Pattle Delamore Partners Limited

TECHNICAL MEMORANDUM

INVESTIGATION	Mataura Water Conservation Order	**PROJECT**	Garvie Aquifer Stream Depletion Model
CLIENT	**Environment Southland**	**PROJECT NO**	C03993509
CLIENT CONTACT		**PREPARED BY**	Tom Garden and Neil Thomas
CLIENT WORK ORDER NO/ PURCHASE ORDER		**SIGNATURE**	
		DATE	10 Sept 2022

1 INTRODUCTION

The Garvie Aquifer is located in the Wendonside Groundwater Management Zone (GMZ), between the Mataura and Waikaia Rivers, north of Riversdale in Southland (Figure 1). Parts of the Mataura River catchment are subject to a Water Conservation Order (MCO) which, amongst other things, limits the amount of water that can be allocated from the catchment to 5% of the naturalised flow in the river at Gore. Understanding the stream depletion effect of groundwater takes is therefore important in ensuring that water allocation in the Mataura catchment remains within the constraints of the MCO. Calculation of stream depletion effects is typically achieved using the aquifer parameters derived from a pumping test within an analytical model that allows for the presence of a river. Many groundwater takes within the Matarua catchment fit within the assumptions of these analytical model. However, the geometry of Garvie Aquifer means that it cannot be represented in an analytical model.

Therefore, Environment Southland (ES) have engaged Pattle Delamore Partners Ltd (PDP) to create a numerical model of the Garvie Aquifer that can be used for estimation of stream depletion effects arising from bore abstractions. The model has been created using MODFLOW 6 and is intended to be a relatively simple representation of the aquifer, simulating the conceptual setting and geometry. It is intended to be used in the same way as the analytical models used for other areas of the catchment i.e. without detailed calibration to observed water levels.

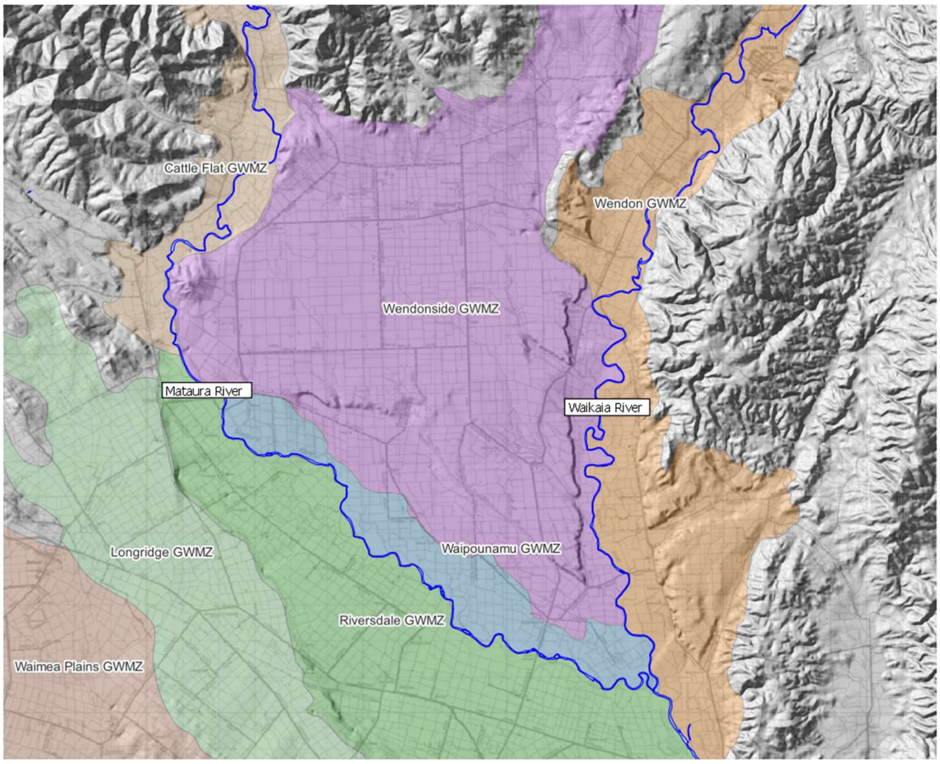

Figure 1: The study area, showing groundwater management zones and the Mataura and Waikaia Rivers.

2 CONCEPTUAL MODEL

The Wendonside Terrace is an elevated alluvial terrace that occupies a roughly triangular area upstream of the confluence of the Mataura and Waikaia Rivers, and south of the Garvie Mountain foothills. The terrace has a complex geological and hydrogeological setting: Uplifted schist basement rock forms the hills north of Freshford, and an area of uplifted basement rock also occurs along the northwestern side of the terrace, adjacent to the Mataura River. The Quaternary alluvial sediments that form the Wendonside Terrace are underlain by Tertiary sediments, such as the Gore Lignite Measures. The Quaternary alluvial sediments are thickest in a roughly linear northwest to southeast trending band across the centre of the Wendonside Terrace, and this area of deeper gravels forms the Garvie Aquifer. A conceptual geological cross-section is shown in Figure 2: Conceptual geological cross-section across the Wendonside Terrace (Environment Southland).Figure 2.

