Investigating the impacts of low permeability layers in the Chalk on groundwater levels and river flows using multiple modelling methods: Lessons from the Ver catchment

Georgia Williams[1], Majdi Mansour[2], Adrian Butler[1], Ilias Karapanos[3], Alessandro Marsili[3] , Chris Jackson[2]

[1]Imperial College London [2]British Geological Survey [3]Affinity Water

Introduction

Context

In northwest Hertfordshire, the Chalk stratigraphy comprises of the New Pit Formation with numerous marl bands. At the base of the underlying Hollywell Nodular is the Melbourn Rock and the Plenus Marls Member. These marl bands are characterized as low hydraulic conductivity horizons [3] and can "split" the aquifer and control its response to perturbations such as recharge and abstraction. In this study we apply numerical modelling to site data of the Chalk aquifer near the River Ver to explore how these various low permeability marl layers might affect Chalk stream baseflow in response to changes in groundwater abstraction.

Motivations

Groundwater in southeast England supports a large proportion of public water supply and sensitive ecosystems [1]. A significant proportion of this groundwater comes from the Chalk aquifer. The Government's 25-Year Environment Plan highlights the importance of restoring flow to ecologically important chalk streams. Here we demonstrate the importance of multi-layer settings of hydrogeological models to improve the management of water resources and protect England's rare chalk streams.

Methodology

Radial Flow model
- Aim: To obtain aquifer hydraulic parameters (optimised using PEST), to inform the conceptual model
- Structure: 3-layered finite-difference radial flow model [5]
- Application: Pumping test analysis at Borehole A

AquiMod Model
- Aim: To estimate groundwater recharge
- Structure: Lumped groundwater model [4]
- Application: Recharge values as bi-product to reproducing daily GWL time-series

Conceptual model
- Developed using regional geology, groundwater levels and topography maps.

Numerical groundwater flow model (ZOOMQ3D) [2]

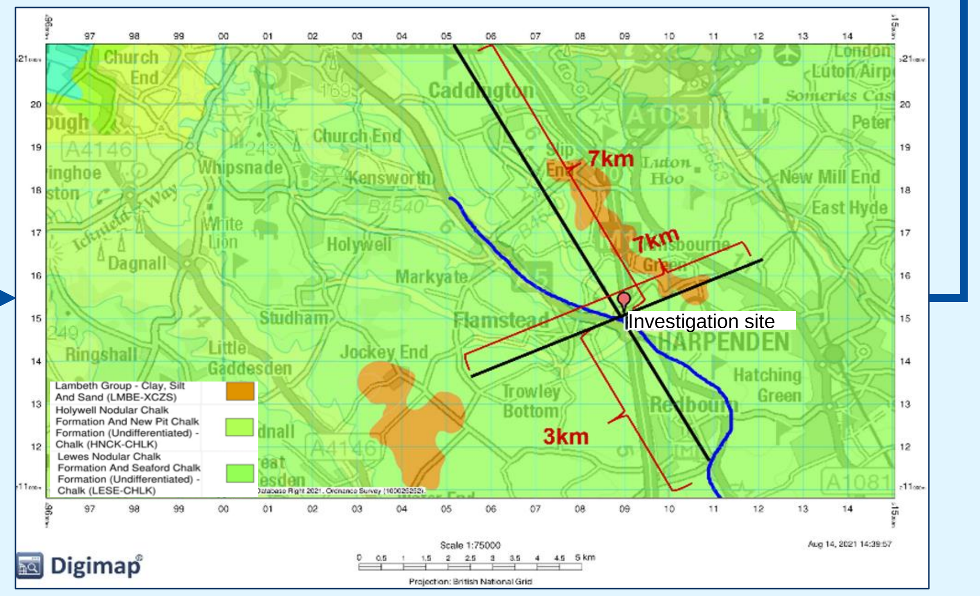

Figure 1. Overview of the components required for the ZOOMQ3D model.
Source: Edina Digimap®. Contains British Geological Survey materials © UKRI 2022 and Ordnance Survey data © Crown copyright and database rights 2022, Ordnance Survey (100025252)

ZOOMQ3D [2] was set-up as a 2D slice model (Figure 2). No flow boundary conditions were set along all sides of the slice model.

