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Groundwater REPORT

RUATANIWHA BASIN Tranche 2 Groundwater Modelling (Revised 2)

PREPARED FOR

Various Collaborative Participants

WL18045

28 September 2022

PREPARED BY

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EXECUTIVE SUMMARY

In 2013, Aqualinc Research Ltd (Aqualinc) developed a three-dimensional numerical flow model of the Ruataniwha basin as part of the Tukituki catchment Plan Change 6 (PC6) hearing. Recently, the model has been updated and used to test the hydraulic response of the groundwater and surface water system in the basin from multiple proposed Tranche 2 groundwater take applications. This work has been completed in a collaborative environment with Hawke's Bay Regional Council (HBRC) and eight Tranche 2 groundwater applicants.

The Tranche 2 groundwater applicants propose to abstract groundwater, and (as required under PC6) mitigate the consequential stream depletion effects via further abstraction to directly augment river flows during drier periods (when takes from the rivers are restricted). The concept of augmentation is based on using groundwater stored in the aquifer system during wetter periods to mitigate stream depletion effects during drier periods. The augmentation takes will also result in additional stream depletion effects, but this too will be delayed and spread over space and time through the storage response of the aquifer system. While there is on average more water abstracted from the basin's aquifer system (compared to current), the rationale is founded on the principle of using the groundwater system to smooth, buffer and delay stream depletion effects using groundwater storage that is later replenished naturally.

Since the original model documented in Weir (2013), the model has been updated with new aquifer test, groundwater level and river flow data received from HBRC. The model was then recalibrated to measured groundwater levels and river flows, with a particular focus on matching low (dry-period) river flows to align with HBRC's water management strategies. Good matches were achieved between measured and modelled outputs. The model simulates the period 1972-2012, which incorporates a wide range of climatic variability from very wet to very dry years. The model is the best tool currently available for predicting the effects of the proposed Tranche 2 activities.

The updated numerical model has been used to quantify the stream depletion effects of the proposed Tranche 2 groundwater takes and the subsequent surface water augmentation requirements. This is not an exact science as there are several variables that need to be assumed or approximated. However, the modelling work has provided a helpful quantification of the magnitude, location and timing of effect. Modelled groundwater levels and river flows have been used to predict the *change* in groundwater levels and river flows (between different scenarios) as a result of the Tranche 2 activities. Therefore, the model's predictive uncertainty is largely eliminated, particularly so given the relatively low uncertainty values reported.

Modern groundwater modelling techniques often include an assessment of predictive uncertainty, but should not be treated as a substitute for robust model construction, nor should they 'muddy' the information needed to make key decisions (uncertainty analyses are often themselves uncertain). A balance is therefore needed between theory and practical application. Simple linear predictive uncertainty analyses have been completed to provide an approximate scale of the uncertainty expected from the predictions of absolute groundwater levels and river flows as well as uncertainty in the changes in these attributes between key scenarios. These assessments have concluded that all observations have contributed to reducing the calibration uncertainty, some significantly. This is expected.

The uncertainty assessment has estimated that the predictive uncertainty in low groundwater levels is in the order of ±0.03-0.8%, and for low river flows the uncertainty is in the order of ±0.2-0.7% for key low-flow restriction sites and 0.1-5.2% for other gauging sites. These uncertainties are relatively small which indicates that there is a large degree of confidence in the predictions for the scenarios considered. Furthermore, the 95% confidence intervals around the predicted *changes* as a result of the proposed Tranche 2 takes are very narrow around the best prediction from the calibrated model. The predictions from the calibrated model are typically closer to the lower bound of the confidence interval, which suggests the prediction is conservative.

Several scenarios of abstraction and augmentation were modelled to arrive at an 'optimised' balance between irrigation takes and augmentation discharges. This includes:

- The inclusion of all existing irrigated areas (i.e. existing surface water and groundwater use) fully operating as though they were in place since the start of the simulation period;

- Tranche 2 irrigated areas and augmentation rates a little smaller than initially applied for by some applicants;
- Adopting higher river low-flow restrictions (than those set out in Table 5.9.6 of HRBC's Regional Resource Management Plan) to provide improved environmental low flows and to protect existing users' reliability;
- Full augmentation whenever these higher river flow restrictions are triggered, regardless of whether or not Tranche 2 irrigation is occurring; and
- Full augmentation occurring from all Tranche 2 applicants when any one of the flow monitoring sites within the basin is triggered; this acknowledges that all Tranche 2 applicants are operating collaboratively, and effects from any one take can propagate across several streams.

