	0.023	121.14	5.2
S2	0.0833	12.00	0.0619	0.002	73.97	860	K1	0.0418	23.93	0.0035	0.001	180.42	23
K2	0.0836	11.97	0.0172	0.003	69.61	32	N2	0.0790	12.66	0.004	0.001	115.71	56
M4	0.1610	6.21	0.0166	0.001	160.39	310	M2	0.0805	12.42	0.0194	0.001	121.16	1400
MS4	0.1638	6.10	0.0117	0.001	226.45	120	S2	0.0833	12.00	0.005	0.001	49.68	77

Table 1. Principal harmonic components of tide and piezometers P1 and P2.

Table 1 show the significant components of tide, P1 and P2 (T_TIDE outputs), where the columns indicate (left to right) *tide identification*, *frequency*, *period*, *amplitude*, *amplitude's error*, *phase* and *snr*. The adjusted components in P1 and P2 are consistent with the obtained tidal frequencies, including the semiannual tide component (*SSA: Solar Semi Annual*), with a period of 4382 hours. As it shown in figure 1, the most notable tidal frequencies are the semidiurnal and diurnal for a month time interval (*K1*, *N2*, *M2* and *S2* for P1 and P2 in table 1), corroborated by spectral density analysis. The semimonthly tide has not been detected due to the minimum affection on the amplitude of groundwater head signals, if it is compared to the high influence of semidiurnal tide (meanly *M2*), so maybe string and neap tides are masked.

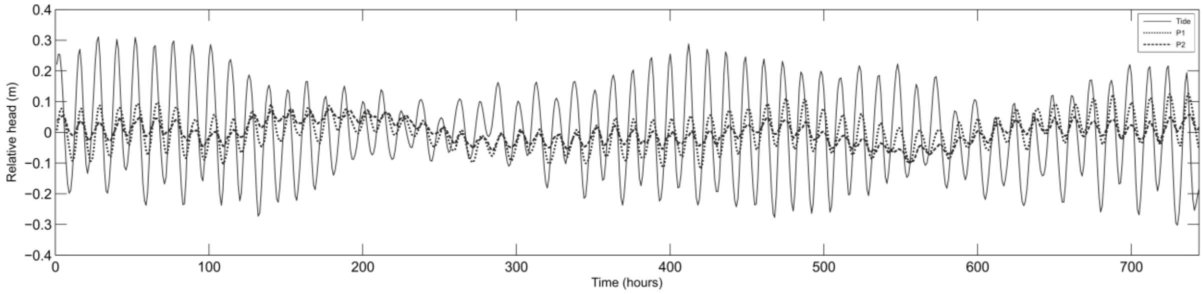

Figure 1. Relative levels of Tide and piezometers P1 and P2 in August 2012.

Figure 2 shows the obtained filtered signals for P1 and P2, together with the original groundwater head data in each case for all the monitoring year.

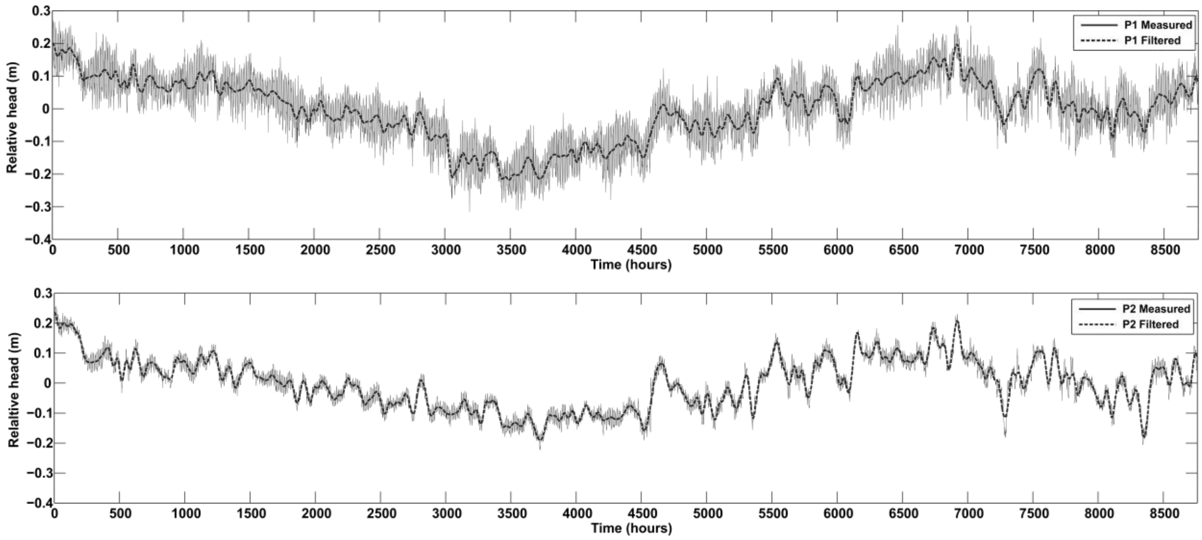

Figure 2. Original and filtered levels in piezometers P1 (upper) and P2 (lower) from 21/03/2012 to 21/03/2013.

The general annual trend is similar in both points, but differences between P1 and P2 regarding to their depths can be detected. The mean amplitude value for tide is around 0.6 m, and it induces amplitude on the groundwater head ranging from 0.1 to 0.3 m depending on the depth of measurement. Thus, P1 measured signal presents an important noise component and high tidal affection, meanwhile in P2 is more damped. The applied filters clean up the original signal at different levels of frequency, remaining non-tidal lower frequencies.

It can be observed differences between the filtering of both time intervals (a month and a year) that involves the treatment of the annual signal at lower frequencies than monthly signal. Nevertheless the method results in a congruent fit between the monthly signal and the same month within the annual signal.

CONCLUSIONS

Tide and groundwater head data have been differentiated by signal processing tools. This allowed to distinguish the affection of tide on wells close to the coast by filtering the groundwater head signals. The changes in the results at different depths confirmed the higher affection deeper in the aquifer. The treatment of different time intervals has showed that the method is accurate regardless of the time interval and pass filters used. The results finally enable to quantify and remove the tidal oscillations from groundwater levels that will lead to a better knowledge of the inland processes and changes in the discharge zone as well as their affections in the settings of the salt wedge.

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