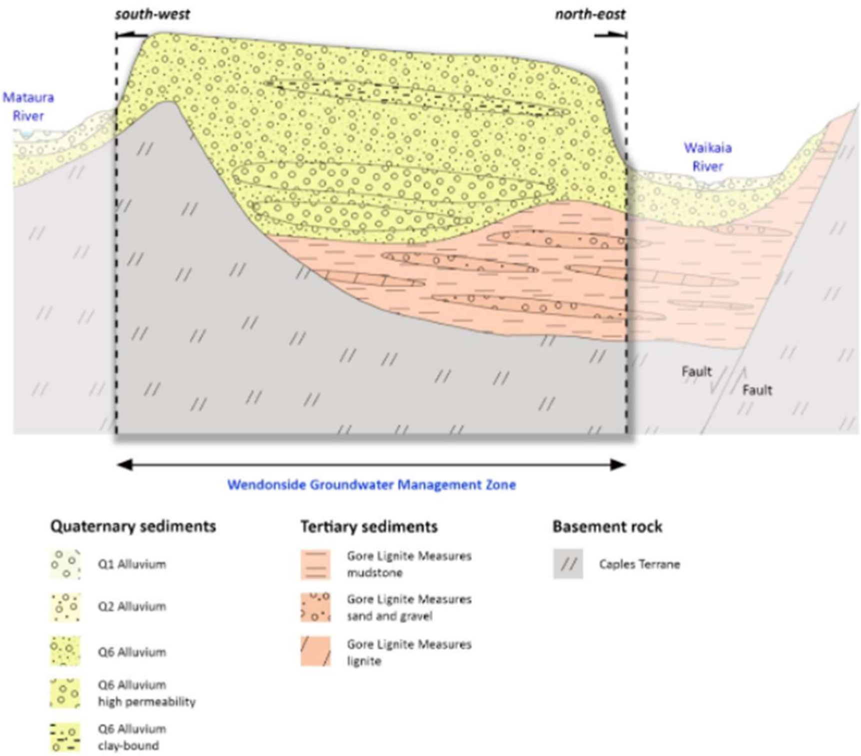

Figure 2: Conceptual geological cross-section across the Wendonside Terrace (Environment Southland).

The Quaternary alluvium hosts a complex stratified aquifer system, with a shallow, unconfined (and possibly perched) aquifer system in the northern part of the terrace, with a highly permeable semi-confined aquifer system (the Garvie Aquifer) in deeper gravel layers across the central and southern parts of the terrace. There is a low yielding aquifer system above the Garvie Aquifer. Figure 3 shows the inferred extent of the various aquifers in the study area. Groundwater discharge is inferred to occur primarily via baseflow to the Waikaia River. This is supported by flow gauging studies, such as one conducted in 2007 which calculated a gain in flow of approximately 2 m^3/s along the reach from Waiparu to the confluence with the Mataura River (Phreatos, 2007), although this would include flow from runoff and streams either side of the river. Approximately half of the gain occurred in the relatively short reach between south of the Wendonside Terrace, between Waipounamu Bridge Road and the confluence with the Mataura River. A conceptual hydrogeological cross-section is shown in Figure 3 (based on interpretation from Hughes, 2011)

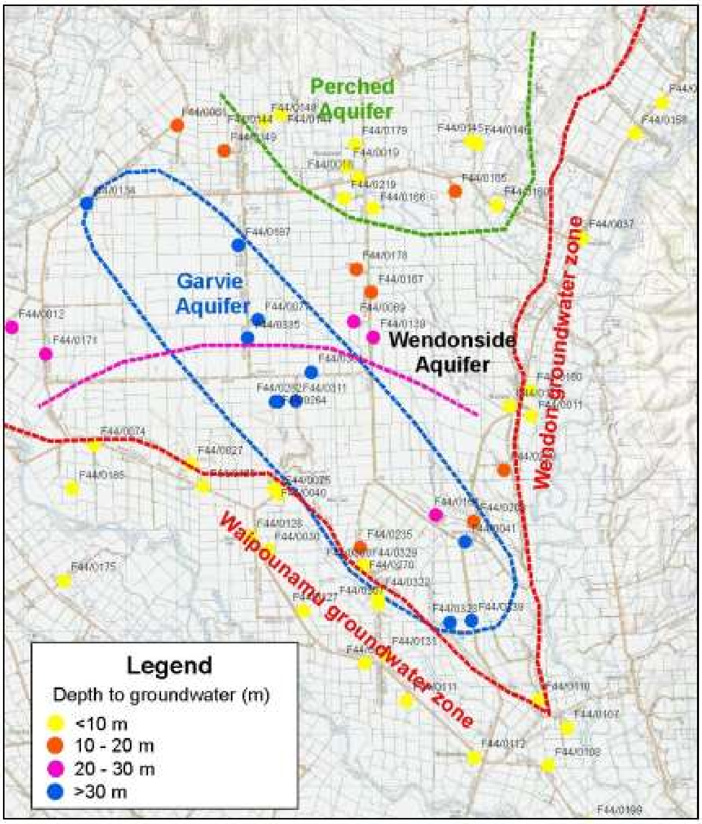

Figure 3: The depth to groundwater across the study area, with the interpreted extents of the various aquifers in the area.

