Summary Paper: Managed Aquifer Recharge (MAR) Exploration Scenario Modelling

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1. Scenario Objectives

The managed aquifer recharge (MAR) scenario modelling explores the feasibility of enhancing flows in streams and wetlands in the Ruamāhanga valley during summer months. MAR entails infiltrating water onto the land surface to raise groundwater levels in connected shallow aquifers

The MAR scenario modelling presented here is a preliminary high-level exploration of the hydrogeological feasibility and effectiveness of infiltrating water into shallow aquifers. In other words, the modeller explores whether:

- it is possible to get water into shallow groundwater without flooding or ponding, and
- how much may be required to have any appreciable effect on stream flows.

The MAR scenarios are therefore intended to provide information regarding whether MAR is an idea worth pursuing further (i.e. through further detailed modelling). The modelling does not explore the methods of how water may be infiltrated nor does it consider finer detail such as optimisation of timing and location or the requirement to meet certain low flow targets in specific streams. These are areas that could be explored in additional scenario modelling if required.

2. How aquifer recharge was modelled

The area between the Waingawa and Waiohine rivers was collectively identified as a suitable area in which to explore the concept and feasibility of MAR with the objective of enhancing the environmental flows in the Parkvale Stream, Booths Creek and Mangateretere Stream.

For convenience, additional water was infiltrated into the shallow aquifer along the channels of the existing Taratahi and Carrington water races within an experimental 'recharge zone' (the purple area in Fig 1). The MAR scenarios increase the recharge only along water race channels located within the recharge zone. Fig 1 shows the recharge area and the two water races.

The calibrated (BAU) model already incorporates some 'artificial' recharge through the bed of the water races as a 50% loss of the race flow. This is believed to have been occurring for many decades and is now integral to aquifer recharge processes. The MAR scenarios will show that the water races currently have an important influence in sustaining environmental flows in small streams in this area. This assumption of 50% loss is maintained for simulating aquifer recharge within this scenario.

Only the Northern Ruamāhanga model (as modelled in Modflow) was used for the MAR scenario modelling (Moore et al., 2016). A version of the calibrated model that runs at 7-day time steps for the period 01/07/1992 to 01/07/2014 was used.

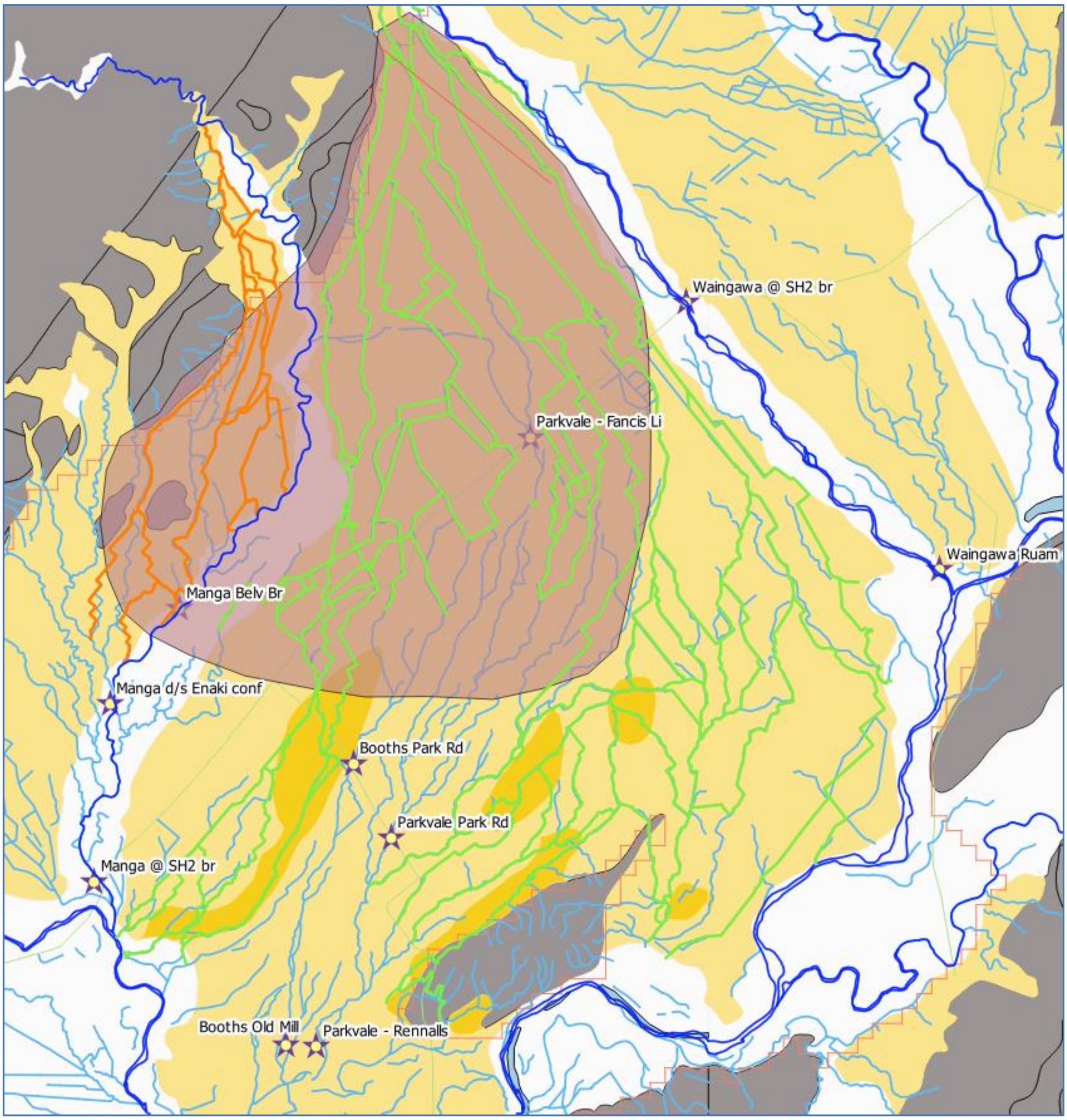

Fig 1: Experimental managed aquifer recharge area (purple shading). Within the recharge area, additional water was infiltrated into the aquifer along the Taratahi water race (green channels) and Carrington water race (orange channels). Changes in stream flow were recorded at various locations on streams (stars).

3. Assumptions and Limitations

For modelling purposes, recharge water is only introduced along pre-existing water race channels within the recharge area. In reality, if MAR was physically undertaken, smaller infiltration basins or injection wells would likely be used. However, the methodology chosen is considered to provide sufficient high-level information to inform MAR feasibility.

The additional water infiltrated is taken only from the Waingawa River or from an external unspecified source (for both the Taratahi and Carrington race MAR scenarios). The Carrington race currently sources water from the Mangatarere Stream, but the flows of this stream are known to not be sufficient to support additional takes. Any additional water required for MAR is therefore required to be taken from the Waingawa River or from an external source. However, the MAR scenario modelling shows that the high quantities for water required for MAR mean that the Waingawa River is also not a feasible source. Some scenarios therefore assume an external, unspecified source (e.g., a water storage scheme for instance).

The scenarios assume that MAR occurs throughout the year. Exploration of potential optimal timings of MAR has not been explored at this stage.

It is assumed that the water races outside the MAR recharge zone (Fig 1) continue to lose 50% of their flow (consistent with BAU conditions) and that the water races continue to divert from various rivers at the BAU rates – the MAR rates being additional to this. This assumption of 50% loss is maintained for simulating the additional MAR aquifer recharge within this scenario (i.e., more water is abstracted for MAR purposes than is recharged to the aquifer).

The model version used runs at 7-day timesteps. This means that output flows represent weekly averages. This is not regarded to represent a problem for these 'high- level' exploratory scenarios. If more detailed scenario modelling is required, it will be necessary to use the model version that runs at 1-day timesteps.

For those scenarios that incorporate groundwater and surface water abstractions, no low-flow take restrictions are incorporated (the water takes are seasonal based upon IRRICALC water demand modelling (Dark, pers. comm. 2017)). Due to the relative volumes of water involved, this assumption is not considered a hindrance to the MAR exploration modelling.