The numerical model domain encompasses the Ruataniwha Basin, and does not extend to HBRC's flow monitoring site on the Tukituki River at Red Bridge, down catchment. Therefore, the combined change in flows predicted at the Waipawa at SH2 and Tukituki at Tapairu Road monitoring sites have been considered to represent the change at Red Bridge. So long as the combined 7-day MALF at the SH2 and Tapairu Road sites are maintained (or improved), then there will be no adverse downstream effects on low flows at Red Bridge as a result of the proposed Tranche 2 activities. This has been verified by adding the change in flows exiting the basin to the river flows measured at Red Bridge, assuming a short delay in travel time between the sites.

Summary of Predicted Effects

Proposed low-flow triggers and net changes in 7-day MALF for key river flow monitoring sites under the optimised scenario are summarised in the table below.

Site				
Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
RRMP Table 5.9.6 minimum flow (l/s)				
2,500	2,300	150	1,043	1,170
Assumed low-flow restriction applied (l/s) (1)				
2,730	2,425	155	1,065	1,315
Change in mean 7-day annual low flow (MALF) (l/s)				
+15	+218	-1	-3	+7
Change in 7-day MALF as a percentage of new low-flow limit				
+0.5%	+9.0%	-0.6%	-0.3%	+0.5%
(1) These are higher than current RRMP Table 5.9.3 limits to provide greater environmental benefit during low flows and to protect reliability of existing users.				

The small residual negative changes to 7-day MALFs in the two Tukipo River sites are smaller than both model uncertainty and measurement precision.

The following key findings have been derived from the modelled scenarios:

- The effects on river flows from the proposed additional Tranche 2 takes are spread over both space and time throughout the basin.
- If augmentation is applied when flow sites reach the higher flow restrictions (discussed above), regardless of whether or not Tranche 2 irrigation is operating, augmentation results in an overall improvement in low flows exiting the basin in both the Tukituki and Waipawa rivers.
- Targeted over-compensation (i.e. the positive changes in MALFs) exiting the basin accommodates modelling prediction uncertainty, enhances environmental low-flows, and accommodates across-catchment effects.

- Groundwater will not be mined. While groundwater levels will lower further with the additional Tranche 2 takes (made available under PC6), they will not continue to lower; they will simply reach a new (lower) dynamic equilibrium. Shallow groundwater levels are predicted to lower a maximum of 0.7 m in the vicinity of the Tranche 2 take locations, and less than 0.2 m further afield.
- The time for the new groundwater level equilibrium to be reached varies depending on location and depth. The full effects of the proposed Tranche 2 activities are predicted to take between zero and 40+ years to be fully realised. On average, the full effects are predicted to be reached within approximately 10 years and 90% within approximately 7 years.
- The model has been used to predict changes in low flows for rivers and streams within the basin. Low-flow changes are typically negative upstream, and positive downstream, of augmentation locations. Negative flow changes are small (in the order of 1-10 l/s) and the larger of these reductions typically occur in the rivers with larger flows.
- Considering future climate predictions, the effects of the proposed Tranche 2 activities on low river flows at key monitoring sites are predicted to be positive or (where negative) small. Groundwater abstraction is predicted to increase in the future, but so too is the frequency of augmentation, which mitigates the effects on low flows from the proposed Tranche 2 takes.

Several management, operational and compliance protocols are recommended to aid practical implementations of the Tranche 2 takes and augmentation, including:

- Staged development and transitional implementation;
- Automated monitoring of river flows; and
- Defining a ‘Water Year’ and associated start date of irrigation and augmentation.

1 INTRODUCTION AND BACKGROUND

In 2013, Aqualinc Research Ltd (Aqualinc) developed a three-dimensional numerical flow model of the Ruataniwha basin as part of the Tukituki catchment Plan Change 6 (PC6) hearing. Recently, the model has been updated and used to test the hydraulic response of the groundwater and surface water system in the basin from multiple proposed Tranche 2 groundwater take applications. The model is the best tool currently available for predicting the effects of the proposed Tranche 2 activities.

The Tranche 2 groundwater applicants propose to abstract groundwater (primarily for irrigation use), and (as required under PC6) mitigate the consequential stream depletion effects via further abstraction to directly augment river flows during drier periods (when takes from the rivers are restricted). The concept of augmentation is based on using groundwater stored in the aquifer system during wetter periods to mitigate stream depletion effects during drier periods. The augmentation takes will also result in additional stream depletion effects, but this will be delayed and spread over space and time through the storage response of the aquifer system. While there is on average more water abstracted from the basin's aquifer system (compared to current), the rationale is founded on the principle of using the groundwater system to smooth, buffer and delay stream depletion effects using groundwater storage that is later replenished naturally.