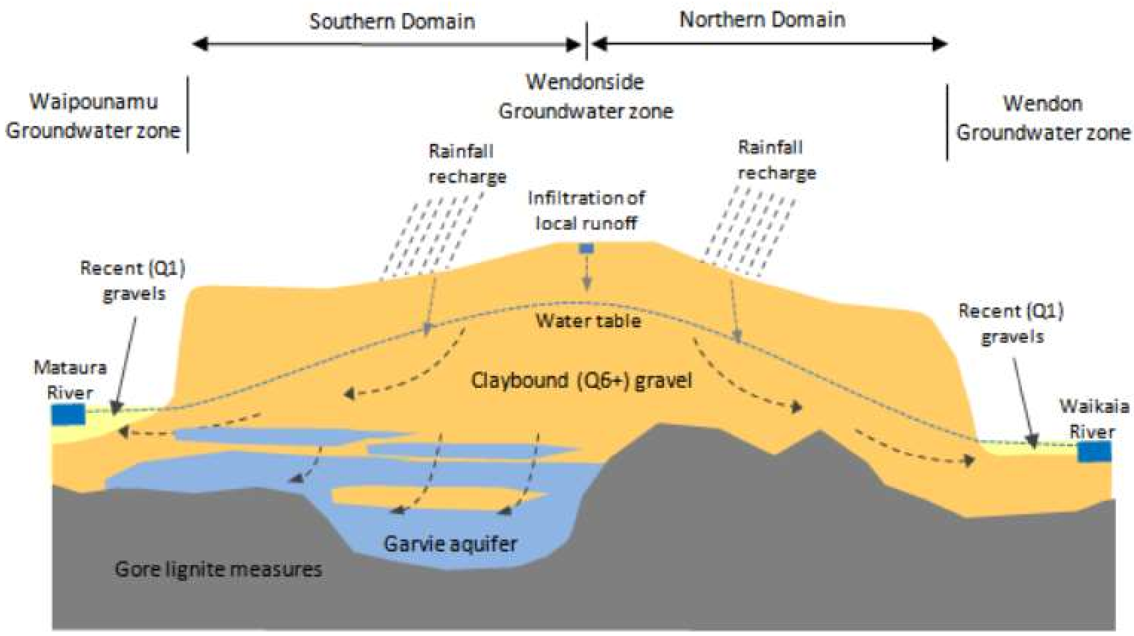

Figure 4: Conceptual hydrogeological cross-section through the Wendonside Terrace.(Hughes, 2014)

3 MODEL STRUCTURE AND DESIGN

The groundwater model developed for this project seeks to replicate the general conceptual setting described above for the purpose of estimating stream depletion effects. The general model configuration is shown in Figure 5. The western to southern boundary of the active cells is the Mataura River and the ridge of the basement on the northwestern margin of Wendonside terrace. The northern boundary of the active cells consists of the northern end of the Wendonside alluvial terrace. The eastern boundary of the active cells consists of the basement hills of Round Downs, on the eastern side of the Waikaia River.