The MAR scenarios use the calibrated BAU model (Moore et. al., 2016; Rawlinson et. al., 2017). This model generally simulates the flow distribution characteristics in rivers and streams reasonably well, however, low flows are sometimes not accurately simulated. Therefore, interpretation of the MAR scenario outputs should focus on the differences between model runs, rather than the flow magnitudes – particularly at the low flow end of the flow-duration hydrographs.

The scenarios do not take into consideration the complex channel connectivity that is thought to occur between the water race network and the natural streams (e.g., Parkvale and Booths). In reality, if flow is increased in the water races then this would result in higher flows in the natural connected streams (note, however, that these scenarios use the race channels as proxy sites for MAR infiltration). The model only considers the effects of increased recharge to groundwater from the races, which results in a downstream increase in stream flows due to raised groundwater levels. (this invites the question as to whether stream flows in this area could be more easily and efficiently enhanced by increasing water race flows and connecting races to streams where necessary).

4. MAR Scenarios

Table 1 shows the various MAR scenarios. There are four groups of scenario runs:

- Scenario set 1(Runs 0, 1 and 2):

  Show current (BAU), natural state, and BAU with no SW or GW abstraction, respectively. These are intended to be a baseline against which to compare MAR scenarios. These also show the influence (or importance) that current (BAU) aquifer recharge from water race losses has on surface water flows.

- Scenario set 2 (Runs 3 and 4):

  Show the effect of increasing current aquifer recharge from water race losses on both the Carrington and Taratahi races within the recharge area by factors of 2 and 4.

- Scenario set 3 (Runs 6 and 8):

  Explore MAR along the Carrington race only and effect on the Mangatarere Stream.

- Scenario set 4 (Runs 10 to 13):

  Explore MAR along the Taratahi race only and effect on the Booths and Parkvale Streams.

(note: runs 5, 7 and 9 are missing in Table 1 as they were exploratory and do not usefully contribute to the findings of the MAR scenario study).

Table 1: MAR Scenario summary table

Ref #	Scenario	Scenario set up	Total recharge from water races m^3/day	Total additional recharge applied (from BAU) l/sec
0	Baseline (BAU)	• All water races losing to aquifer at 'current' assumed rates (50% of flow) • Current (BAU) abstractions – GW+SW but no restrictions implemented.	48,471	-
1	'Natural' state	• No water races or GW/SW abstractions.	0	-
2	No abstraction / current water race recharge	• Water races losing (recharging) at current assumed BAU rates (as run 0) • No SW or GW abstraction, except: • Water race diversions (abstractions) as BAU	48,471	-
3	2 x BAU recharge	• Carrington recharge doubled from BAU (run 0) • Taratahi race within recharge zone (see Fig 1) doubled from BAU (run 0). • Elsewhere water races losing at BAU rates. • Extra water above BAU water race abstractions taken from Waingawa River. • No SW or GW abstraction (except water races diversions)	64,127	180
4	3 x BAU recharge rate	• Carrington recharge 3 x BAU (run 0); • Taratahi race within recharge zone (see Fig 1) 3 x BAU (run 0). • Elsewhere water races losing at current rates. • Extra water above BAU water race abstractions taken from Waingawa River. • No SW or GW abstraction (except water races diversions)	95,439	543
6	Carrington Recharge 1	• Carrington recharge 20 x BAU (run 0) • Taratahi race same as BAU (run 0). • Elsewhere water races losing at current (BAU) rates. • Extra water above BAU water race abstractions taken from Waingawa River. • No SW or GW abstraction (except water races diversions)	165,495	1,354
8	Carrington Recharge 2	• As run 6 but additional recharge water is not taken from the Waingawa River (assume external source)	165,495	1,354
10	Taratahi Recharge 1	• Taratahi race within recharge zone (see Fig 1) 12 x BAU (run 0). • Carrington recharge same as BAU (run 0); • Elsewhere water races losing at current (BAU) rates. • Extra water above BAU water race abstractions are taken from Waingawa River. • No SW or GW abstraction (except water races diversions)	163,663	1,333
11	Taratahi Recharge 2	• As run 10 but additional recharge water is not taken from the Waingawa River (assume external source)	163,663	1,333
12	Taratahi Recharge 3	• As run 10 but SW or GW abstractions switched on (low flow restrictions not implemented)	163,663	1,333
13	Taratahi Recharge 4	• As run 12 but additional recharge water is not taken from the Waingawa River (assume external source)	163,663	1,333

5. How the scenarios were assessed

The MAR scenarios were evaluated using a combination of two attributes:

a) flow duration curves at selected sites on rivers; and

b) mean summer groundwater levels.

Fig 1 shows the locations of the flow output sites. These are located at selected points on the following streams and rivers:

- Parkvale Stream
- Booths Creek
- Mangateretere Stream
- Waingawa River

The outputs for each scenario run are contained in Appendix 1 (flow duration curves) and Appendix 2 (groundwater levels).

6. Summary of Results

Table 2 contains the outputs for each of the scenario sets described in Section 4 in terms of the low flow and groundwater level attributes.

Table 2: Summary of Results

Attribute	Scenario set 1: Natural state - no water race recharge	Scenario set 2: Increased Taratahi and Carrington race recharge	Scenario set 3: Carrington race increased recharge	Scenario set 4: Taratahi race increased recharge
	This scenario compares a 'natural' system with no water race recharge and no water abstractions to the current (BAU) state (which assumes historical 50% leakage through the water race channels), both with and without water abstractions.	Runs 3 and 4: These scenarios explore the sensitivity of stream flows to small increases in recharge along both the Taratahi and Carrington water races. Water race recharge is increased by factor of 2 (run 3) and 4 (run 4).	Runs 6 and 8: These scenarios explore what happens to flows in the Mangatarere catchment when the recharge rate in the Carrington race only is substantially increased by a factor of 25 (a total increase in recharge of 1,354 L/sec). In run 6 the additional water is taken from the Waingawa River, in run 8 additional water is not taken from any local river and is assumed to be derived from an external source.	Runs 10 – 13: These scenarios explore what happens to flows in the Parkvale/Booths catchment when the recharge occurs from the Taratahi race only and is substantially increased by a factor of 12 (a total increase in recharge of 1,333 L/sec). Table 1 provides the details of the various model runs for this scenario.
Low flow in Parkvale Stream and Booths Creek	Flows in both streams are substantially lower than BAU/ current state. 95-percentile flow in Parkvale Stream drops by 40% @ Park Road, and by 35% at Rennalls Weir if there is no Taratahi water race. (Figs A1.1 and A1.2). Flows will probably drop further if the channel connectivity between the Taratahi race and Parkvale/ Booths systems are also considered. The water races appear to be very important in sustaining the low flows in these streams – both via groundwater recharge and channel connectivity. Booths Creek appears to be only marginally influenced by water race recharge.	Low flows (95-percentile) increase in the Parkvale Stream (@ Park Road) by a factor of 1.3 (27%) and 1.8 (85%) when recharge from the Taratahi race is increased by a factor of 2 and 4, respectively. A similar increase is observed downstream at Rennalls Weir. (Fig A1.2). An increase in infiltration of a factor of 4 in the Taratahi race equates to about 400 L/sec. Booths Creek shows only a small increase in flow by a factor of about 1.06 (7%). When the recharge rate is doubled or quadrupled from the Taratahi Race, only about 20-25% returns to the streams under low flow conditions.	This scenario results in only a small change in the flows in the Parkvale Stream or Booths Creek	A significant increase in streamflow occurs in the Parkvale stream. When groundwater and surface water abstraction are switched off (run 10), the 95-percentile flow at Park Road increases by a factor of 4.6 (from 100 to 460 L/sec) and at Rennalls Weir it increases by a factor of about 4.2 times the BAU rates (from 147 to 615 L/sec). When groundwater and surface water abstraction are switched on (run 12), the 95-percentile flow at Park Road increases by a factor of 4.3 and at Rennalls Weir it increases by a factor of about 4.1 times the BAU rates.

