Forecasting Groundwater Levels from Sparse Data Sets in an Alluvial Aquifer Subjected to Heavy Pumping and Flooding

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1. Introduction

Water sharing plans must be able to balance the impact of climate extremes, especially droughts. In Australia historical rainfall records show that in the semi-arid lower Murrumbidgee irrigation district (Figure 1) the duration of a drought can be as long as a decade (Figure 2). Annually up to 270 hm^3 per year of groundwater is extracted (that is 675,000 Olympic swimming pools of water per year). This water is used to irrigate rice, cotton, wheat, orange trees, nut trees, and grapes vines. This research examines what will happen to the groundwater level under existing pumping rates if in the future we have a drought similar to the one that occurred between 1938 to 1949. The lack of data on physical hydrogeological properties of the aquifers (specific yield, permeability etc) makes it challenging to develop a physics based spatially distributed model (MODFLOW or FEFLOW). However, there are high quality long-term records of rainfall, temperature, streamflow, groundwater level and annually pumped groundwater volumes. These data sets are suitable for building an Artificial Intelligence (AI) model to predict the groundwater level under various climatic conditions.

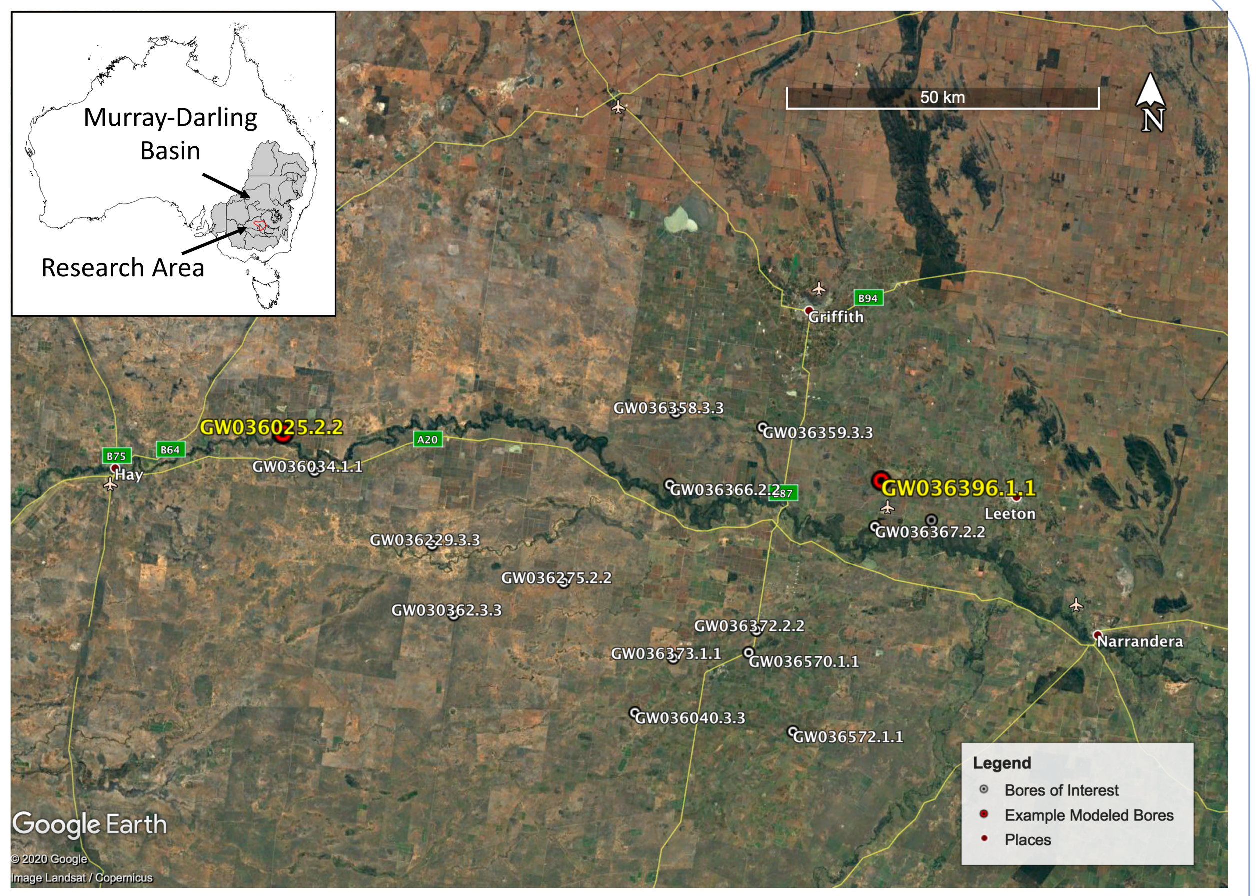


Figure 1. Lower Murrumbidgee catchment, Australia.

