Characterising hydrodynamic controls on groundwater in a coastal urban aquifer using time and frequency domain responses at multiple spatiotemporal scales

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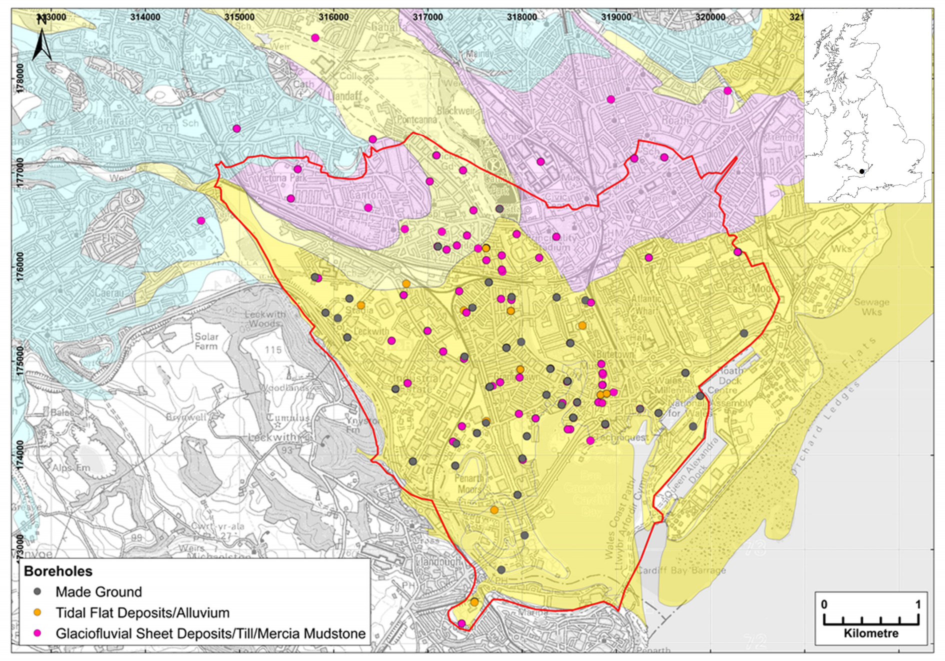
1. Introduction

Coastal, urban environments often have highly variable & evolving hydrogeology. This presents challenges to hydraulic & thermal conceptualisation & parameter estimation due to their complex dynamics & the heterogeneity of ocean-influenced hydraulic processes. Traditional investigative methods are time consuming, expensive, & difficult to conduct in built-up areas. A novel approach using passive sampling of groundwater head data to understand subsurface processes & derive hydraulic & geotechnical properties in an urban-coastal setting is presented. It is anticipated that linking the improved hydraulic characterisation will also help better characterisation of the subsurface thermal regime, & management of shallow geothermal energy resources in coastal, urban aquifers.

2. Methodology



- 20 years of data from Cardiff, U.K.
- Pre- & post-impoundment of the rivers by a barrage to form a freshwater bay.
- Hourly groundwater levels for 234 boreholes.
- Sea & river levels.
- Cardiff Bay levels.
- Barometric pressure data.
- Comparing Tidal Subsurface Analysis (TSA) with Barometric Response Function (BRF).

Fig. 1. Location map of boreholes coded by lithology of the screened section. Contains DiGMap 1:50 000 British Geological Survey © NERC & Ordnance Survey data © Crown Copyright & database rights 2020.

3. Tidal Subsurface Analysis

- TSA applied to Earth, atmospheric & oceanic signals in groundwater time-series used to assess changes in ocean tide influence across the aquifer pre/post impoundment.
- Measuring the relationship between tidal signals & groundwater levels allows characterisation of subsurface hydrogeological properties.