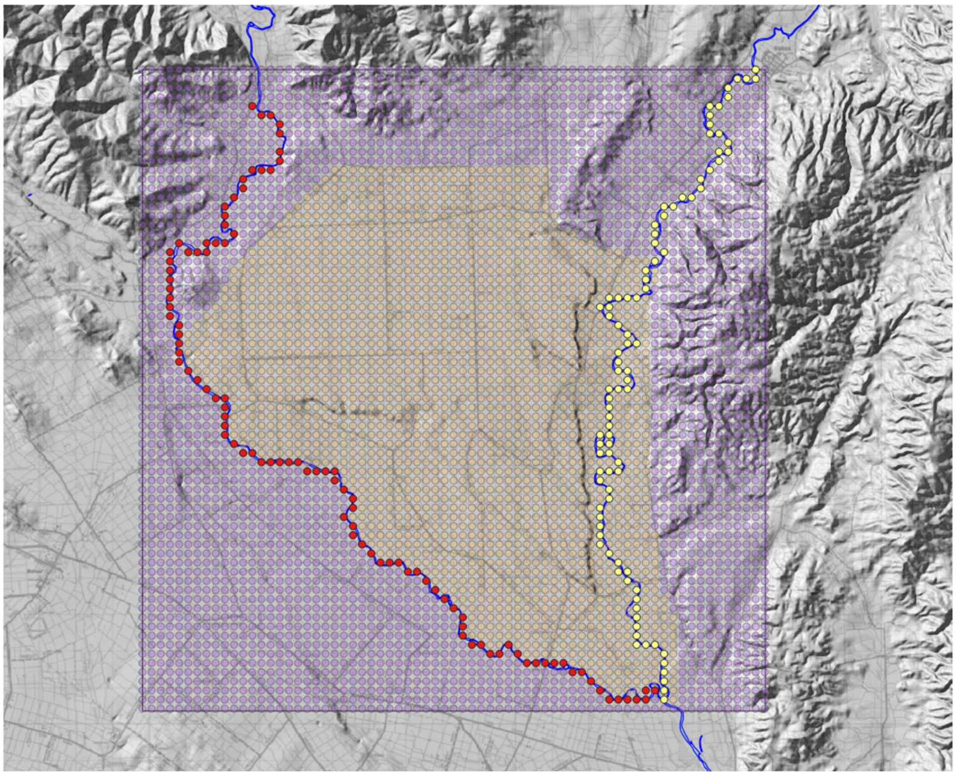

Figure 5: Map showing the model grid and boundary. Purple cells are inactive, brown cells are active. Red cells are Mataura River cells. Yellow cells are Waikaia River cells.

The model grid consists of a structured grid with a cell size of 250 m and three layers, each of which is 20 m thick. The top layer (layer 1) comprises the Wendonside terrace. Its extent is shown in Figure 6. The 20 m thickness of layer 1 is consistent with the general height of the terrace above the flood plains of the Mataura and Waikaia Rivers.

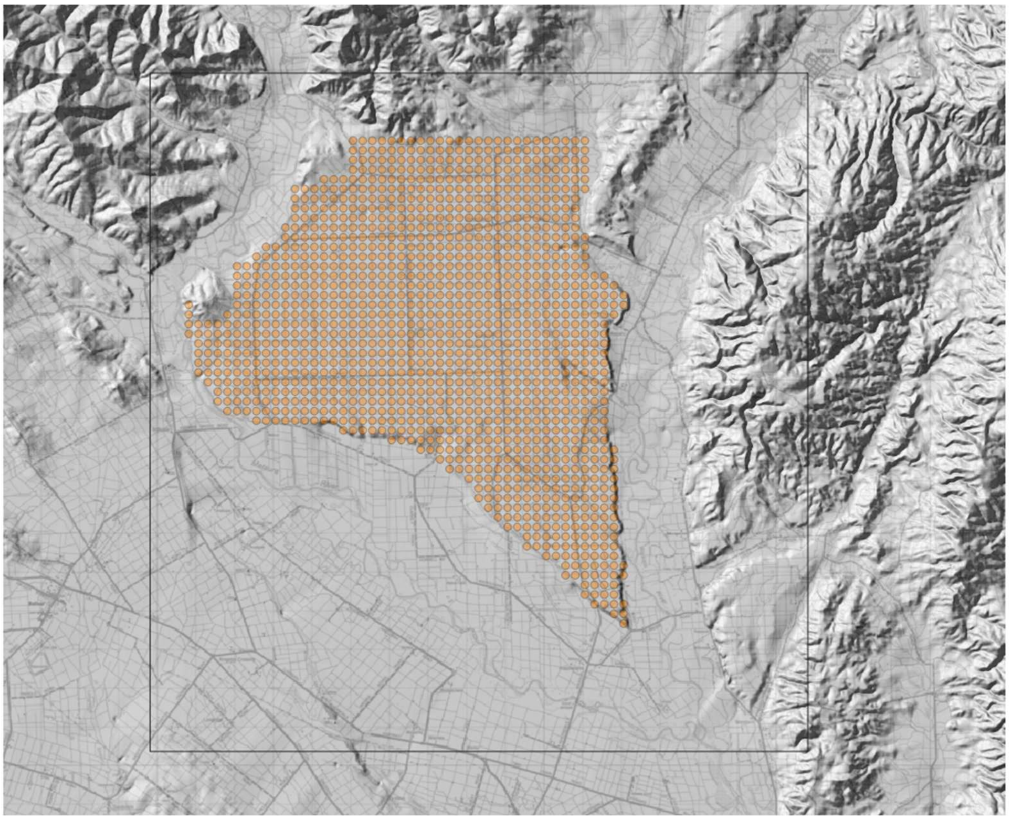

Figure 6: The spatial extent of layer 1, which represents the Wendonside terrace.