				When groundwater and surface water abstractions are switched off (run 10), the low flows (95 percentile) in Booths Creek at Park Road increase by a factor of 3 (from 8 to 24 L/sec) and by only about 1.2 at Old Mill downstream (from 178 to 209 L/sec). When groundwater and surface water abstractions are switched on (run 12), the low flows (95 percentile) in Booths Creek at Park Road increase by a factor of 2.4 and do not change at Old Mill. About 35% of the total water applied (at a rate of 1,333 L/sec) returns to the streams in the Parkvale catchment during the summer low flow period.
Low flow in Mangatarere Stream	Any benefits in Mangatarere Stream low flow resulting from recharge from the Carrington Water race is neutralised by the water race abstraction upstream (Figs A1.6-7). Along the lower reaches and at the Waiohine confluence, the effects of BAU abstractions (SW and GW) strongly impact low flows and negate any recharge effects from the water races (Fig A1.8).	This scenario results in only approximately 180 L/sec of additional water being supplied to the Carrington Race (and 375 L/sec to the Taratahi Race). Low flows (95 percentile) increase in the Mangatarere Stream (@ Belvedere Bridge) by about 13-30% when recharge from the Taratahi and Carrington race is doubled and quadrupled, respectively. It appears that the Mangatarere Steam receives recharge from both the Carrington and Taratahi race recharge.	(Figs A16-8) This scenario applies an additional 1.3 cumecs to the Carrington race only. There is a significant increase in the Mangatarere summer low flow (95 percentile) by a factor of approximately 3 in the Belvedere Bridge and Enaki confluence areas (reaches that currently dry up during summer). The recharge increases the flow in the lower reaches of the stream by a factor of approximately 2.3. About 60-70% of the recharged water returns to the stream.	There is a small but appreciable increase in the Mangatarere flow at Belvedere Road. The low flows (95-percentile) increase by a factor of 1.5 when there is no GW and SW abstraction, and by 1.3 when there is abstraction occurring. At SH2 bridge, the Mangatarere low flows (95-percentile) increases by a factor of 1.3 when there is no GW and SW abstraction, and do not change when there is abstraction occurring.

Low flow in the Waingawa River	Nothing note-worthy is observed.	If the MAR recharge water was to be sourced from the Waingawa River or Run 4 (quadruple recharge), the low flow (95 percentile) in the river would decline by about 25% at SH2 Bridge.	(Fig A1.8) Run 6 sources the additional MAR water for the Carrington Race from the Waingawa River (from the Taratahi Race source). If this were to happen, the low flow in the Waingawa River at SH2 bridge would drop by about 60%. This indicates that there is no local source of water for a MAR scheme of this magnitude in the area (i.e. water would need to be sourced from elsewhere).	This scenario abstracts from the Waingawa River and has a very large negative effect on the low flows. At SH2 Bridge the low flows (95-percentile) drop by 90%. (Fig A1.8) At the Ruamahanga confluence the low flows drop by 70%. (Fig 81.9). This shows that the water required for this MAR scenario could not be sourced locally from the Waingawa River (i.e. water would need to be conveyed from elsewhere).
Mean summer groundwater levels	(Fig A2.1-2) Compared to BAU, if there are no water races, then mean summer groundwater levels are approximately 1 m lower beneath the Taratahi water race in the Parkvale-Booths catchment area, and up to about 1.5 m lower in the Fernhill area to the east. Groundwater levels are about 1 m lower in the Greytown area beneath the Moroa race. There is a small drop in groundwater level of about 0.3 m beneath the lower part of the Carrington race.	(Fig A2.3) Groundwater levels rise by up to a metre beneath much of the lower reaches of the Taratahi race – this area appears to be more sensitive to recharge application possibly due to reduced aquifer permeability. (Fig A2.4) Groundwater levels generally remain below ground level and tripling recharge from the races does not cause ponding to occur.	(Fig A2.5) Rises in groundwater levels occur along the Mangatarere and lower Parkvale Basin. No significant areas of ponding or flooding are observed (in winter or summer) – most of the additional water appears to enter the streams.	(Fig A2.6) Groundwater levels rise by 1 – 3 m beneath much of the lower reaches of the Taratahi race – this areas appears to be more sensitive to recharge application possibly due to reduced aquifer permeability. The largest water table rises occurs upstream of the Masterton Faultline. (Fig A2.7) Groundwater levels rise to close to the land surface in the Parkvale – Booths catchment during summer.

7. Conclusions

a) MAR appears to be a feasible management option from a geological perspective – the modelling indicated that water can be infiltrated into shallow aquifers without causing significant ponding.

b) To produce a significant increase in low flow (i.e. 2x) in the Parkvale stream and tributaries, the current leakage rates from the Taratahi race would need to be at least quadrupled. This would require sourcing about 500 L/sec (0.5 cumecs).

c) At low MAR rates (2-4x current race leakage rates) it is estimated that the efficiency in the Parkvale/Booths catchment is only about 20-25% (i.e. only one fifth to one quarter of the recharged water reaches the streams). When MAR rates are substantially increased, the efficiency rises to about 35%.

d) MAR in the Mangatarere catchment appears to be more efficient.

e) If water for MAR is sourced from the Waingawa River, then there is a significant depletion of low flows. There does not appear to be a feasible local source of sufficient water to supply a MAR scheme in this area which would result in a significant enhancement of stream flows during summer – water would need to be conveyed from a distant source.

f) Although no modelling of this has been carried out, it may be significantly more effective and efficient to increase the flows in the existing water race system via these direct surface water connections rather than rely on groundwater recharge and discharge. This is because the (Taratahi) water race network has some channel connections to spring fed streams, and more could be created.

g) The extensive Taratahi water race network appears to be a long-established and important recharge source to the shallow groundwater environment. It helps to sustain the flows in natural spring-fed streams during dry periods. If the races were closed down, significant adverse effects on natural streams would be experienced.

References

Dark A. 2017. Andrew Dark, Water Resource Engineer, Aqualinc Research Ltd, personal communication, 10/04/2017.

Moore C, Gyopari M, Toews M. 2016. Ruamāhanga Catchment Groundwater Modelling, GNS Science Consultancy Report 2016/162. 139 p.

Rawlinson Z.J., Toews M., Gyopari M., Moore C. 2017. Results of Ruamāhanga groundwater flow and transport modelling for the Ruamāhanga Whaitua Committee: Business as Usual (BAU), Silver and Gold scenarios, GNS Science Consultancy Report 2017/101. 19 p.