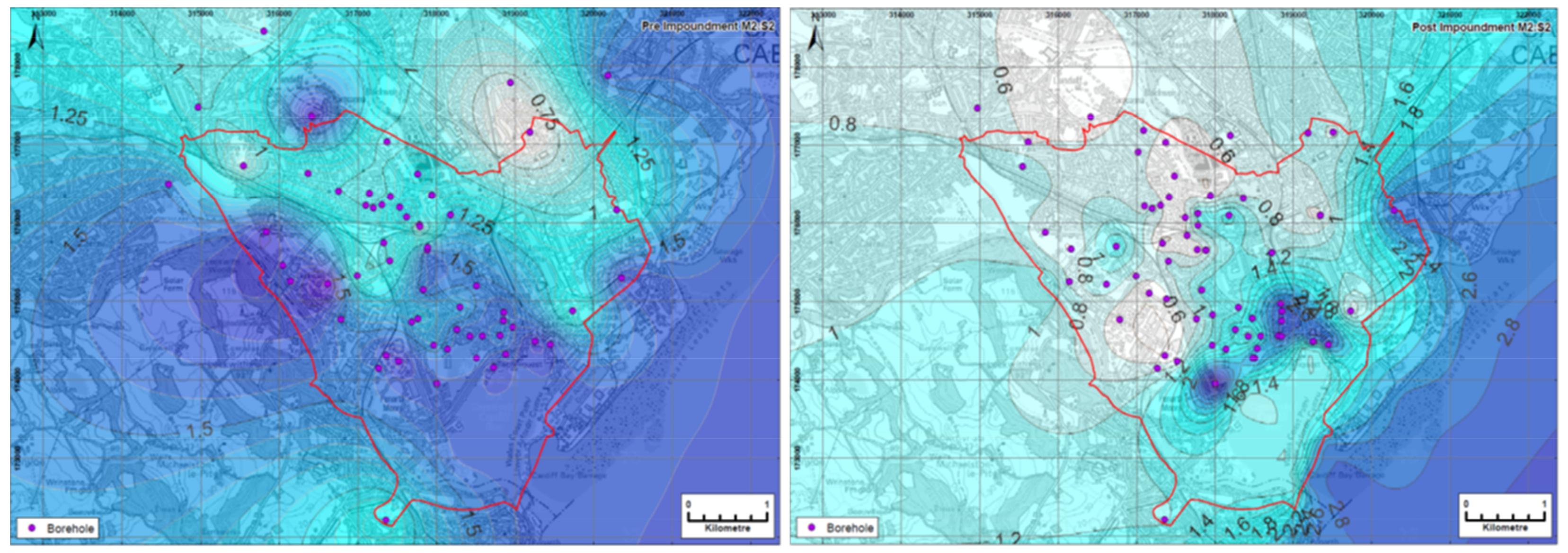


Fig. 2. Contour plots show difference in strength ratio of Principle Lunar (M_2) & Principle Solar (S_2) tidal components in groundwater pre/post impoundment (gravel boreholes). Decrease in M_2 reflects weakening of the ocean tide signal. Contains Ordnance Survey data © Crown Copyright & database rights 2020.