Research Aims

- Forecast groundwater level change (GWLchange) under the extreme drought condition (1938-49) using the current pumping rate allowed in the Water Sharing Plan.
- Assess the suitability of gradient boosting and neural networks for forecasting groundwater levels.

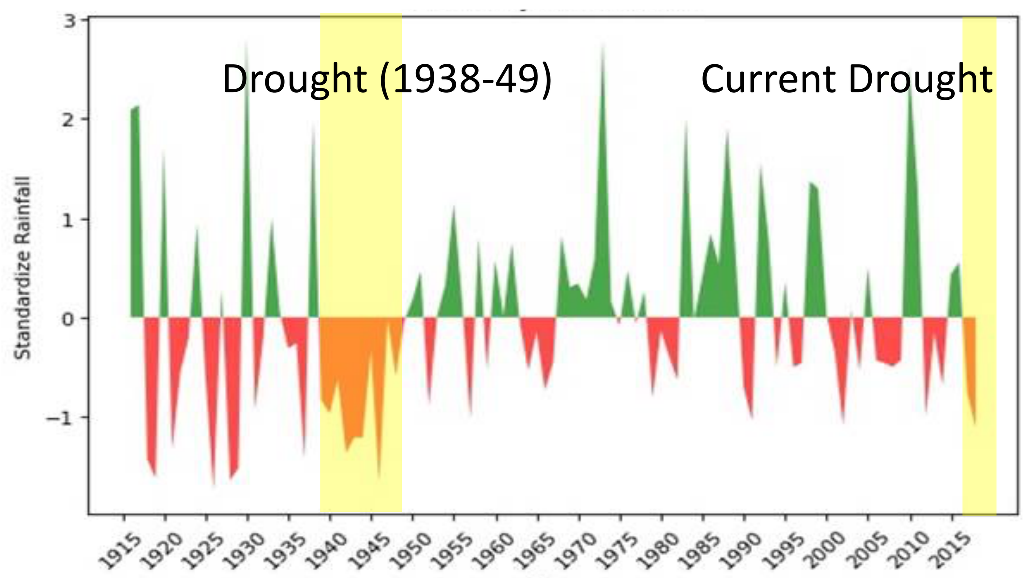


Figure 2. Standardized rainfall and highlighted dry and wet runs in the research area.

2. Methods

Groundwater recharge in the lower Murrumbidgee alluvial floodplain district is dominated by continuous river leakage, lateral recharge of groundwater from upgradient, and floodwater recharge. Groundwater hydrograph analysis shows that floodwaters are the dominant source of recharge. Diffuse (areal) rainfall and irrigation return recharge are considered only minor inputs. Neural Networks (NN) and Gradient Boosting regression (GB) (Figure 3) were trained using: up-catchment and local rainfall, up-catchment and local streamflow, temperature; groundwater level data from 16 locations, and pumping records for the years 1982 to 2016. The years 1982 to 2016 were used for the training data because the data set is small, and this period captures just one cycle of groundwater level fall followed by a rise (Figure 4). The recent 2017 and 2018 high intensity drought years were used to assess the performance of NN and GB for forecasting the groundwater level. Data sets for the modelling were obtained from the Australian Bureau of Meteorology, WaterNSW and Water - NSW Department of Planning and Environment.