Appendix 1: MAR Scenarios Flow Duration Curves

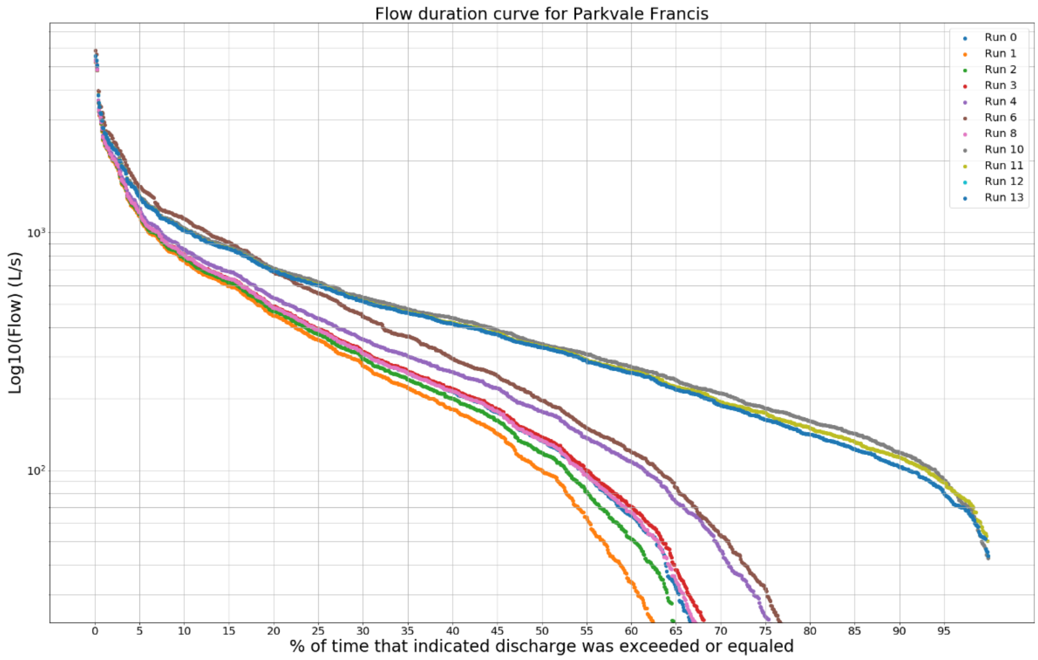

Fig A1.1: Flow duration curve for Parkvale Stream @ Francis Line

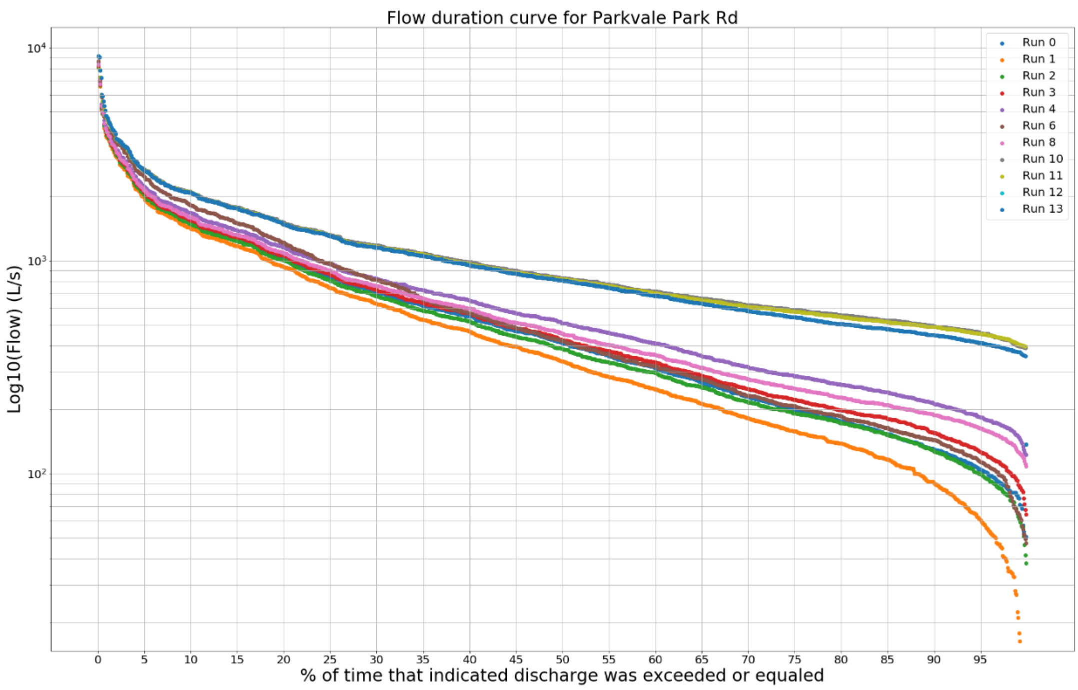

Fig A1.2: Flow duration curve for Parkvale Stream @ Park Road

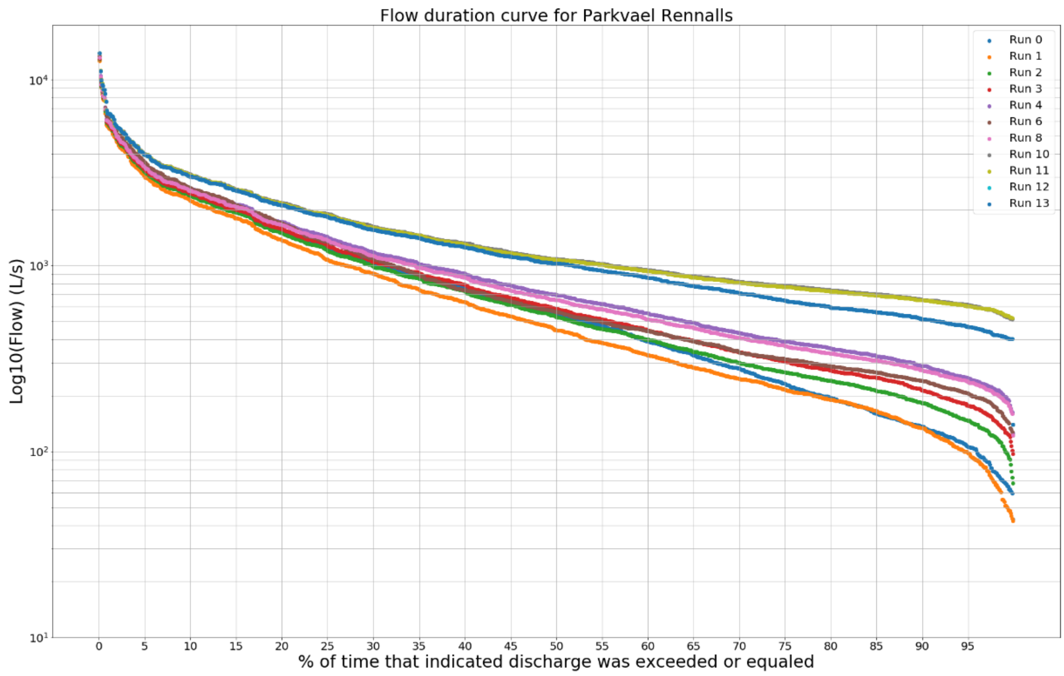

Fig A1.3: Flow duration curve for Parkvale Stream @ Rennalls Weir

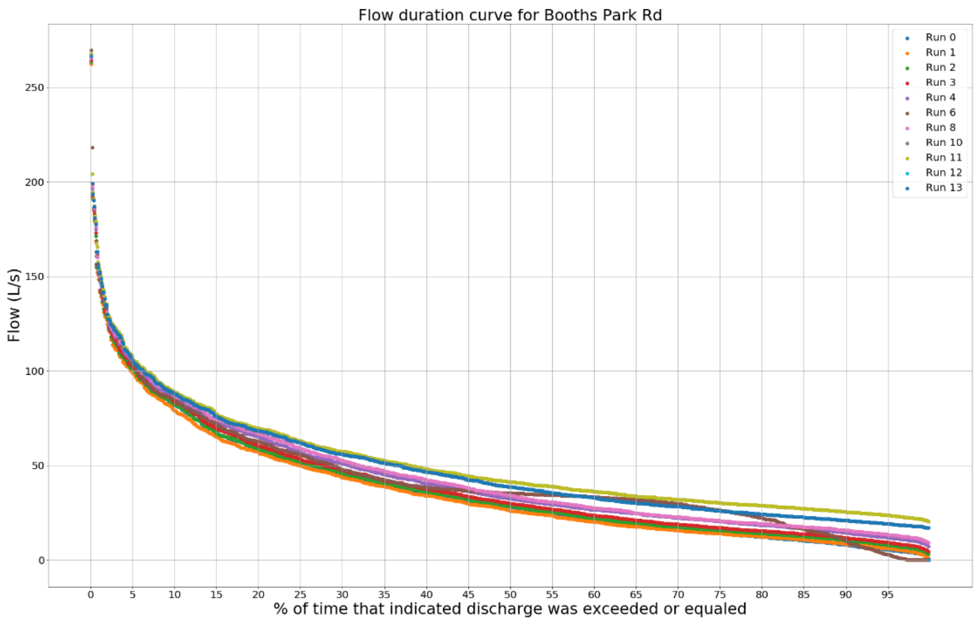

Fig A1.4: Flow duration curve for Booths Creek at Park Road