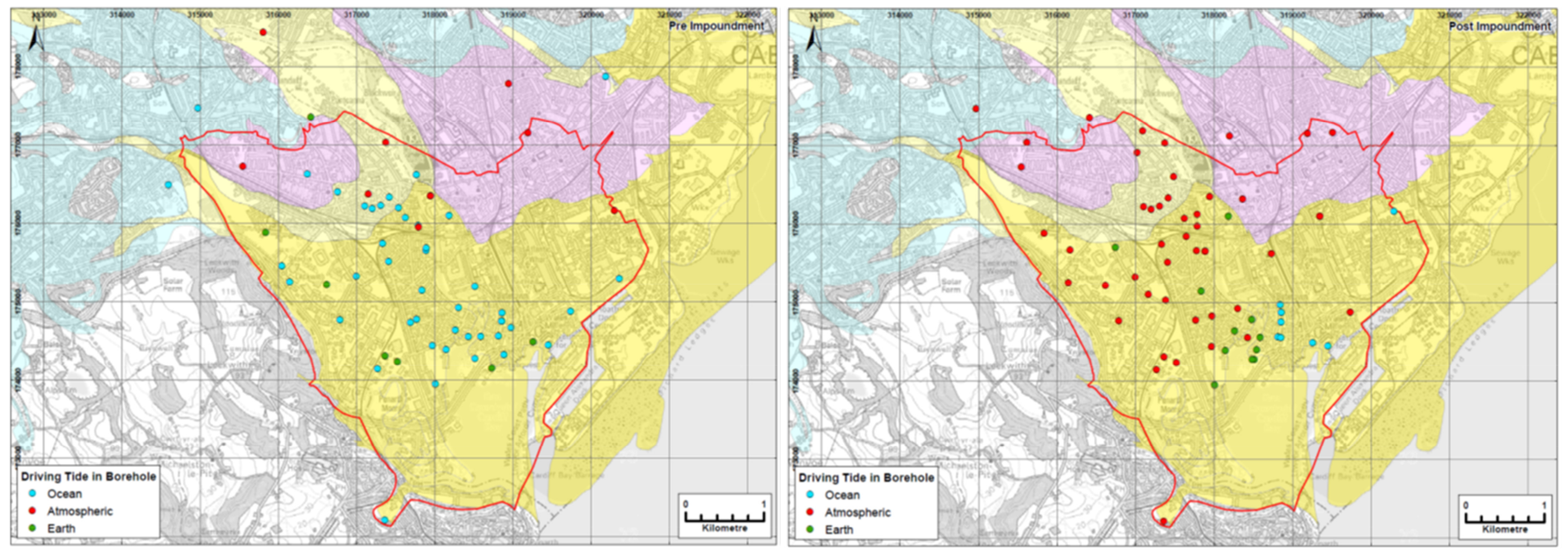


Fig. 3. Principle driving tides seen in gravel boreholes pre/post impoundment derived from the M_2:S_2 ratio. Contains DiGMap 1:50 000 British Geological Survey © NERC & Ordnance Survey data © Crown Copyright & database rights 2020.

4. Barometric Response Function

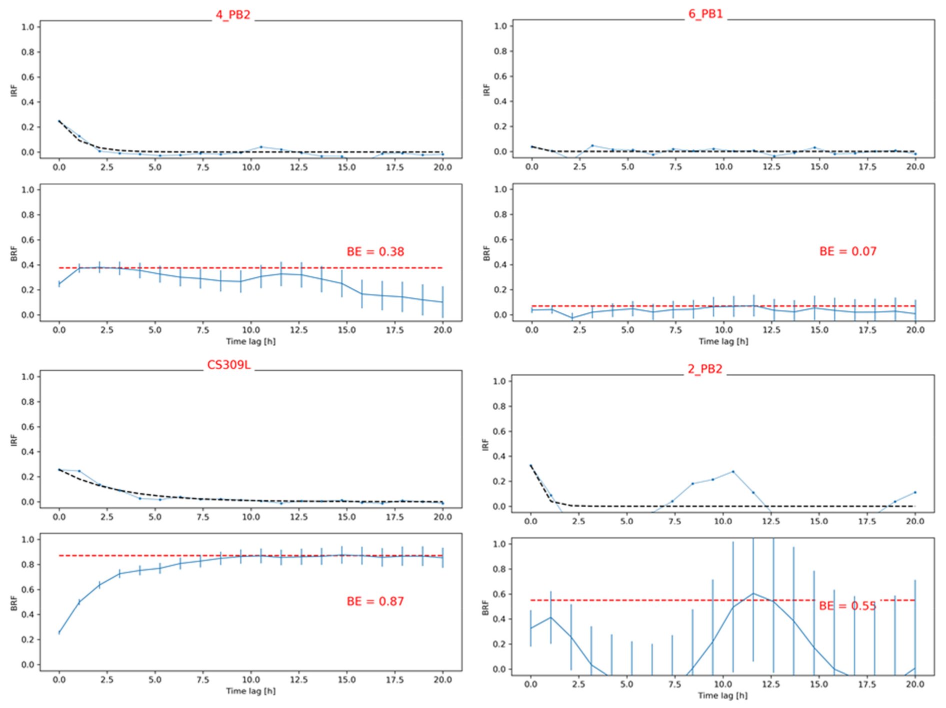


Fig. 4. Typical plots derived from the BRF method: Falling (top left), Flat (top right), Rising (bottom left) & Peaked (bottom right).