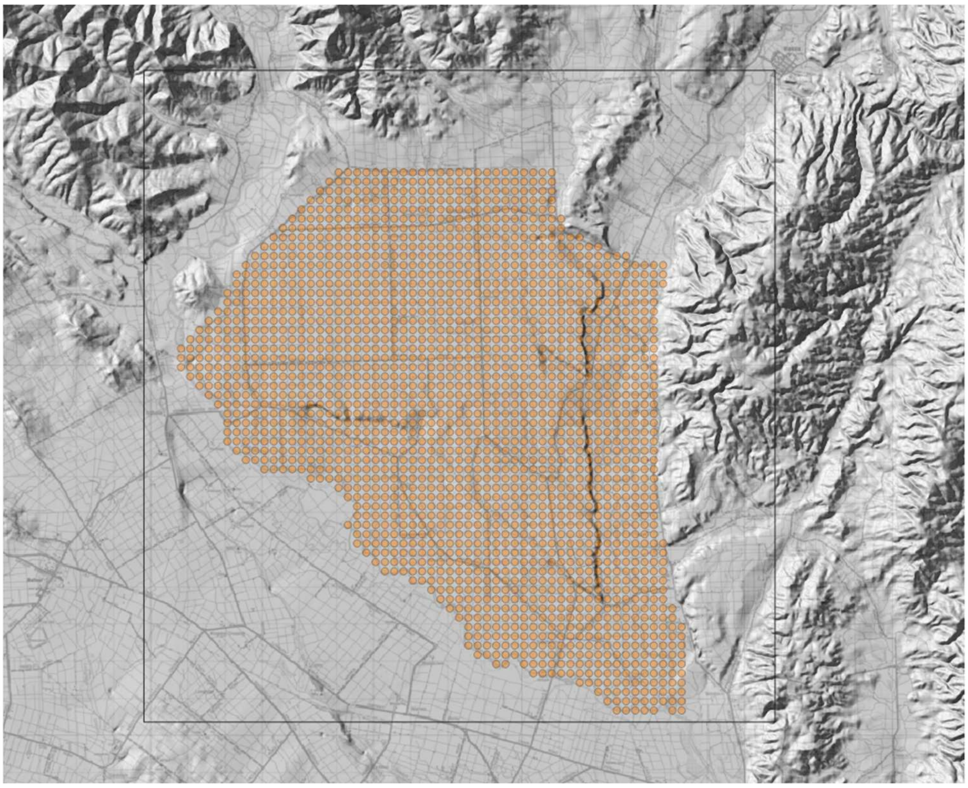

Figure 7: The spatial extent of active layer 2 cells in the model.

Layer 2 is present across the entire active model area and represents the recent alluvium on the active floodplains of the Mataura and Waikaia Rivers, and the alluvial deposits overlying the Garvie Aquifer. Layer 2 is 20 m thick and both the Mataura and Waikaia Rivers occur in this layer. The extent of layer 2 is shown in Figure 7.

Layer 3 represents the Garvie Aquifer and is present across a linear northwest – southeast trending band across the centre of the model area. This covers the known extent of bores that abstract from the Garvie Aquifer. Layer 3 is 20 m thick (i.e. 40 – 60 m below ground level on the Wendonside Terrace), which is generally consistent with the depth of bores that abstract from the Garvie Aquifer. The extent of layer 3 is shown in Figure 8.

Layers 1 and 2 have a horizontal hydraulic conductivity of 25 m/d, which is equivalent to a transmissivity of 500 m^2/d for each layer when they are fully saturated, with an aquifer thickness of 20 m for each. Layer 3 has a horizontal hydraulic conductivity of 250 m/d, which is equivalent to a transmissivity of 5,000 m^2/d. This is generally consistent with the available pumping test data from the Garvie Aquifer.

Layers 1 and 2 have a vertical hydraulic conductivity of 0.32 m/d, and layer 3 has a vertical hydraulic conductivity of 5 m/d. The vertical hydraulic conductivity for layers 1 and 2 is based on the average leakage value (K'/B') of 0.008 day^{-1} that has been estimated from pumping tests in the Garvie Aquifer. The K'/B' values was converted to a vertical conductivity value by multiplying the K'/B' value of 0.008 day^{-1} by 40 m (the combined thickness of layers 1 and 2 in the model) to give a vertical hydraulic conductivity of 0.32 m/d (or 0.16 m/d where Layer 2 is not overlain by Layer 1).

The vertical hydraulic conductivity of layer 3 has been estimated from an assumed 1:5 ratio of horizontal to vertical hydraulic conductivity in the Garvie Aquifer. These aquifer parameters are considered consistent with our conceptual understanding of the groundwater system of the model area and are consistent with the typical values from pumping tests in the area, where the Garvie Aquifer is generally much more permeable and productive than the overlying strata in the area.

