On the vertical connectivity in fluvial Hot Sedimentary Aquifers (HSA) and its influence on Geothermal and Managed Aquifer Recharge (MAR) doublet performance

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Introduction

The deep sedimentary aquifers of the Perth Basin have been exploited for water supply since the beginning of the late 19th century. In the last 20 years they have been increasingly targeted for low enthalpy direct-use geothermal applications [1] and MAR [2].

Perth geothermal systems have been used primarily for heating of pools and space in large leisure centres instead of the more common district heating [3] and greenhouse heating applications [4] in, for example, Denmark and the Netherlands . As a result the installed capacity is relatively modest with doublet capacity ranging from about 0.5 MW to 2.5 MW (average 1.3 MW). Nonetheless, with 14 operating geothermal doublet, the Perth Basin now has the biggest concentration of geothermal projects in Australia and is becoming one of the main geothermal play targeting fluvial aquifers in the world. The Perth Basin market is mature, with well-established technical and regulatory framework demonstrated by multiple commercial applications [5] and by Levelised Costs of Energy (LCOE) ranging from AU$6 to AU$14/GJ. Opportunities for future geothermal projects development will require scaling-up to larger energy delivery and exploration for hotter and deeper aquifers which will require a better understanding of the fluvial HSA resource.

Currently most geothermal projects target the mid-Jurassic (Bathonian) clastic sedimentary rocks of the Yarragadee Formation. The aquifer is exploited by a doublet system, consisting of a hot water production and a heat-depleted water reinjection bore. The target formation is exceptionally thick (>1,000 m) and the heat-depleted water is commonly re-injected at a shallower depth within the aquifer (typically 50 to 400 m shallower than top of the production zone), with both production and injection bores drilled vertically with about a 25 m horizontal spacing. This is different to most other HSA geothermal play where the aquifer thickness is insufficient to allow vertical spacing, a horizontal bore spacing of 1,500 m is commonly used [6].

MAR projects have also targeted the Yarragadee Formation. Injection (replenishment) bores are commonly constructed across several sandstone bodies with an injection length of up to 400 m. Water supply production bores are generally located several kilometres away from injection locations and screened across different sandstone bodies.

In fluvial aquifer rocks the doublet connectivity is via a network of permeable fluvial channel sandstone bodies embedded in non-permeable floodplain mudstone. Detailed knowledge of the size, shape, spatial distribution and connectivity of the fluvial sandstone bodies is required to assess the risk of pressure response loss between the bores and the impact on pumping costs [7]. Conversely, as the project energy delivery is scaled up, where connectivity exists, the risk of recycling between the bores and associated thermal breakthrough will also need to be assessed.

Current Perth Basin projects are designed based on the assumption that vertical separation and the occurrence of beds of mudstone and siltstone between the production and injection intervals minimize thermal breakthrough. Previous preliminary numerical modelling studies [8] have supported this assumption; however, the modelling only considered vertical anisotropy in permeability values but did not consider the effect of the fluvial facies distribution.

[9] used a radial-symmetric flow and transport model to assess the preferential movement of injected water at the Mirrabooka Aquifer Storage and Recovery bore. Whilst the model was able to calibrate acceptably well for field data recorded in monitoring bores located less than 50 m away, the adopted constant layer thickness did not allow for the

likely horizontal change of facies over kilometric scales. The adopted approach is thus unlikely to provide useful results for assessment of pressure responses in water supply production bores.

A better understanding of connectivity anisotropy could help define vertical spacing criteria for sustainable HSA operations, whereby pumping and injection costs are optimized. Similarly a horizontal spacing criteria for safe residence time for the injected treated waste water, whereby optimizing injection costs could be defined.

Therefore, the first goal of this paper is to evaluate the Net to Gross ratio (N/G) in the aquifer and estimate the connectivity anisotropy. The geological modelling in this study is based on all available subsurface data for deep bores in the central Perth Basin. The dataset was used to derive the range of N/G heterogeneities to constrain predictive uncertainty analyses. The dataset includes Gamma-Ray (GR) logging data and builds on lithofacies type identified by [10]. GR datasets highlight fining-up sequences from around 10 to 45 m in various bores. These indicate river channels 150 m to 2 kilometres wide which would have produced meanderbelts 1.5 to 20 kilometres wide [11]. The Yarragadee formation exhibits high N/G in some bores, e.g. Beatty Park (N/G 70%), and moderate N/G in others, e.g. St Hilda's (N/G 40-50%) as shown in Figure 1.