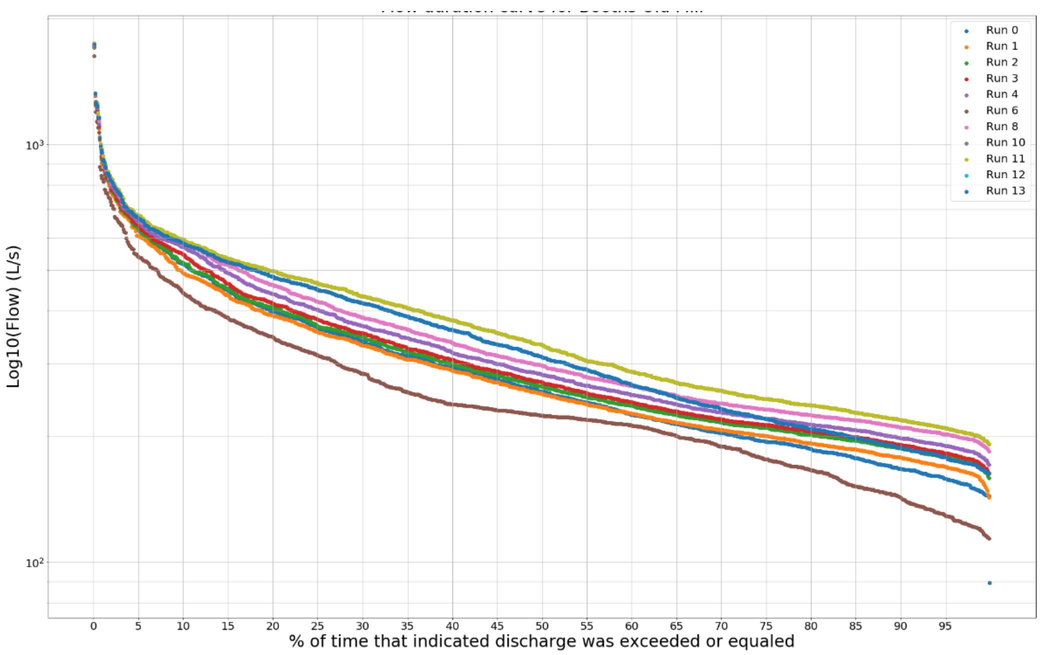

Fig A1.5: Flow duration curve for Booths Creek @ Old Mill

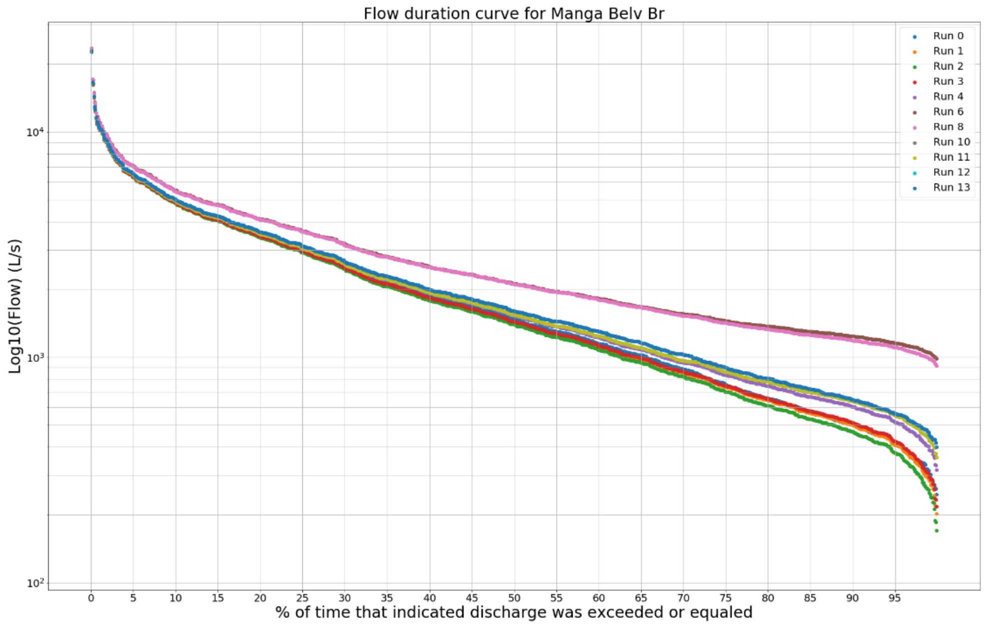

Fig A1.6: Flow duration curve for Mangatarere Stream @ Belvedere Bridge

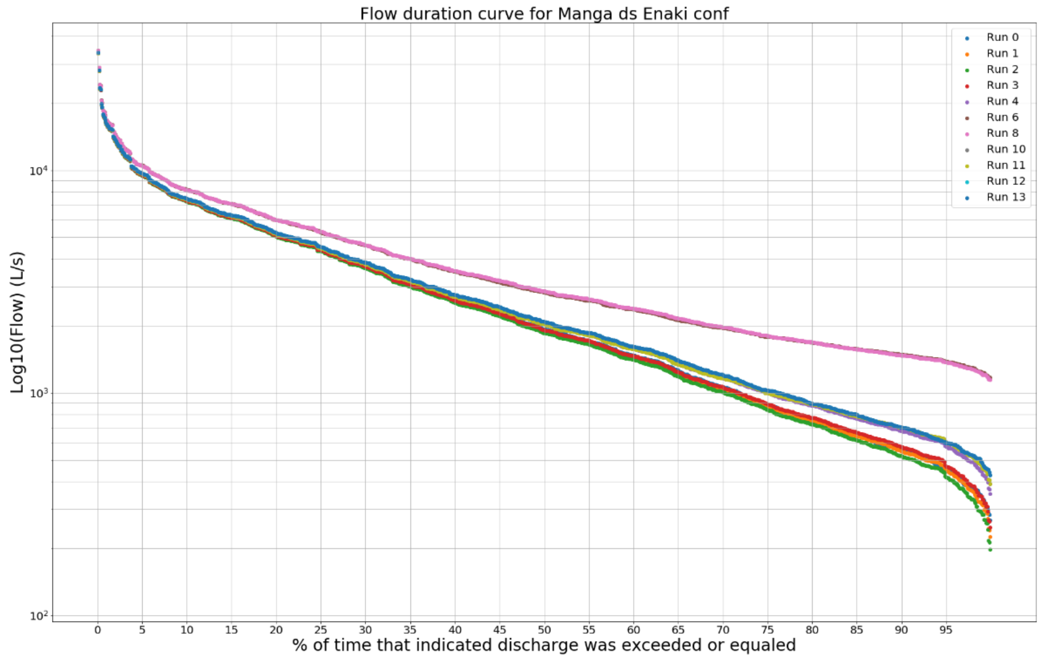

Fig A1.7: Flow duration curve for Mangatarere Stream @ Enaki confluence

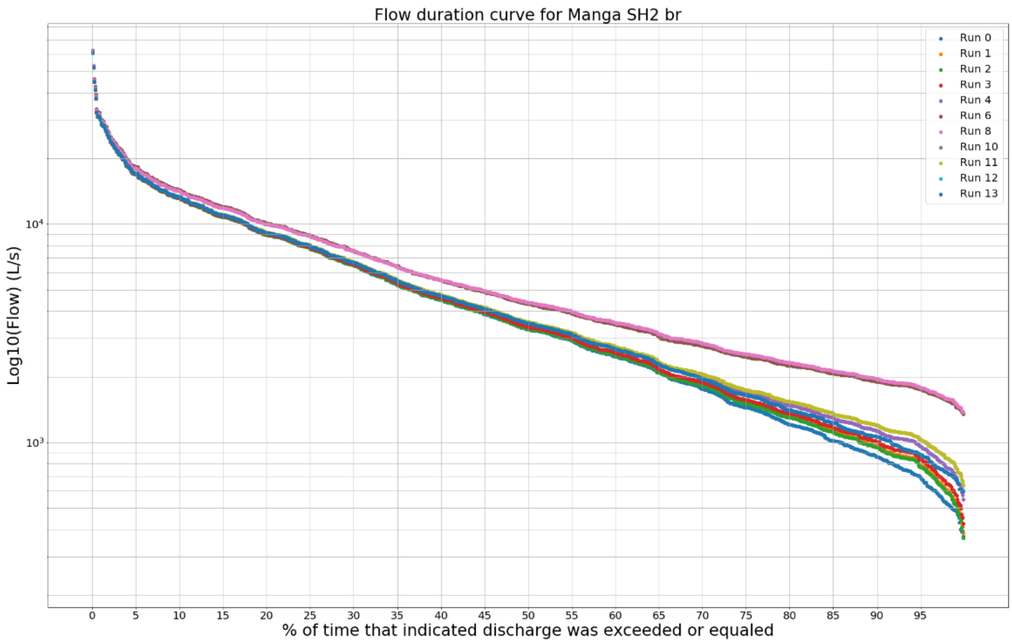

Fig A1.8: Flow duration curve for Mangatarere Stream @ SH2 Bridge

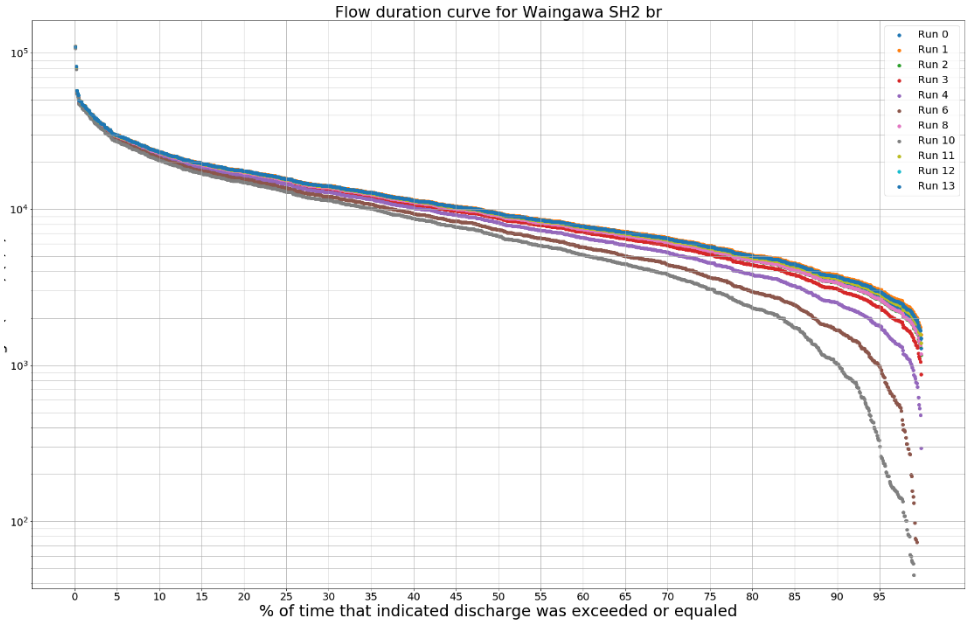