- BRF used to derive a function relating the influence of barometric pressure variations on groundwater levels to filter head fluctuations caused by the atmosphere.
- BRFs generated in the time domain for the same boreholes where TSA was applied in the frequency domain.
- BRF plots classified into four shapes; Falling, Flat, Rising & Peaked (Fig. 4).
- BRF shapes identify hydraulic properties - Falling = unconfined, Flat = Confined, Rising = confined or unconfined with borehole storage, Peaked = ocean tidally polluted.

5. Barometric Efficiency - TSA versus BRF

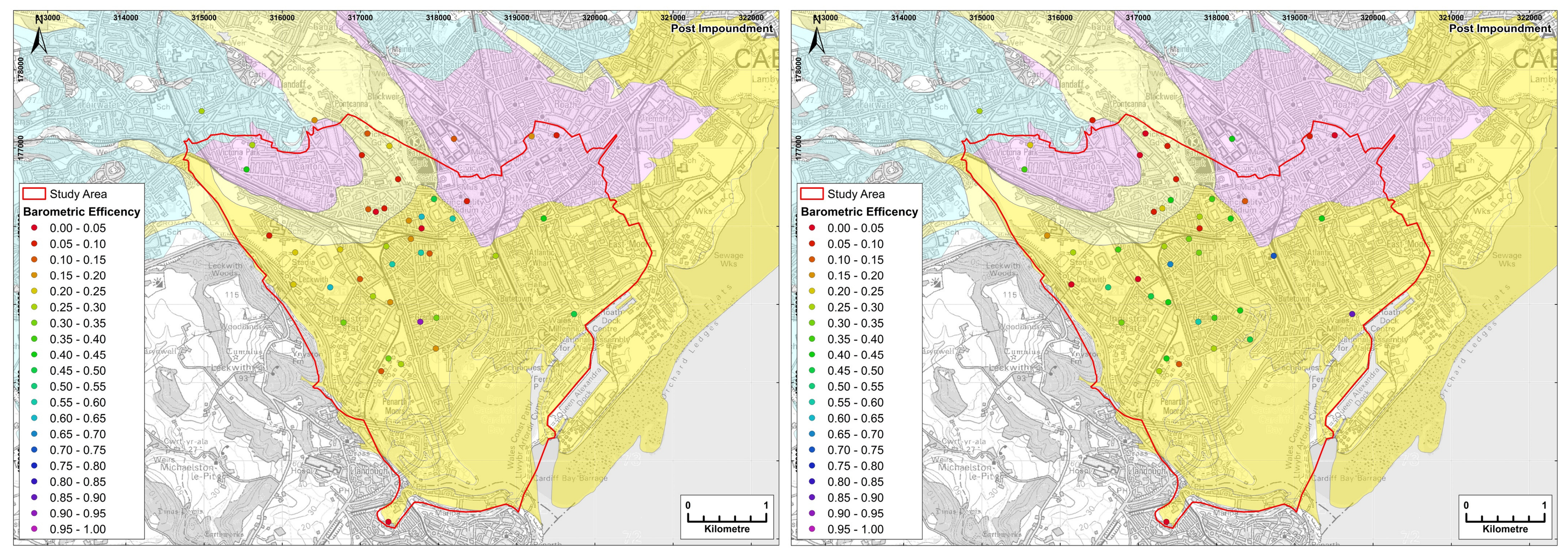


Fig. 5. Comparison of the barometric efficiencies calculated using TSA (left) & BRF (right) methods.