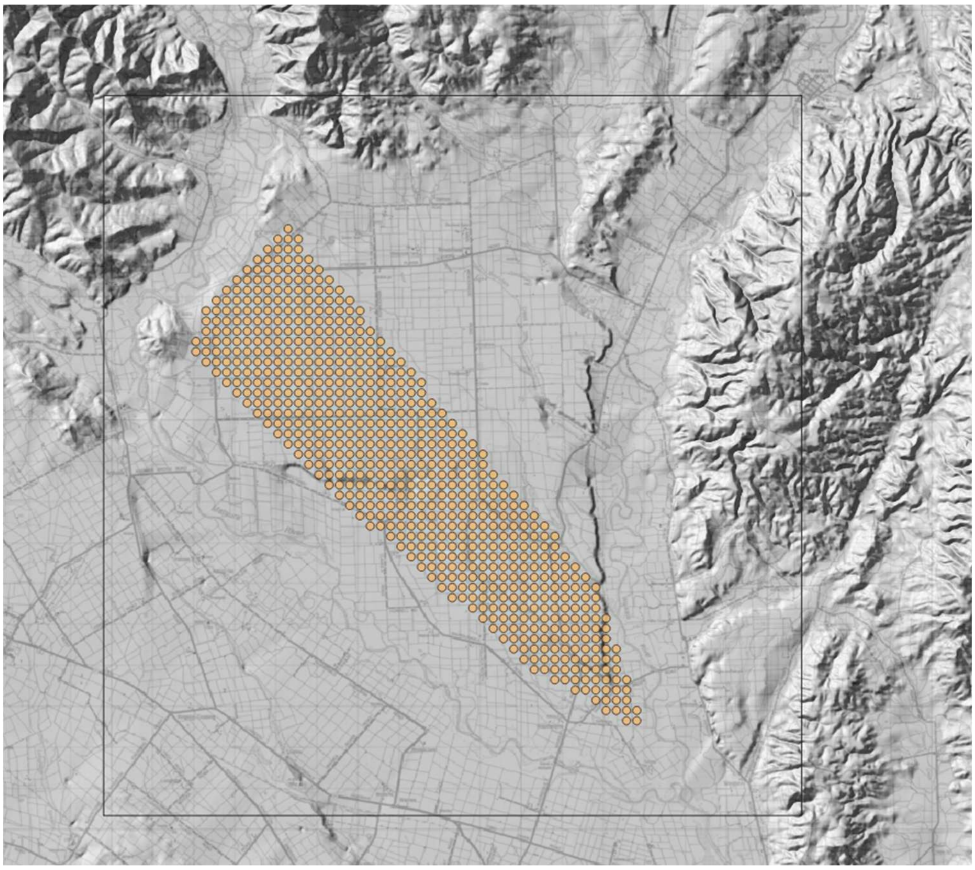

Figure 8: Spatial extent of layer 3, which represents the Garvie Aquifer.

The streambed conductance of both the Mataura and Waikaia Rivers was set at 100 m/d, which is consistent with the values used in the analytical model for calculation of stream depletion effects on the Mataura and Waikaia rivers due to shallow bore abstractions.

Recharge to the model area has been set assuming 211 mm of annual recharge (0.58 mm/day), evenly distributed across the model area. This is similar to the average annual rainfall recharge of 211 mm per year that has been estimated by Environment Southland for the Wendonside GMZ (https://www.es.govt.nz/environment/water/groundwater/groundwater-management-zones/wendonside),.

The initial steady-state model was modified into a transient model to assess stream depletion effects. For assessment of stream depletion effects 183 stress periods of 2 days each were used. For the transient model the specific yield was set to 0.1 (i.e. Layer 1 and Layer 2 where it extends beyond the Wendonside GWMZ), while the specific storage for confined cells was set to be 0.0001 (i.e. Layer 3 and Layer 2 where it is overlain by Layer 1).

4 MODEL RESULTS

The overall, steady state model water balance (with no groundwater pumping occurring) is shown in Table 1 below. The results show that the Waikaia River gains approximately 353 L/s of flow, while the Mataura gains approximately 227 L/s of flow. As discussed in section 2 above, flow gauging conducted in 2007 estimated a total gain to the Waikaia River of 2 m^3/s along this reach. However, this would include recharge from the Round Downs to the east of the Waikaia River and the Wendon GMZ, which is not simulated in our model. Therefore, the model water balance is considered in the correct order of magnitude as the measured gain to the Waikaia, and considered appropriately similar to be representing the conceptual understanding of the groundwater system.

Table 1: Overall steady state model water balance

Component	Inflow (m^3/day) (L/s)	Outflow (m^3/day) (L/s)
Rainfall Recharge	48,144 (557)	
Mataura flow in [1]	1.369 (15)	
Waikaia flow in [1]	645 (7.4)	
Mataura flow out		19,587 (227)
Waikaia flow out		30,571 (353)
Total	50,159 (580)	50,159 (580)

Notes:

1. *The model only simulates groundwater-surface water interaction in this section of the river. total river flow will be greater than these numbers due to inflow from outside the model. Some losses from the Mataura and Waikaia Rivers occur. In the model, the Waikaia River loses some water to Layer 2 around the upper modelled reaches. The Mataura River loses a small volume of water into Layer 2 upstream of Riversdale.*

The simulated groundwater head elevations in layer 2 of the model are shown in Figure 9. The pattern of groundwater flow is generally as would be expected based on the conceptual understanding of the groundwater system. The simulated groundwater flow pattern is generally similar in layers 1 and 3 of the model, showing a generally south-easterly flow direction. In layer 1 the northernmost cells are simulated as being dry, where there is in reality a shallow aquifer that is interpreted to be perched over clayey gravels.