A river node was added at the downstream end of the aquifer to discharge the groundwater flow. A 0.1m thick low permeability layer was included to represent the marl band. Initial run (10 years) was undertaken to simulate long term groundwater levels in the deep and shallow observation boreholes. Subsequent runs for a period of 3-months with intermittently pumped.

Additional simulations with extended river file that was the length of the River Ver, so to simulate the river profile under different scenarios.

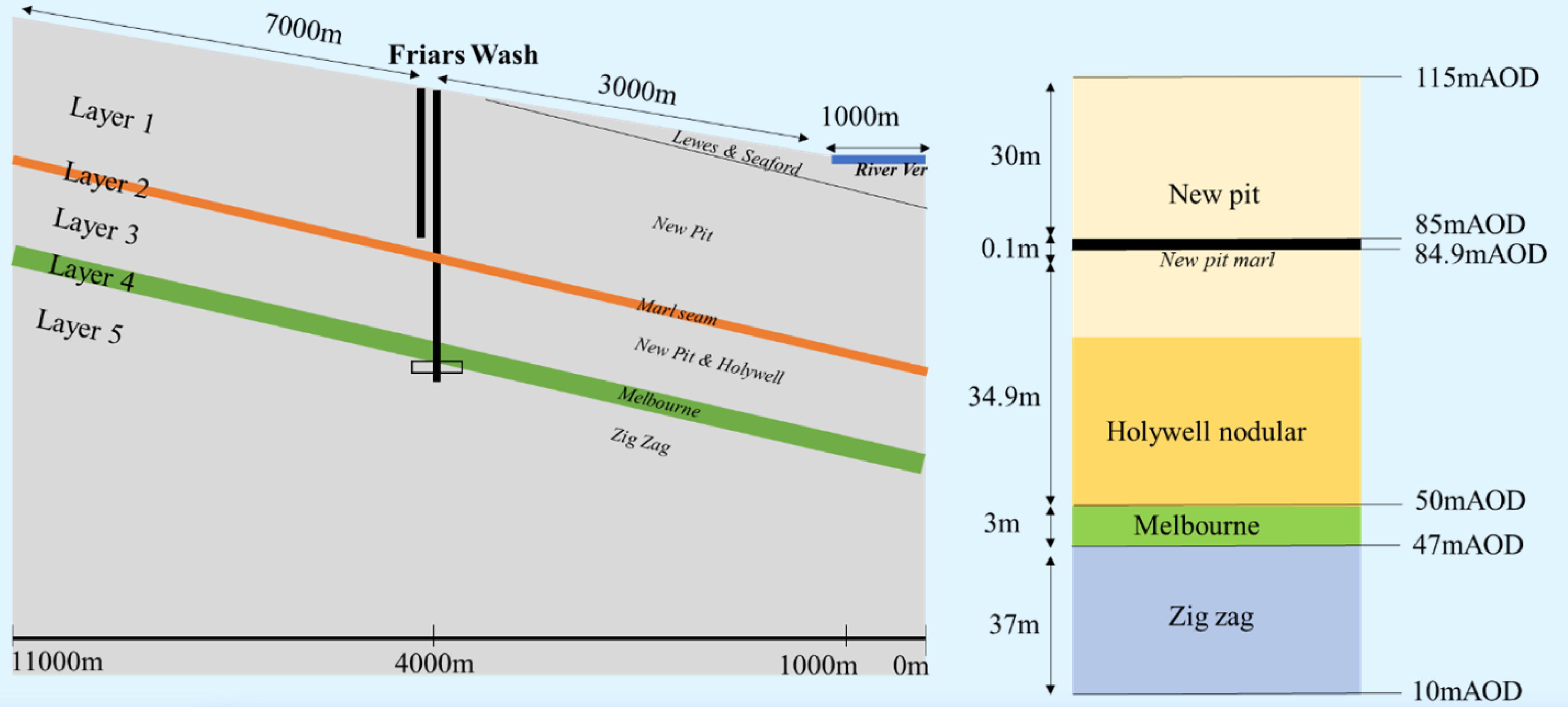

Figure 2. The conceptual model set-up for the numerical model

Results and Discussion

Radial flow model

Multi-layered R-Z numerical settings. Calibration shows that the hydraulic conductivity values decrease with depth.