- Both TSA & BRF methods used to derive barometric efficiency.
- BRF method generates less extreme BE values for ocean tide boreholes but neither method can currently be used in boreholes polluted by ocean tide signals.
- For non-ocean tide boreholes TSA & BRF methods show general agreement in barometric efficiency calculations (Fig. 6) with some discrepancies accounting for very localised characteristics (Fig. 5).
- Both methods needed to disentangle signals & characterise hydrogeological settings.

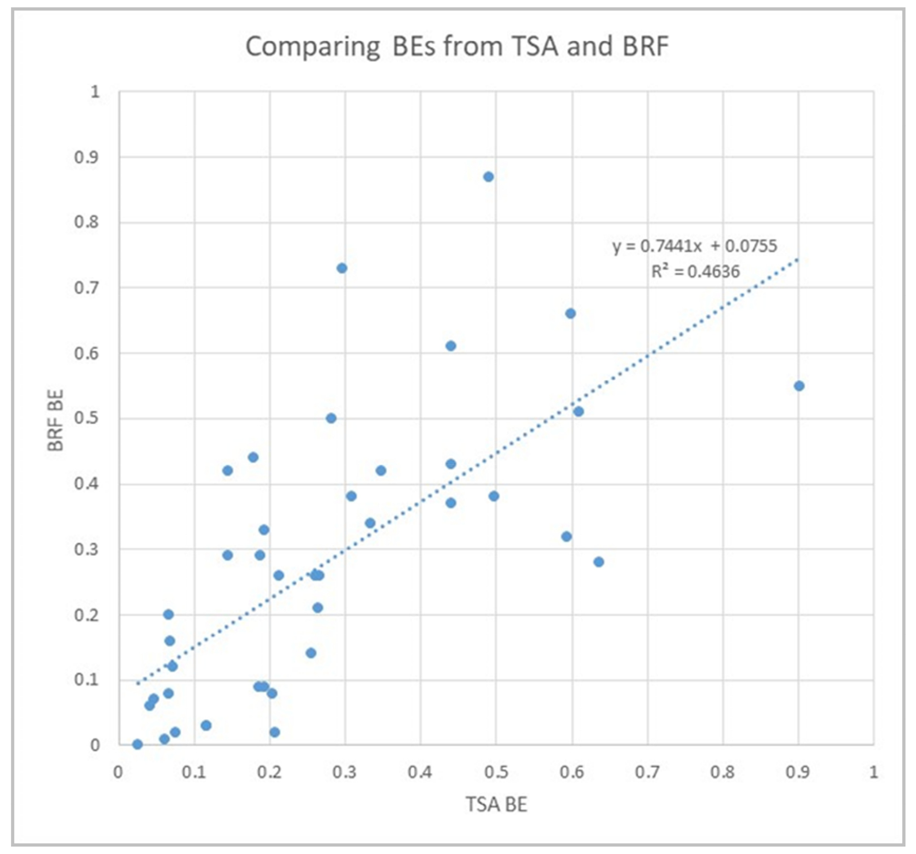


Fig. 6. Comparison of the barometric efficiencies calculated using the TSA & BRF methods.

6. Key Findings

- TSA & BRF methods allow inexpensive & non-invasive characterisation of the subsurface. In Cardiff previous hydrogeological assumptions have been refined.
- TSA currently only suitable where there is no ocean tide signal but may be used to disentangle the influence of different tide components & estimate aquifer properties & processes.
- TSA can be used to calculate hydraulic diffusivity from damping & attenuation response to ocean tides with distance from the coast/rivers.
- M_2:S_2 ratio may be used to determine driving tides. TSA can be used to identify strength & propagation of ocean tide signals across an aquifer.
- TSA reveals variations in hydraulic responses & values of hydraulic diffusivity spatially & between different lithologies & shows heterogeneity within units.
- Made ground boreholes are less sensitive to ocean tides than the sand & gravel aquifer, having no strong ocean tide-derived M_2 signal.
- TSA & BRF compare well at estimating barometric efficiency from which formation compressibility & confinement can be derived.
- Shape of BRF plots can identify aquifer confinement.
- TSA & BRF useful in determining changes pre- & post- impoundment.

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