Fig A1.8: Flow duration curve for Waingawa River @ SH2 Bridge

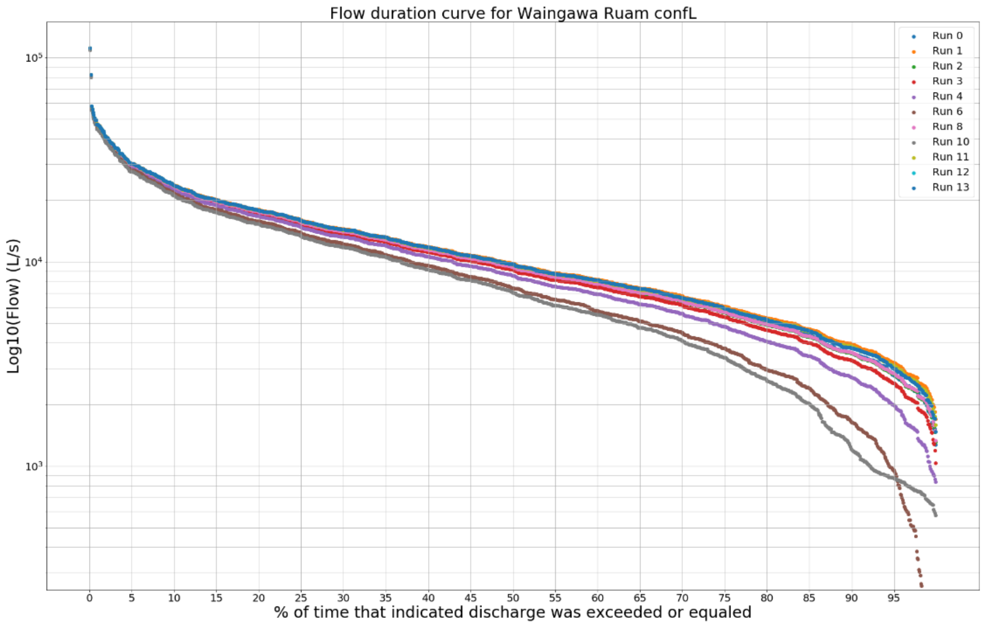

Fig A1.9: Flow duration curve for Waingawa River @ Ruamahanga confluence

Appendix 2: MAR Scenarios – changes in depth to groundwater plots

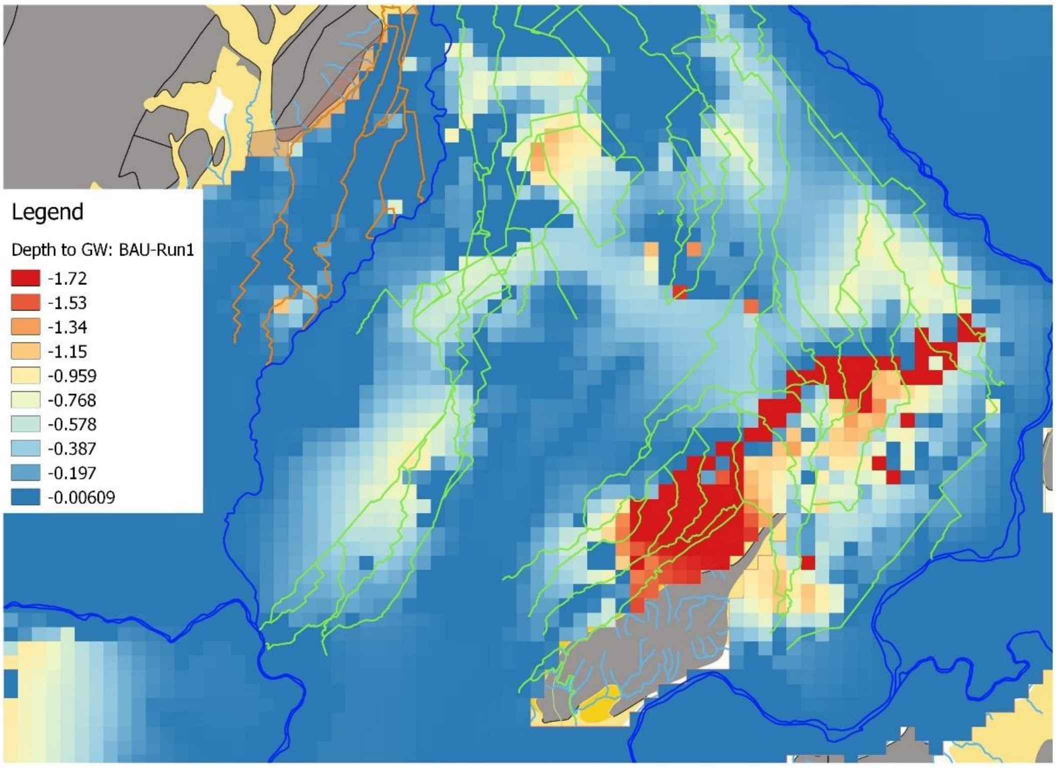

Fig A2.1 Changes in depth to groundwater BAU (run 0) minus natural state/no water races (run 1) using mean annual summer levels. Map shows that Run 1 has a deeper groundwater level beneath the water races (negative values).