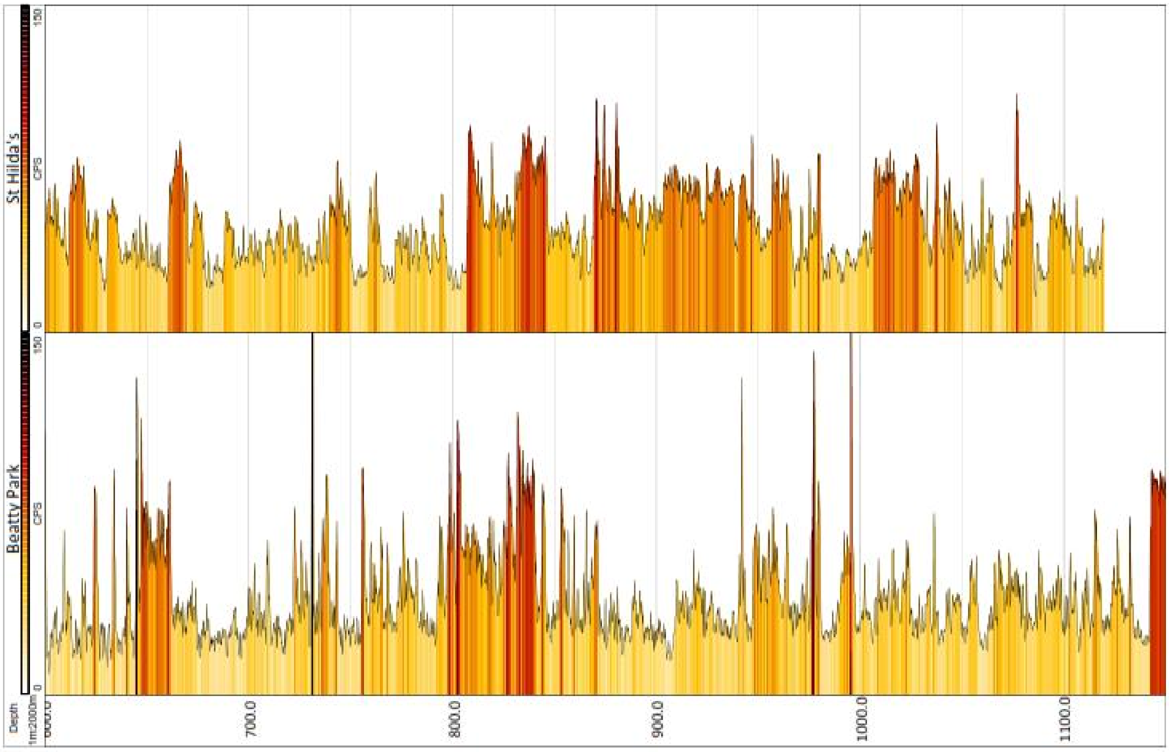

Figure 1: Selected GR logs of the Yarragadee Formation

In the high N/G areas, the Yarragadee is a complex of vertically and laterally stacked and apparently communicating sandbodies with discontinuous eroded remnants of the originally extensive floodplain claystones, soils and thin coals. In the moderate to low N/G areas, sandbodies may be isolated by floodplain sediments. However the seal quality of the floodplain sediments is variable from poor in the soils to good in lake claystones [11]. [7] showed that the horizontal connectivity threshold occurs for a N/G of at least 30%, while below 70% equivalent permeability is higher in the direction parallel to the paleo flow direction, thereby limiting potential vertical connectivity.

These data are incorporated into a detailed FEFLOW finite element numerical model with equivalent vertical and horizontal permeability values. Predictive uncertainty methods are utilised to estimate possible effect of this anisotropy on doublet performance, namely the likely pump energy losses and thermal breakthrough time for a range of vertical and horizontal distances between the production and injection intervals for geothermal projects and travel time and injection energy losses for MAR projects.

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