The layer separating main aquifer units has considerably low K values highlighting a possible presence of a barrier to the vertical flow.

Layer	Vertical hydraulic conductivity (m/day)
1	1.04
2	0.93
3	**1 x10^{-6}**

Table 1. Vertical hydraulic conductivity (m/day) obtained from the best Radial Flow model manual run

ZOOMQ3D Model

Groundwater levels at the site observation boreholes show vertical hydraulic head difference.

Model runs indicate that this head difference can be produced with the addition of a marl band and/or pumping.

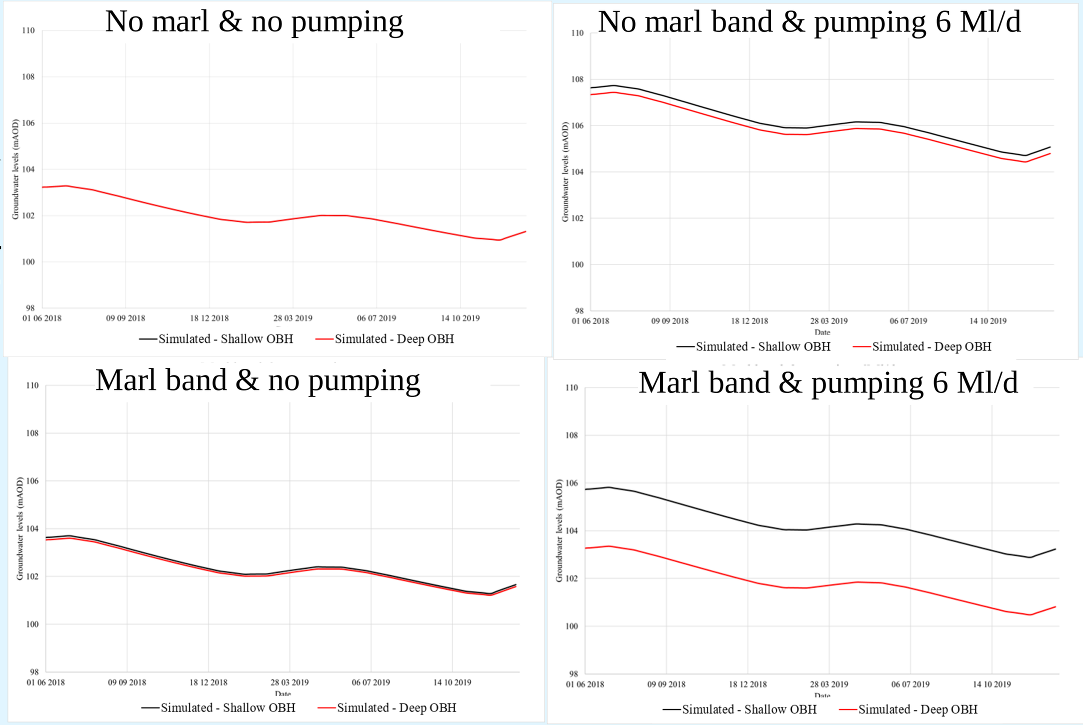

Figure 4. Graphs of the simulated groundwater levels at the OBH's for each scenario

Observed GWLs don't recover to the same level when abstraction is changed from consistently pumped to intermittent, suggesting pumping isn't the only cause of the hydraulic head difference.

There are similar rhythmic fluctuations in the shallow and the deep OBH's suggesting only a partial hydraulic disconnection within this aquifer system, i.e. there is limited vertical leakage between the upper to the lower groundwater systems.