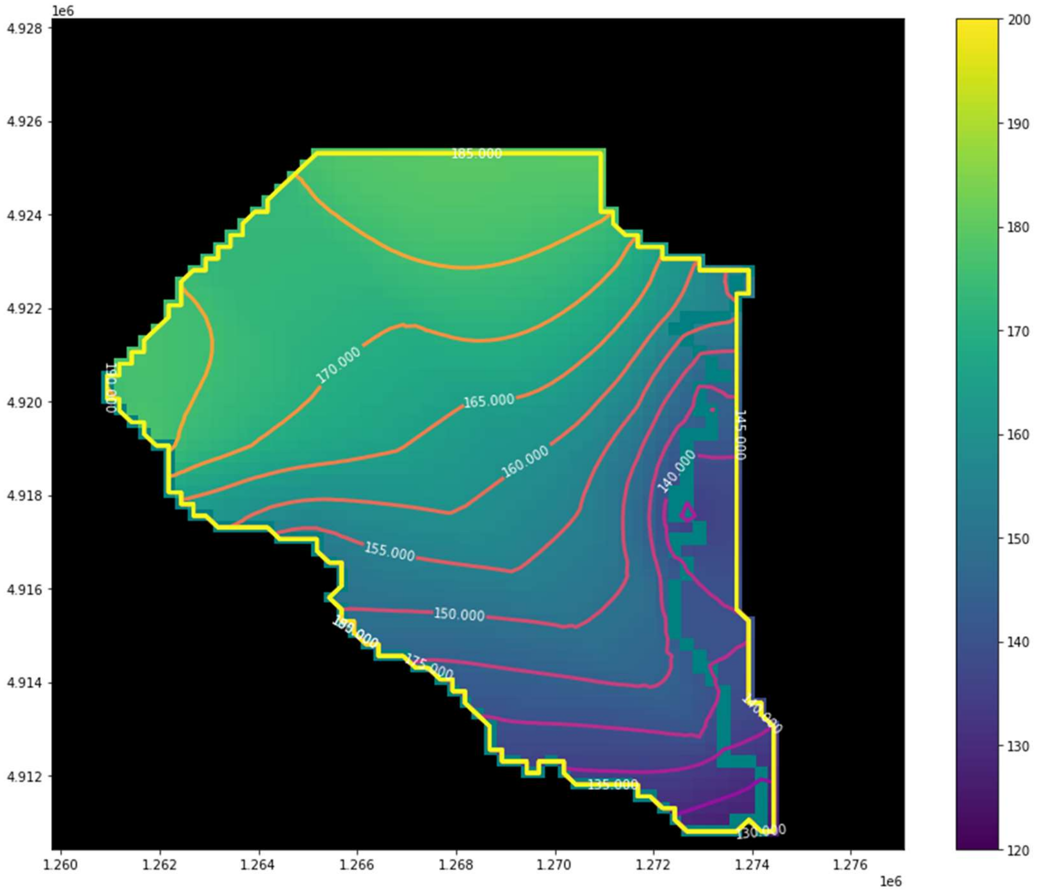

Figure 9: Simulated groundwater head elevations in layer 2 of the model.

5 MODELLED STREAM DEPLETION EFFECTS

The results of the transient model used to assess stream depletion affects are presented in Table 2 below. The stream depletion category was assessed in accordance with Appendix L.2 (Table L.2) of the Proposed Southland Water and Land Plan.

Table 2: Modelled stream depletion effects

Bore	Max flow (L/s)	Annual volume (m^3)	Max pumping period (days) [1]	Mataura Stream depletion effect (%)	Matarua Stream depletion effect (L/s)	Waikaia Stream depletion effect (%)	Waikaia Stream depletion (L/s)	Stream depletion category
F44/0387	2.08	657,000	90	1.7	0.0	0.4	0.0	Low
F44/0388	121.53	682,500	65	2.2	2.6	0.2	0.2	Low
F44/0339	60	678,400	90	7.9	5.5	11.7	8.2	Moderate
F44/0359	70	506,000	84	7.9	5.6	10.9	7.6	Moderate
F44/0323	10	678,400	90	8.2	0.8	11.0	1.1	Low
F44/0228	80	565,422	82	5.6	4.5	3.6	2.9	Low
F44/0389	424.19	1,993,834	54	0.2	0.8	0.0	0.0	Low
F44/0390	60.19	380,744	73	7.4	4.5	10.7	6.4	Moderate
F44/0075	25	194,400	90	4.4	1.1	1.4	0.4	Low
F44/0406	120	957,000	90	4.4	5.3	1.4	1.7	Moderate

Notes

1. *The time period of pumping at the maximum instantaneous rate that it takes to use total annual volume, up to a maximum of 90 days.*

The location of these abstraction bores are shown in Figure 10. It is noted that for those takes that are relatively distant from the Waikaia and Mataura Rivers the model indicates a delayed stream depletion effect such that the peak stream depletion effect occurs after abstraction has ceased. For example, the stream depletion effect from bore F44/0389 is around 0.5% when pumping ceases after 54 days, however the stream depletion effect peaks at just over 3% 365 days after the commencement of pumping (311 days after pumping ceases). In these cases, the stream depletion may build cumulatively through time and may ultimately be greater than estimated in Table 2.

