Groundwater Assessment of the Glendalough Alluvial Aquifer

The shallow alluvial aquifers at Glendalough Station host a groundwater resource that offers genuine opportunities for future irrigated agriculture development around Hughenden, Qld. However, very little is currently known about these aquifers and there is limited data available to understand the scale of potential development. Innovative Groundwater Solutions Pty Ltd. was contracted by the Australian Governments’ North Queensland Water Infrastructure Authority to provide a defensible and independent evaluation of the sustainable extraction limit for this resource.

Summary
The assessment found the sustainable extraction limit (SEL) for the alluvial aquifer is likely in the range of 1,400 to 17,800 ML/year, with a high confidence (80% probability) limit of 2,300 ML/year, a moderate confidence (50% probability) limit of 3,100 ML/year, and a low confidence (20% probability) limit of 13,300 ML/year. This large range depends on the relative abundance of deep, high-permeability sands and gravels, which to date have only been found in certain parts of the property. Drilling results for many other locations on the property indicate the alluvium in these areas is characterised by low-yielding clays and silts that do not provide bore yields sufficient for irrigation supply. The opportunity for managed aquifer recharge (MAR) to enhance the SEL appears limited because there is very little aquifer storage potential above the water table. This assessment has shown that MAR could potentially increase the high confidence SEL by 400 – 500 ML/yr.

Approach
The approach adopted for the assessment involved a review of historical drillers logs, the collection and analysis of downhole geophysical logs, and the development of a novel stochastic approach to represent the structure and hydraulic properties of the alluvial aquifer. This enabled a rigorous and transparent numerical modelling-based examination of the sustainable extraction limit (SEL) whilst acknowledging all of the key sources of uncertainty introduced through limited data.

Drillers logs and downhole geophysics provided a means to define the lateral and vertical extent of the alluvium as well as to characterise its composition at multiple locations based on a binary ‘clay’ or ‘sand’ categorisation. This showed that most of the high yielding ‘sand’ portions of the aquifer are below the current water table and hosted in paleochannels. The data also provided hard and soft constraints for stochastic realisations of the alluvium that were developed through a combination of a floodplain deposition model (Flumpy) and multi-point geostatistical software (SGEMS). Seventy (70) different stochastic realisations were produced comprising ten different structural models of the alluvium and seven different clay-sand fractions.

The centrepiece of this assessment was a numerical groundwater flow model of the alluvium developed using industry leading software (Modflow6 with FloPy). A Latin Hypercube method was used to sample 100 different combinations of
possible recharge rates and hydraulic conductivities for sand and clay, which, when propagated through the 70 different stochastic realisations, yielded 7000 models in total. These models were run in steady-state mode and calibrated using automated inversion software (PEST) to measured groundwater heads. A schematic representation of the model domain and key components of the steady-state water balance are shown in Figure 1.

![Figure 1. Conceptual model water balance for the Glendalough alluvium.](image)

Due to the limited value of historical aquifer pumping tests at Glendalough Station, the hydraulic properties of the alluvium are effectively unknown. Hence, the hydraulic conductivity of clay and sand fractions was expressed as wide ranges of possible values, rather than assumed unique values, that were computed using different mixtures of various fine (clay/silt) and coarse (gravel/sand) sediment types and theoretical values from the literature. This resulted in a range of 0.005 m/d to 185 m/d for sand, and $1.37 \times 10^{-6}$ m/d to 0.75 m/d for clay. The range for sand was later extended to a maximum of 300 m/d based on improved calibration of a simple Analytic Element Model (AnAqSim) that was used as a screening tool to guide development of the numerical groundwater flow model.

**Results**

A review of previous studies indicated that net vertical groundwater recharge rates to the alluvial aquifer are very low and possibly in the range 1 to 30 mm/year. This was corroborated with groundwater level measurements taken from 15-Mile Reserve in the six-month period following the February 2019 flood, which showed very little water table response despite prolonged inundation of the floodplain. The AEM screening tool also confirmed that vertical recharge is likely to be very low, instead demonstrating the importance of groundwater connectivity with the Sturgeon Basalt to the north and the upstream and downstream alluvium.

From the 7000 different models of the alluvium a subset of the 245 most acceptable calibrated models was selected on the basis of routinely accepted metrics that reflect the degree of misfit...
between the modelled and measured heads. These adopted models revealed that average annual recharge is likely in the range -10 to -1 mm/year, probably reflecting a net discharge flux in the form of evapotranspiration from areas of shallow water tables. The adopted calibrated models covered the full range of clay-sand fractions and the structural alluvium realisations, although a greater number of models were from the lower clay/higher sand content simulations.

The ensemble of 245 adopted models was then run in transient mode to simulate groundwater abstraction from a network of 40 hypothetical production bores distributed evenly across the alluvium within Glendalough Station (Figure 2). Pumping and drawdown responses were simulated over ten years consisting of nine-month pumping periods, representing prolonged dry seasons, each followed by a three-month recovery period representing the wet season when groundwater demand will be negligible. Maximum pumping rate for each dry season was determined at each production bore regardless of whether it intercepts sand, clay or a mixed region of the aquifer.

The modelling results indicate a broad range in the potential sustainable extraction limit (SEL) for the alluvial aquifer of 1,400 ML/year to 17,800 ML/year (Figure 3) reflecting the various depictions of the alluvium and possible ranges of hydraulic properties and recharge rates.

![Figure 2. Location of 40 hypothetical production bores within Glendalough Station property boundary (grey dashed line) relative to model domain (green line) and one-kilometre river buffer (orange dashed line).](image)

![Figure 3. Total volumetric extraction per nine-month irrigation season for all models that ran in transient pumping mode. Dashed red lines represent 20th and 80th percentile values, while the solid red line represents the 50th percentile (median) value.](image)
Because all of the models shown in Figure 3 are considered equally plausible, a high level of confidence was defined as the 20th percentile value (2,200 – 2,300 ML/year), a moderate level of confidence was defined as the 50th percentile value (3,100 ML/year) and a low level of confidence was defined as the 80th percentile value (13,200 – 13,300 ML/year). The ranges expressed for each confidence level reflect uncertainty due to aquifer storage coefficient, which was tested using high and low specific yield scenarios.

The model that produced the minimum total extraction volume, as well as those models that correspond to the high confidence and moderate confidence values, were calibrated with the most plausible values of hydraulic conductivity for the sand (13 to 17 m/d) and a small negative vertical recharge (i.e., a discharge) flux. In contrast, models that produced the low confidence and maximum total extraction volumes required positive vertical recharge rates and excessively high values of hydraulic conductivity for the sand (187 to 289 m/d). Accordingly, the moderate and high confidence extraction limits are considered the most reliable estimates for future water resource planning.

**Managed Aquifer Recharge**

The opportunity for managed aquifer recharge (MAR) to enhance the total extraction limit by injecting surface water from the Flinders River into the alluvial aquifer appears limited. This is primarily because the analysis of drillers logs and downhole geophysics has shown that the main sand deposits are located below the current water table. Hence, there is limited aquifer storage potential above the water table. Secondly, the infrequent nature of high river flow events means that surface water is unlikely to be available for MAR every year. Hence, infrastructure may need to sit idle for a number of years between injection events. In any case, this assessment has shown that MAR could potentially increase the high confidence SEL by 400 – 500 ML/year, the moderate confidence SEL by 600 – 700 ML/year and the low confidence SEL by 600 – 800 ML/year.

**Full technical report reference**

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