Monitoring and modeling a shallow unconfined aquifer to determine long term environmental change

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EXTENDED ABSTRACT

Seasonal and long term variation in groundwater levels in an unconfined coastal aquifer near Liverpool (UK) are described. The aquifer comprises windblown sand and is 20km long, 4km wide and approximately 40m thick. Environmental managers are concerned about falling groundwater levels in several Sites of Special Scientific Interest. Groundwater has been monitored in 12 wells each month from 1972-2018 and at 30-minute intervals from 2010-2018.

Figure 1. Location map and aerial view of the coastal dune system at Ainsdale (image: Google Earth)

Figure 2 shows the seasonal variations measured in a typical well (ref ASDNNRW11 – circled in Figure 1). Annual rainfall at the site is 860mm/yr and Potential Evapotranspiration 550mm/yr with recharge being greatest in the months November – March. The well level data illustrates the interannual variability of groundwater levels and forcing caused by seasonal groundwater recharge.

Forcing caused by climate change is less apparent. Since 1972 the mean annual air temperature has increased by 0.5^{o}C and these has been a slow change seasonal pattern of rainfall. Winters (November-March) are 10% wetter and summers (April-October) slightly drier. Figure 2 shows a 15cm lowering of the water table levels over the 46 years of observations. This is also reflected in the trend of spring maxima and late summer minima (trend lines in Figure 2).

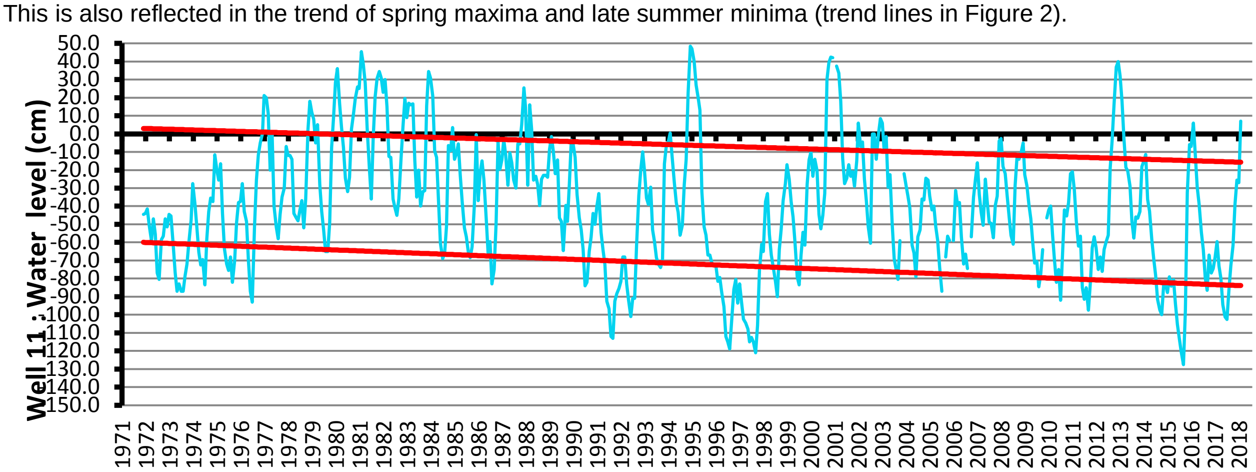

Figure 2. Monthly observations of water table levels in well ASDNNRW11 in the sand dune aquifer at Ainsdale, 1972-2018. Reference level (0cm) is the ground surface.

Clarke and Sanitwong (2009) describe a 1-D recharge model used simulate the water table levels in the dune system. The understanding obtained when constructing the water balance model was used to create a local groundwater model with differing recharge rates depending on land use cover and changes in rainfall and evapotranspiration, anticipated sea level rise and projected coastal erosion. Results are shown in Figure 3.

