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Insights into aquifer vulnerability and potential recharge zones from the borehole response to barometric pressure changes

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Borehole water levels fluctuate in response to deformation of the surrounding aquifer caused by surface loading due to barometric pressure or strain caused by Earth and ocean tides. The magnitude and nature of this response mainly depend on the hydraulic properties of the aquifer and overlying units and borehole design. Thus water level responses reflect the effectiveness of a confining unit as a protective layer against aquifer contamination (and therefore groundwater vulnerability) and to potential aquifer recharge/discharge zones. In this study, time series of borehole water levels and barometric pressure are being investigated using time series analysis and signal processing techniques with the aim of developing a methodology for assessing recharge/discharge distribution and groundwater vulnerability in the confined/semi-confined part of the Chalk aquifer in East Yorkshire, UK.

The chalk aquifer in East Yorkshire is an important source for industrial and domestic water supply. The aquifer water quality is threatened by surface pollution particularly by nitrates from agricultural fertilizers. The confined/semi-confined part of this aquifer is covered by various types of superficial deposits resulting in a wide range of the aquifer's degree of confinement. A number of boreholes have been selected for monitoring to cover all these various types of confining units. Automatic pressure transducers are installed to record water levels and barometric pressure measurements at each borehole on 15 minutes recording intervals.

In strictly confined aquifers, borehole water level response to barometric pressure is an un-drained instantaneous response and is a constant fraction of the barometric pressure changes. This static confined constant is called the barometric efficiency which can be estimated simply by the slope of a regression plot of water levels versus barometric pressure. However, in the semi confined aquifer case this response is lagged due to water movement between the aquifer and the confining layer. In this case the static constant barometric efficiency is not applicable and the response is represented by a barometric response function which reflects the timing and frequency of the barometric pressure loading.

In this study, the barometric response function is estimated using de-convolution techniques both in the time domain (least squares regression de-convolution) and in the frequency domain (discrete Fourier transform de-convolution). In order to estimate the barometric response function, borehole water level fluctuations due to factors other than barometric pressure should be removed (de-trended) as otherwise they will mask the response relation of interest. It is shown from the collected borehole data records that the main four factors other than barometric pressure contribute to borehole water level fluctuations. These are the rainfall recharge, Earth tides, sea tides and pumping activities close to the borehole location.

Due to the highly variable nature of the UK weather, rainfall recharge shows a wide variation throughout the winter and summer seasons. This gives a complicated recharge signal over a wide range of frequencies which must be de-trended from the borehole water level data in order to estimate the barometric response function. Methods for removing this recharge signal are developed and discussed. Earth tides are calculated theoretically at each borehole location taking into account oceanic loading effects. Ocean tide effects on water levels fluctuations are clear for the boreholes located close to the coast. A Matlab code has been designed to calculate and de-trend the periodic fluctuations in borehole water levels due to Earth and ocean tides using the least squares regression technique based on a sum of sine and cosine fitting model functions. The program results have been confirmed using spectral analysis techniques.