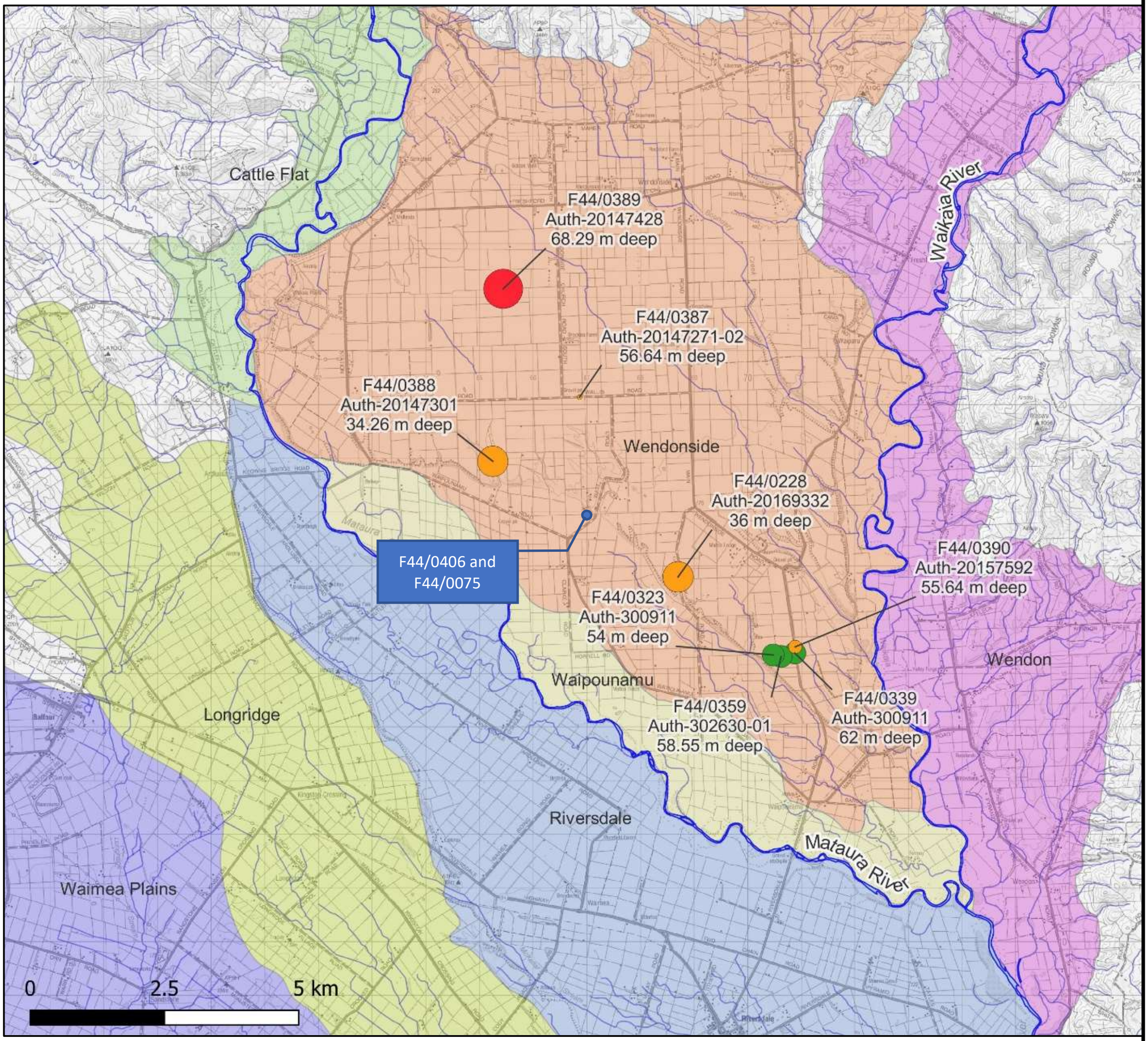

Figure 10: Location of bores within the Garvie Aquifer.

6 CONCLUSION AND RECOMMENDATIONS

The memo describes the results of a groundwater model that seeks to represent the conceptual model of the Garvie Aquifer. The intent of the model is to estimate the stream depletion effect of current takes within the Garvie Aquifer whilst allowing for the geometry of the aquifer, which cannot be accurately represented in analytical model that is typically used to estimated stream depletion effects from pumping bores. All models are an approximation of real hydrogeological conditions, however the parameters chosen here are considered to be similar to the approach used for the analytical modelling of other groundwater takes.

The total stream depletion of those takes that are classified as ‘Moderate’ in Table 2 is 32 L/s. Under the proposed Southland Water and Land Plan, this effect will be included in the surface water allocation regime for the Mataura catchment, but low flow restrictions would not be imposed on those takes.

7 REFERENCES

Hughes B (2011). Review of Water Permit Application M509-001 – RT & TE Miller, Wendonside for Environment Southland

Hughes B (2014). Review of Water Permit Application – Wilkins Farming Co Ltd, Ardlussa for Environment Southland.

Phreatos (2007). Mid-Mataura Groundwater Model. Report for Environment Southland.