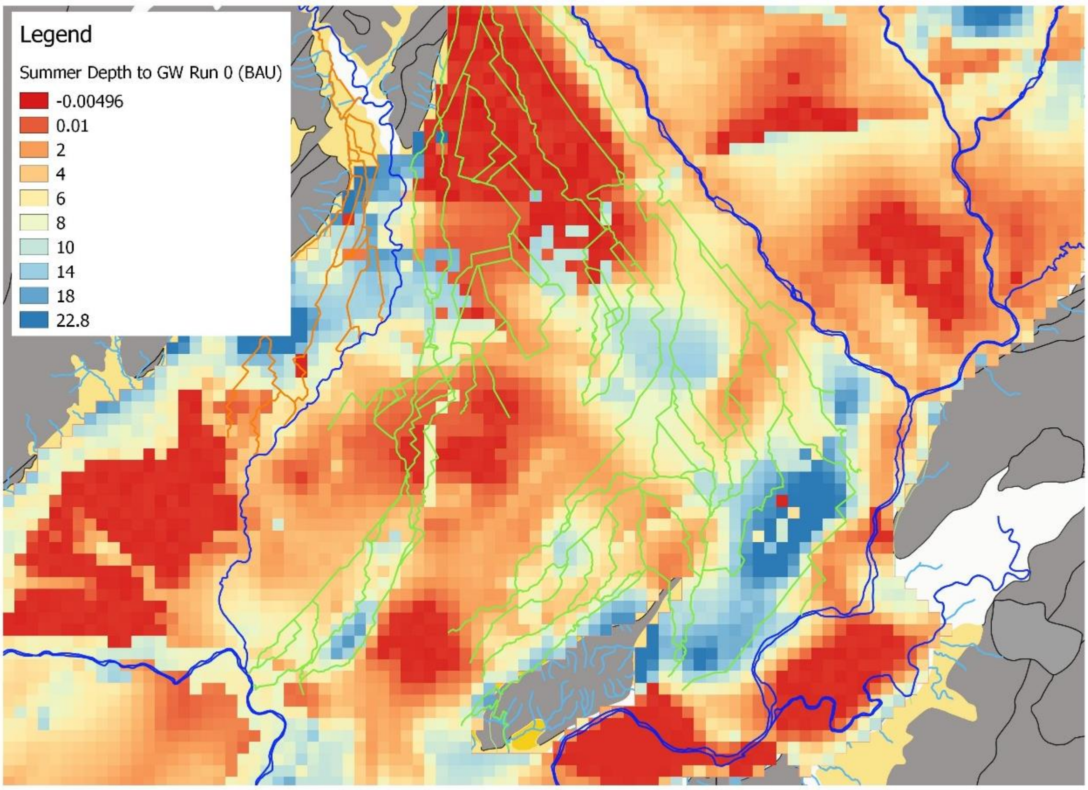

Fig A2.2 Mean summer depths to groundwater for Run 0 (BAU). Areas with negative values show a water table above ground level.

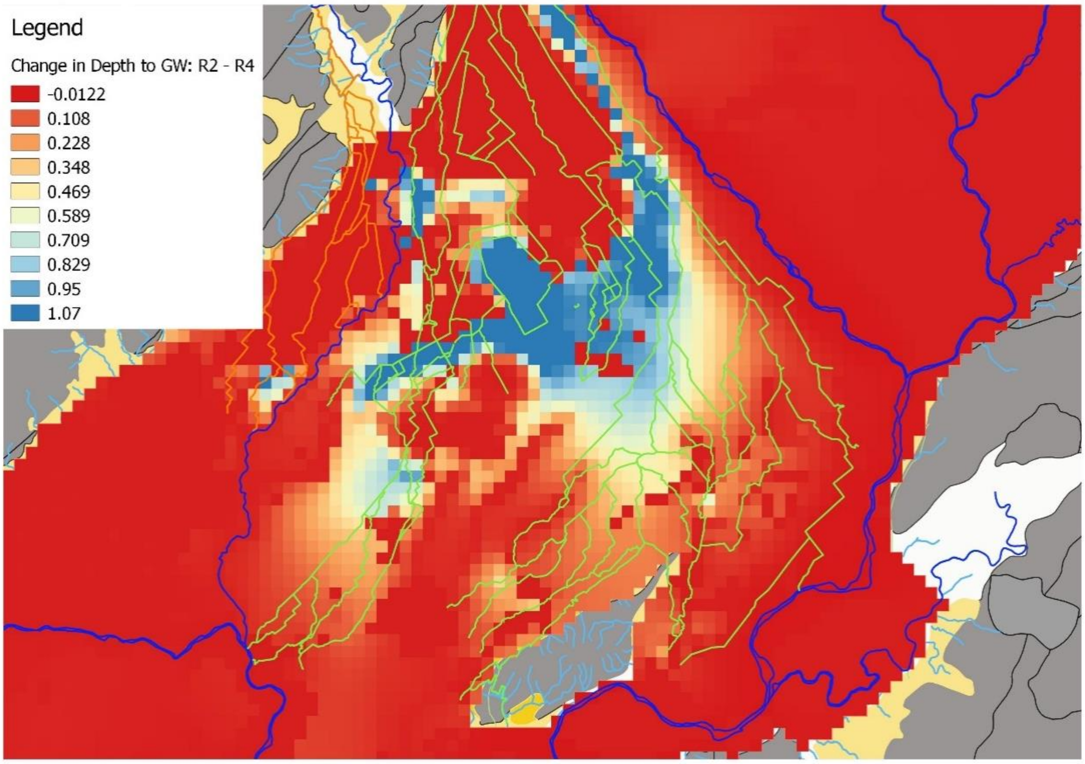

Fig A2.3 Changes in depth to groundwater: Run 2 (current race recharge) minus Run 4 (Taratahi and Carrington recharge quadrupled) using mean average summer levels. Areas with positive values show a rise in shallow groundwater level

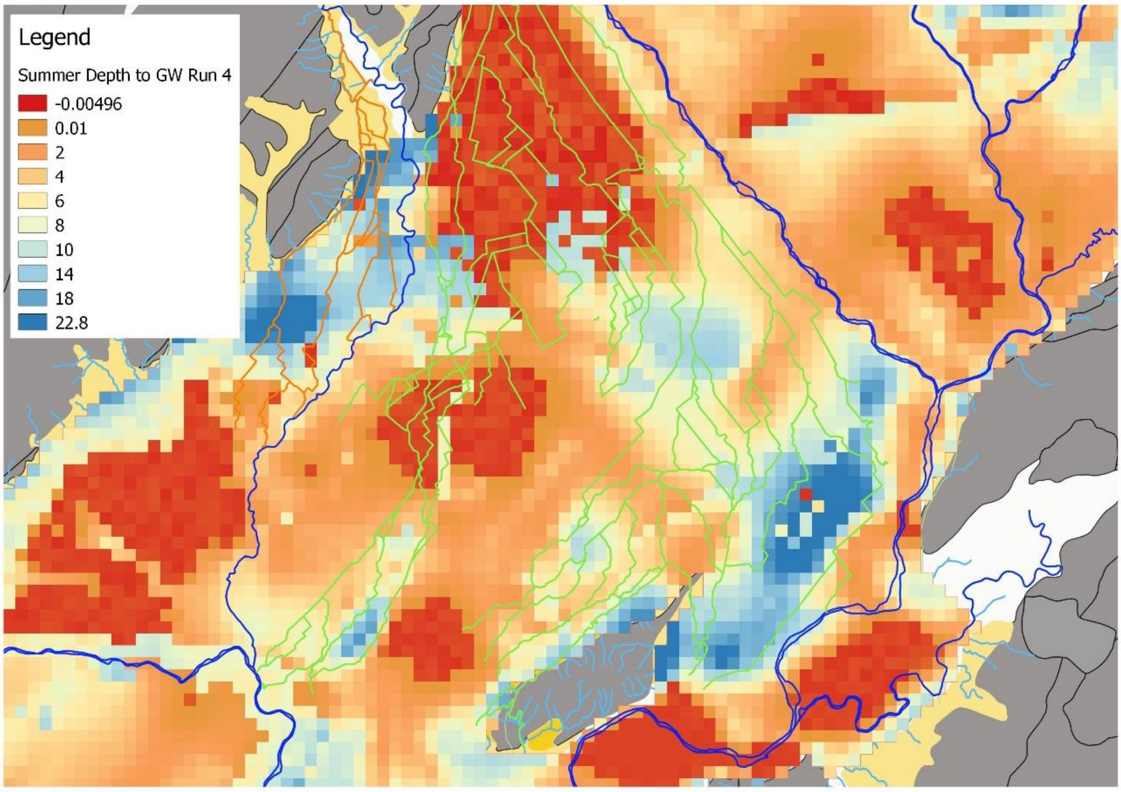

Fig A2.4 Mean summer depths to groundwater for Run 4. Areas with negative values show a water table above ground level.