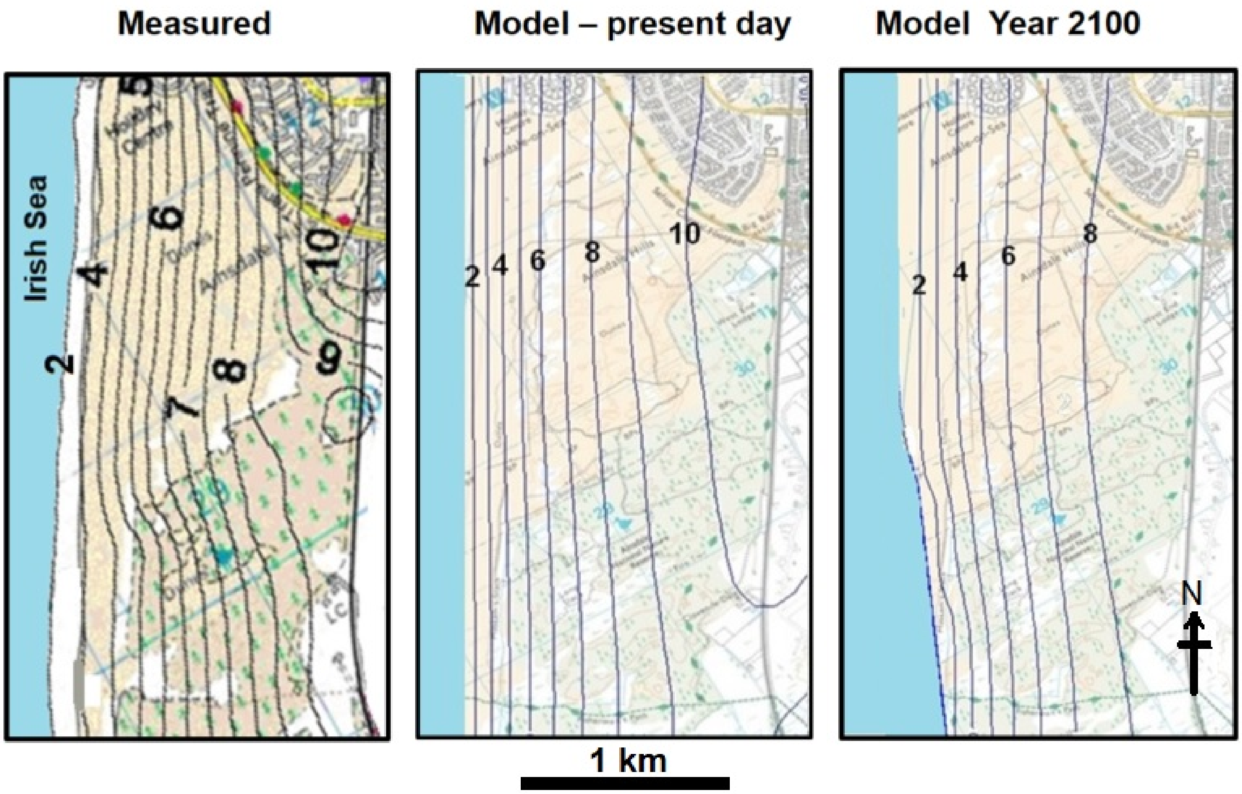

Figure 3. Mean water table levels. Left to right : Measured, MODFLOW model for observed data period, MODFLOW Model for year 2100 with anticipated climatic change and 0.5m sea level rise.

The analysis shows that by the year 2100, reduced summer recharge and higher evaporation will cause an accelerated decrease in mean groundwater levels. Anticipated sea level rise 2009-2100 is 20-40cm but it could be as high as 70cm (http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87903&filetype=pdf), which would shift the baseline of the groundwater model upwards, but this is counteracted by the reduced groundwater recharge. Between 1972-2018 mean levels fell by 15cm (Figure 2) but by 2100 the modelling results suggest that the fall is between 100 and 150cm. Another notable feature is the projected effect of coastal erosion in this region where the southern end of the system is retreating by up 6m/year (Esteves et al 2009).