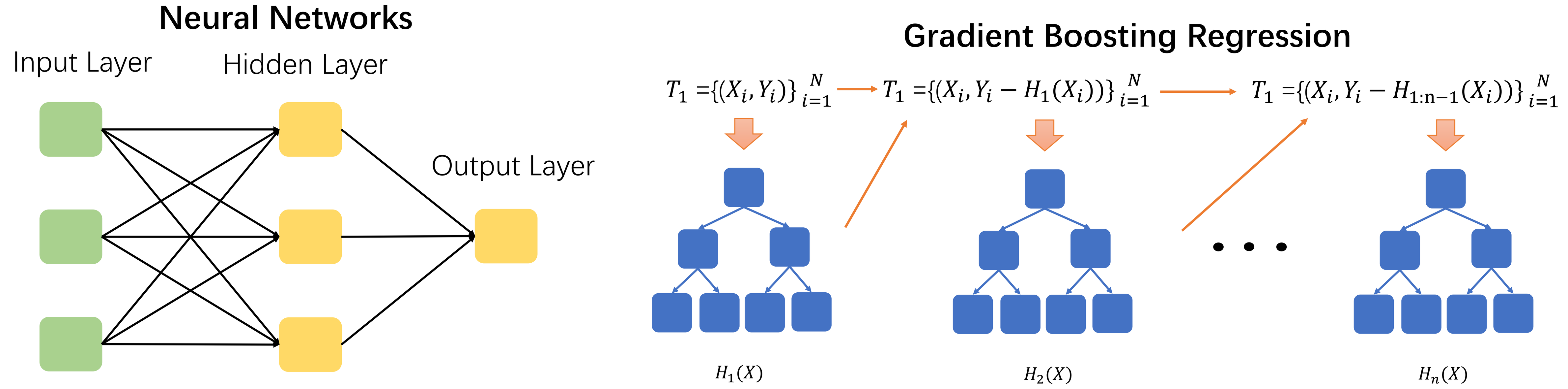
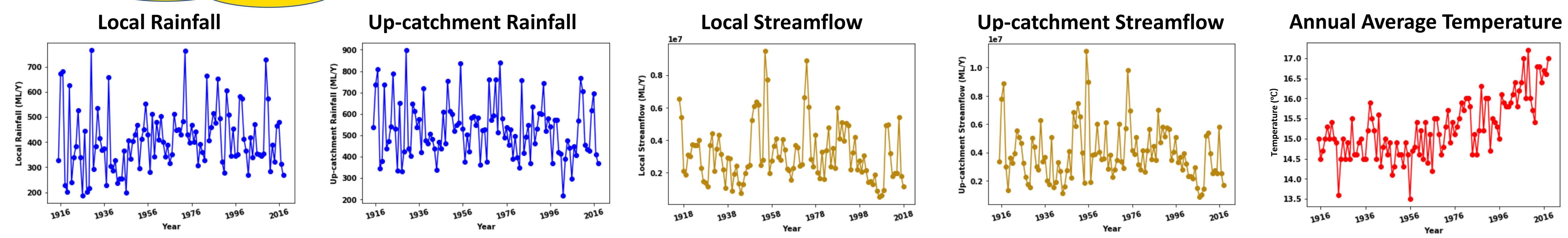


Figure 3. Prediction methods.

3. Model Inputs



Groundwater Monitoring Site GW036025
Slotted interval: -108.2 m to -114.3 m (below ground surface)
Distance from River: 0.85 km

Groundwater Monitoring Site GW036396
Slotted interval: -139 m to -145 m (below ground surface)
Distance from River: 8.9 km

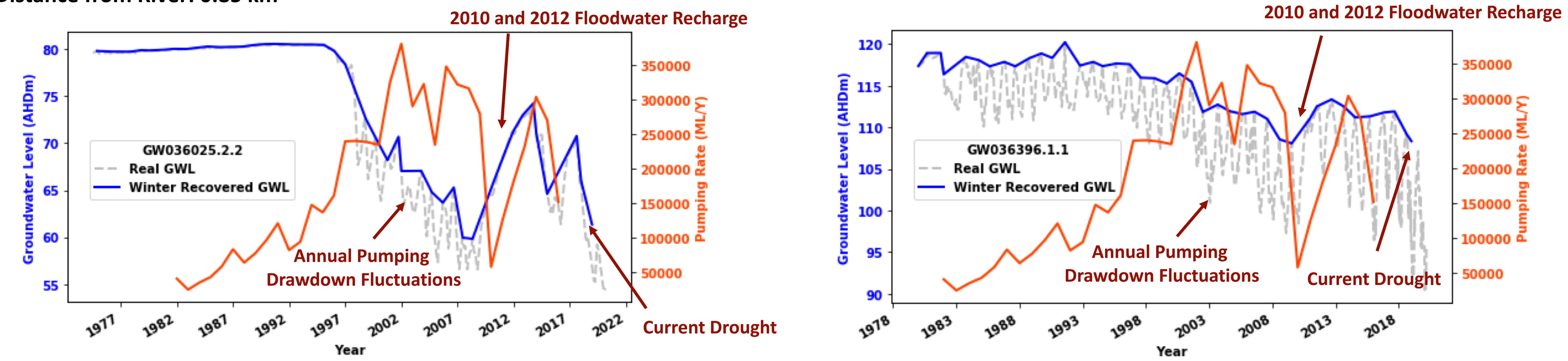


Figure 4. Input data and representative groundwater hydrographs.