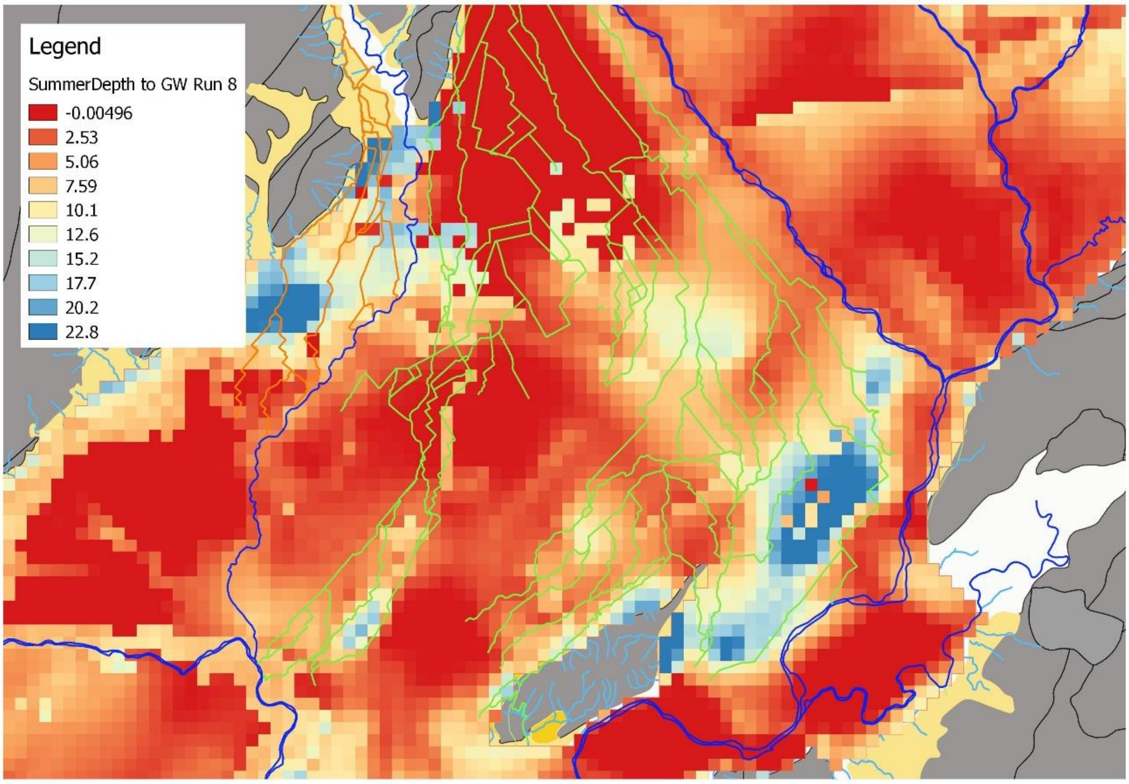

Fig A2.5 Mean summer depths to groundwater for Run 8. Areas with negative values show a water table above ground level.

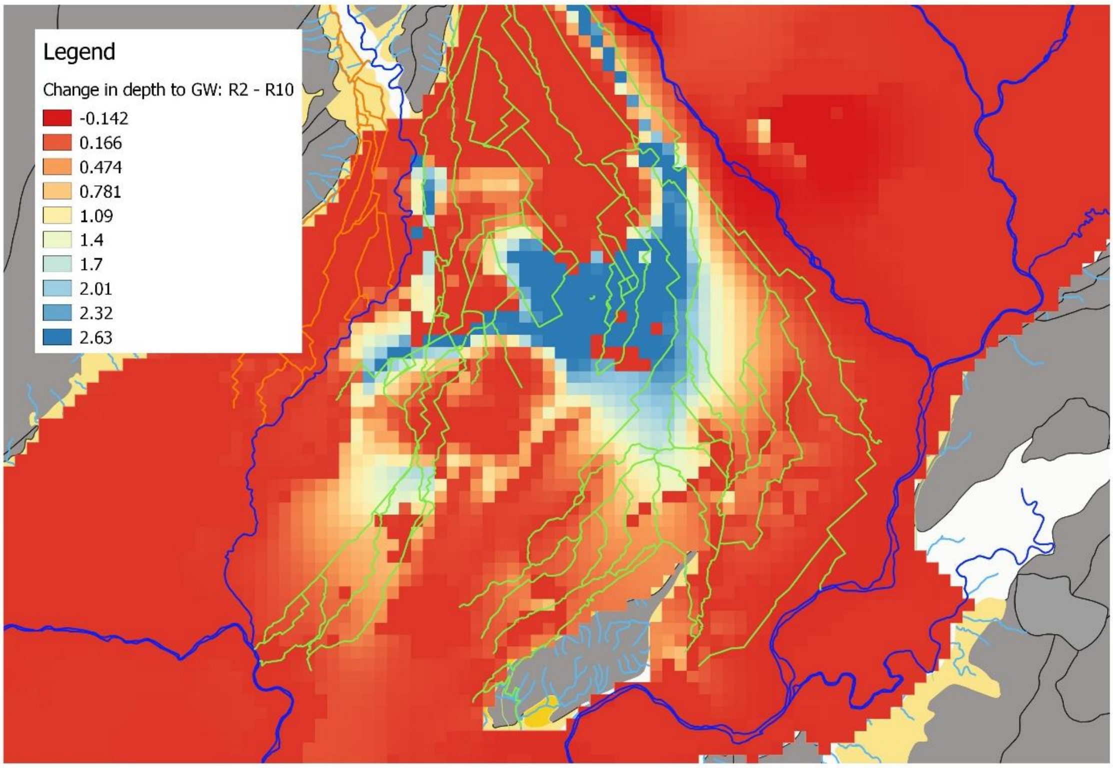

Fig A2.6 Changes in depth to groundwater: Run 2 (current race recharge) minus Run 10 (Taratahi recharge) using mean average summer levels. Areas with positive values show a rise in shallow groundwater level.

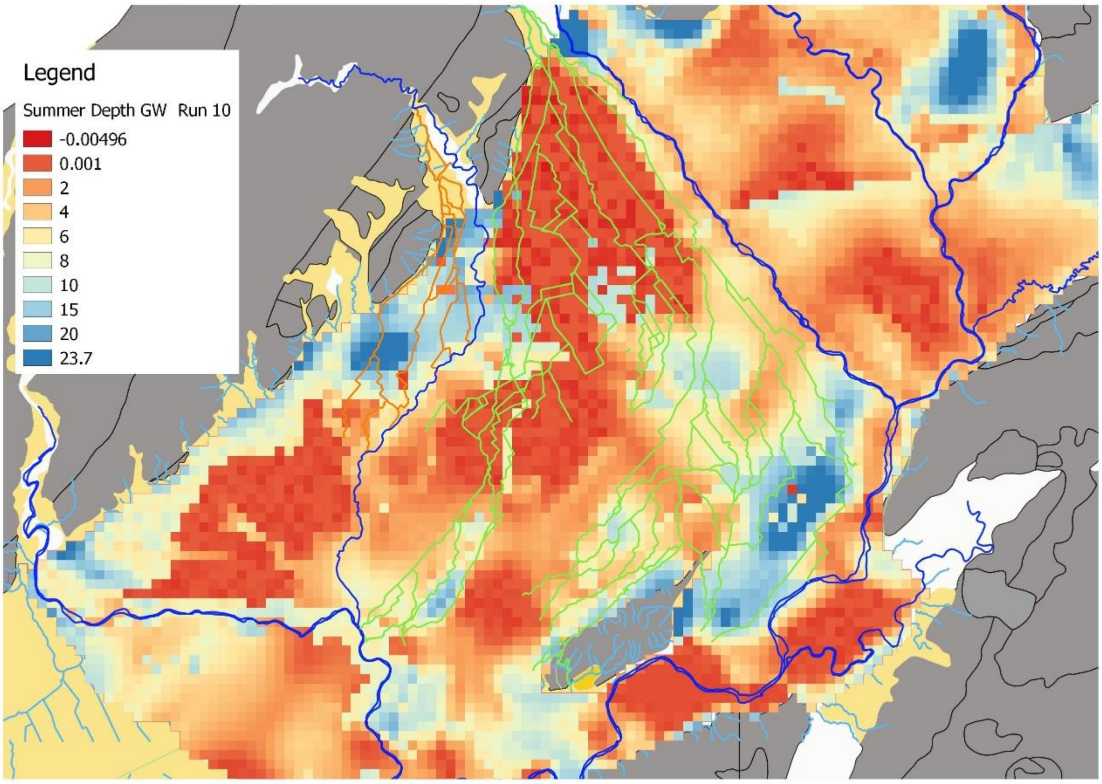

Fig A2.7 Mean summer depths to groundwater for Run 10. Areas with negative values show a water table above ground level