Clarke and Stratford (2010) used the 1-D recharge model with stochastic series of recharge events based on the UK Climate Impact Program Weather Generator (UKCP09, 2009) – Figure 4. This demonstrates that by 2095 ground water levels may be up 1.5m lower in summer and the frequency of winters with standing water (above the surface) will also decrease. This will have a significant impact on the natural ecosystems. The sand dune system contains several Local Nature Reserves, SSSI's and a National Nature Reserve (https://www.sefton.gov.uk/around-sefton/coast-countryside.aspx). A key ecological characteristic is the seasonal filling of the low lying areas between the sand dune ridges (known as "slacks"). These areas are extremely biodiverse, supporting up to 100 plant species per square meter (Houston, 2008, Natural England, 2014) together with IUCN Red List species (www.iucnredlist.org/) such as the Natterjack Toad (*Epidalea calamita*).

A feature of the stochastic simulations is the presence of large interannual changes in the simulated water table levels over the rest of the 21st century. Many species in the region are dependent on regular fresh water flooding of the slack floors in winter/spring. The modelling indicates that some flora and fauna in the conservation areas is unlikely to survive or persist and that a change in the ecology of the district may become inevitable (Grootjans et al 1998, Cureli et al 2013, Provoost et al 2011).

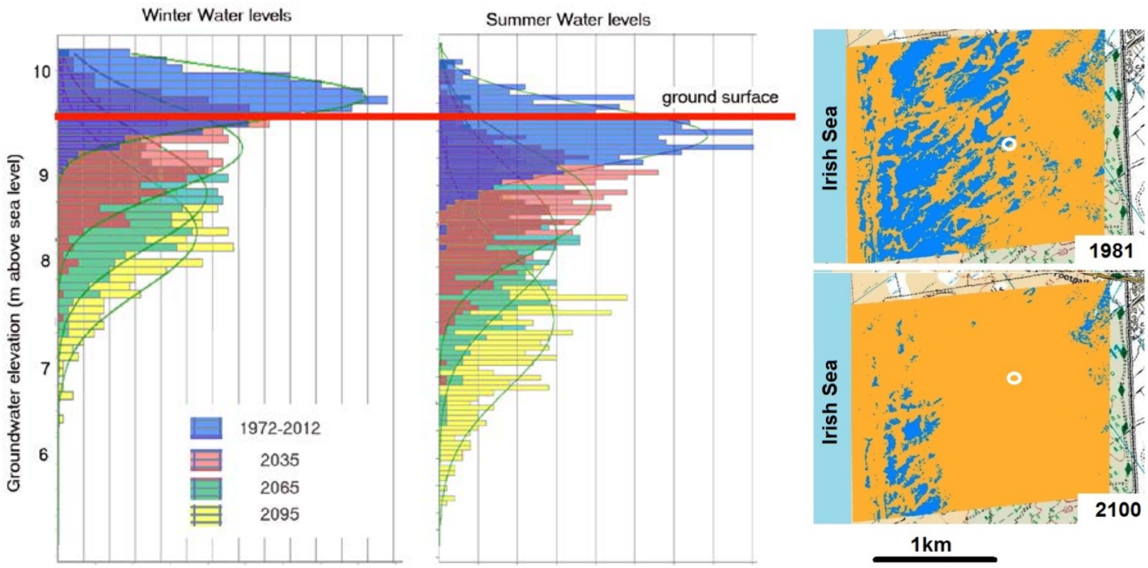

Figure 4. Left and Centre : Water table levels based on 500 simulations of climate sequences between 1972 and 2095. Right : Maximum extent of flooded fresh water slacks in winter, 1980's (observed), 2090's (modelled). White circle – location of well ASDNNRW11.

Information from this modelling work is enabling conservation planners to identify areas of the dune system that will be of concern to managers. As the southern end of the dune system is being eroded, material is being deposited 5-10km further north and a new "green beach" has developed in the last 20 years. This new land contains many of the hydrological characteristics of the dune system modelled in the 1970's (Natural England 2014) and these areas will become more suitable to protect over the next 100 years. This suggests that a new dynamic approach to conservation may become necessary, where ecosystems relocate spatially and simple land use zoning may no longer be appropriate for conservation management.

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