4. Training and Testing

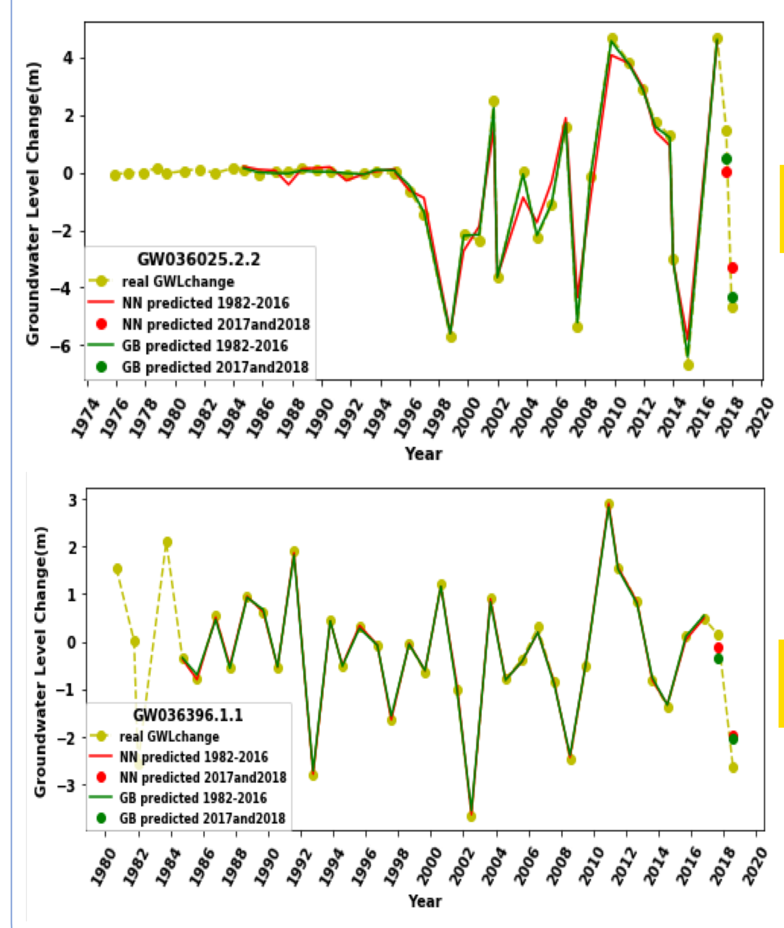


Figure 5. Modelled annual change in the winter recovered groundwater, with predictions for 2017 and 2018.

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5. Groundwater Level Predictions under Extreme Drought Conditions