River-aquifer interactions were explored to understand why flow did not recover in the River Ver, when pumping was switched off at the site borehole A. Steady state model runs show that the addition of the marl band increases the groundwater heads, leading to more river baseflow. However, the model failed to explain why the flow does recover in the river when abstraction was reduced.

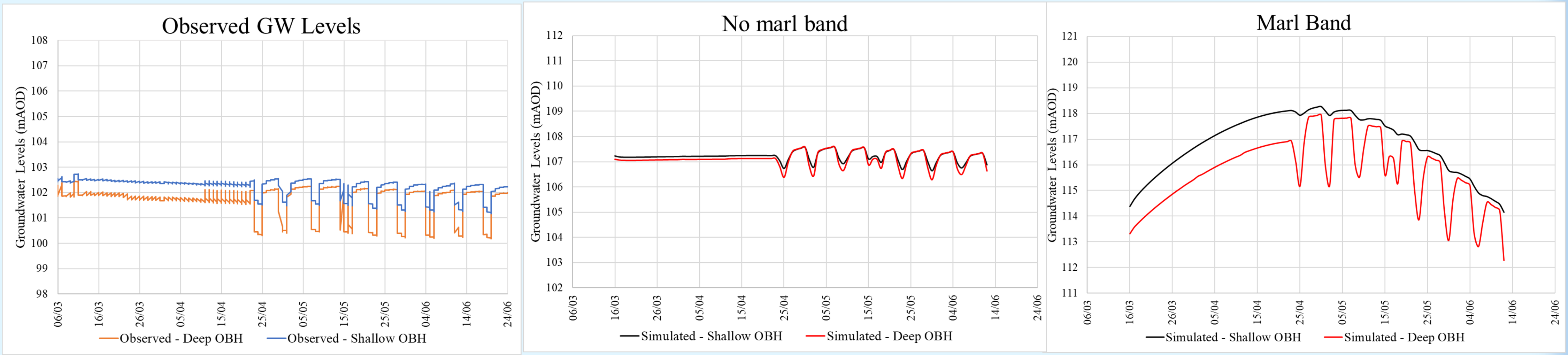

Figure 6. Simulated groundwater levels at the OBH's for each scenario for intermittent pumping

Conclusion

- Simulations showed that there is inherent vertical heterogeneity at the investigated site in Hertfordshire.
- Partial hydraulic disconnection reproduces the similar rhythmic fluctuations in the upper and lower groundwater heads.
- To restore river baseflow and to better manage water resources, conceptual and hydrogeological models of the Chalk need to include the vertical heterogeneity identified in the Chalk aquifer.
- It has been demonstrated that low hydraulic conductivity horizons can have important impacts on groundwater levels and stream flows and should be the subject of further investigation.

References

[1] Allen, DJ., Brewerton, LJ., Coleby, LM., Gibbs, BR., Lewis, MA., MacDonald, AM., Wagstaff, SJ., Williams, AT., 1997. The physical properties of major aquifers in England and Wales. British Geological Survey Technical Report WD/97/34, Nottingham, UK. pp. 312.
[2] Jackson, C.R., Spink, A.E.F. 2004. User's manual for the groundwater flow model ZOOMQ3D. Nottingham, UK, British Geological Survey, 107pp. (IR/04/140) (Unpublished)
[3] Karapanos, I., Jaweesh, M., Yarker, D., Sage, R., Marsili, A. and Powers, E., 2020. Evidence of layered piezometry system within the Chalk aquifer in parts of SE England. Quarterly Journal of Engineering Geology and Hydrogeology, 54(2).
[4] Mackay, J., Jackson, C. and Wang, L., 2014. A lumped conceptual model to simulate groundwater level time-series. Environmental Modelling & Software, 61, pp.229-245.
[5] Mansour, M M., Hughes, A G. and Spink, A E F., 2007. User Manual for the Layered R-Theta Numerical Model. British Geological Survey Research Report, OR/07/029. 71pp.