GB smallest residuals

NN smallest residuals

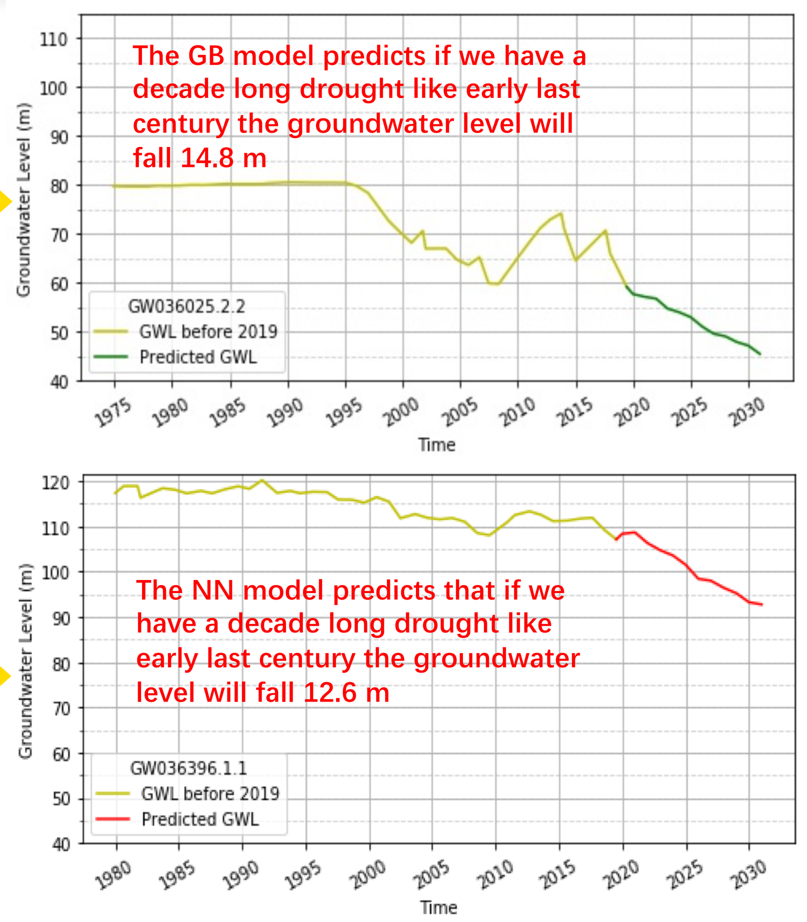

Figure 6. Groundwater level predictions under 1938 to 1949 drought conditions.

6. Performance Comparison NN vs GB

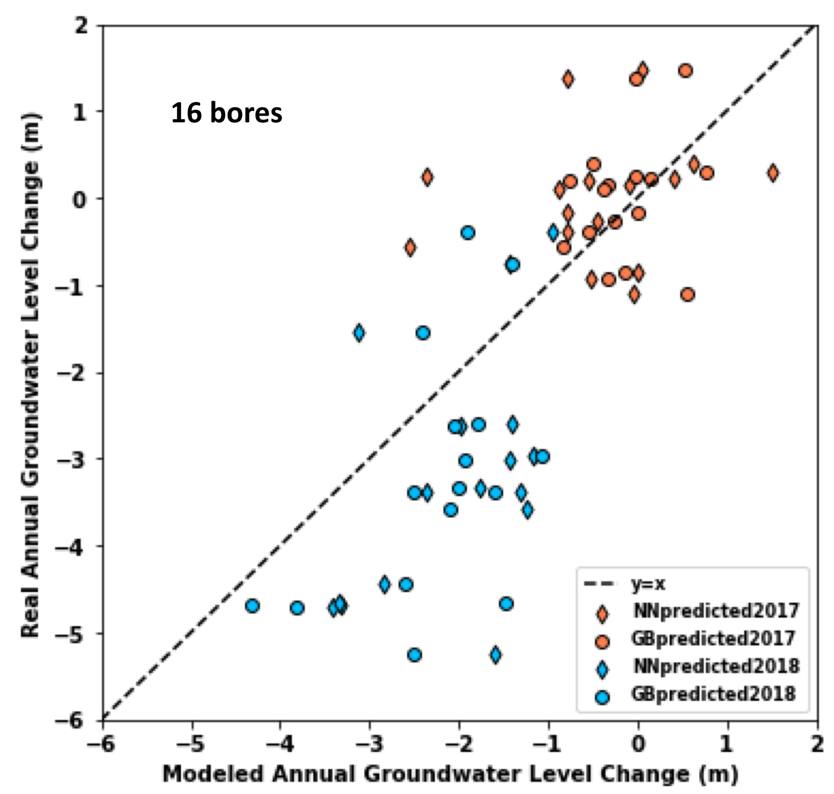

Figure 7. Comparison between modelled annual groundwater level change and the real change (we are exploring solutions for the systematic under prediction in 2018 and beyond).

Conclusions

In alluvial catchments both NN and GB are powerful tools for predicting where the groundwater level will rise and fall, in both space and time. There was no one best algorithm, rather the best predictor depends on the monitoring well location. In the lower Murrumbidgee catchment the duration of the current drought is just over two years, but historical droughts have been much longer. Under existing annual pumping rates (270 hm^3/Y), the groundwater level is predicted to drop more than 14 m in some areas if the catchment has a period of below average rainfall as occurred from 1938 to 1949. At some locations in the catchment it is likely under these condition that the groundwater level will fall to such an extent that reduction in access to groundwater will be triggered according to the Water Sharing Plan rules.