The numerical model has been used to quantify the change in stream flows and groundwater levels resulting from the proposed Tranche 2 takes and the subsequent surface water augmentation requirements. This is not an exact science as there are several variables that need to be assumed or approximated. However, the modelling work has provided a helpful quantification of the magnitude, location and timing of effect. There is currently no better tool available for this purpose.

To reduce the influence of measurement and model uncertainty, the most appropriate application of model results is to consider *changes* in key outputs (river flows and groundwater levels) between scenarios, rather than absolute values. In this regard, the model tests the effectiveness of the proposed augmentation to mitigate the changes in river flows that would be induced by the Tranche 2 takes. The modelled changes can be compared to measured values to derive absolute values, if required.

The original model development and calibration is documented in Weir (2013), key points of which have been reproduced herein. More recently, the model has been updated with new monitoring data, and used to run various scenarios to predict the hydraulic responses of the proposed Tranche 2 takes and to test the ability to mitigate adverse effects on surface waters during low-flow periods through augmentation. Model updates, scenarios and results are documented below.

1.1 Collaborative Approach

This work has been completed in a collaborative environment with Hawke's Bay Regional Council (HBRC) and the following eight Tranche 2 groundwater applicants:

- Te Awahohonu Forest Trust (TAFT)
- Papawai Partnership
- Tukituki Awa
- Plantation Road Dairies
- Springhill Dairies (formerly Ingleton Farms)
- I & P Farming (formerly Abernethy Partnership)
- Buchanan Trust No 2
- Purunui Trust

TAFT and I&P Farming have helpfully provided overall coordination and leadership from the perspective of the Tranche 2 Applicants, and further planning advice and technical expertise have been provided by Enfocus, Bay Geological Services, Susan Rabbitte, Boffa Miskell, AgFirst, Sage Planning, vVEnvironmental and Aqualinc.

2 MODEL OVERVIEW AND UPDATES

The Ruataniwha basin flow model covers a study area of approximately 78,000 ha as shown in Figure 1. The model was developed as a MODFLOW-NWT model (Niswonger *et al*, 2011) with a 200 x 200 m size grid over 10 numerical layers. Total model thicknesses range from approximately 10-40 m around the perimeter to over 400 m nearer the centre of the model domain. The model surface was assigned from a digital elevation model (DEM) and the model base was determined from a combination of bore logs (supplied by HBRC) and geological cross sections. It includes the main rivers and streams in the basin, land surface recharge (both dryland and irrigated) and groundwater pumping.

Rivers were simulated using MODFLOW's stream flow routing package (SFR2). Within the SFR2 package, variably-shaped river cross-sections and bed invert levels were specified based on survey data supplied by HBRC and the DEM. River flows entering from the greater catchment above the basin have been synthesised by Fraser *et. al.* (2013) using a rainfall run-off model calibrated to measured river flows (supplied by HBRC). These synthesised flow time series were further refined to match low-flows as best as possible given the few river flows measurements available.

The model runs with daily stress periods from 1 July 1972 to 30 June 2012. It has been calibrated against transient groundwater levels and river flows, with a particular focus on matching low (dry-period) river flows to align with HBRC's water management strategies. The graphical user interface GMS (2022) has been used to generate the MODFLOW-NWT input files, and to post-process and visualise most model outputs. Additional scripting has been developed to extract river flows and run uncertainty analyses.

Since the original model documented in Weir (2013), a review of aquifer tests in the basin has been received from HBRC following a review by PDP (2018). Aquifer test results from this work have been incorporated into the model, specifically horizontal hydraulic conductivity, vertical hydraulic conductivity and aquifer storage parameters. In addition, HBRC provided updated groundwater level and river flow data for the basin. After this new data was integrated into the model, it was recalibrated to measured groundwater levels and river flows (again, with a particular focus on matching low river flows).

The model run period was not extended through to present date (i.e. not beyond 2012) as climate variability over the period 2012-2021 was not sufficiently different to the simulation period to warrant the extensive time and workload required to generate new model inputs. The current model run period (1972-2012) incorporates a wide range of climatic variability from very wet to very dry years. This is demonstrated in Figure 2 which presents a histogram of annual rainfall totals (for each calendar year) for Ongaonga over the period 1970-2021. The range of annual rainfall totals over the simulation period is also shown on this figure, and covers the full range on record, apart from the wettest year (this was 1971). Hence, extreme dry years (when the groundwater and surface water systems are most stressed) are captured in the simulation period, and therefore there was no need to re-run the model to include post-2012 climate data.

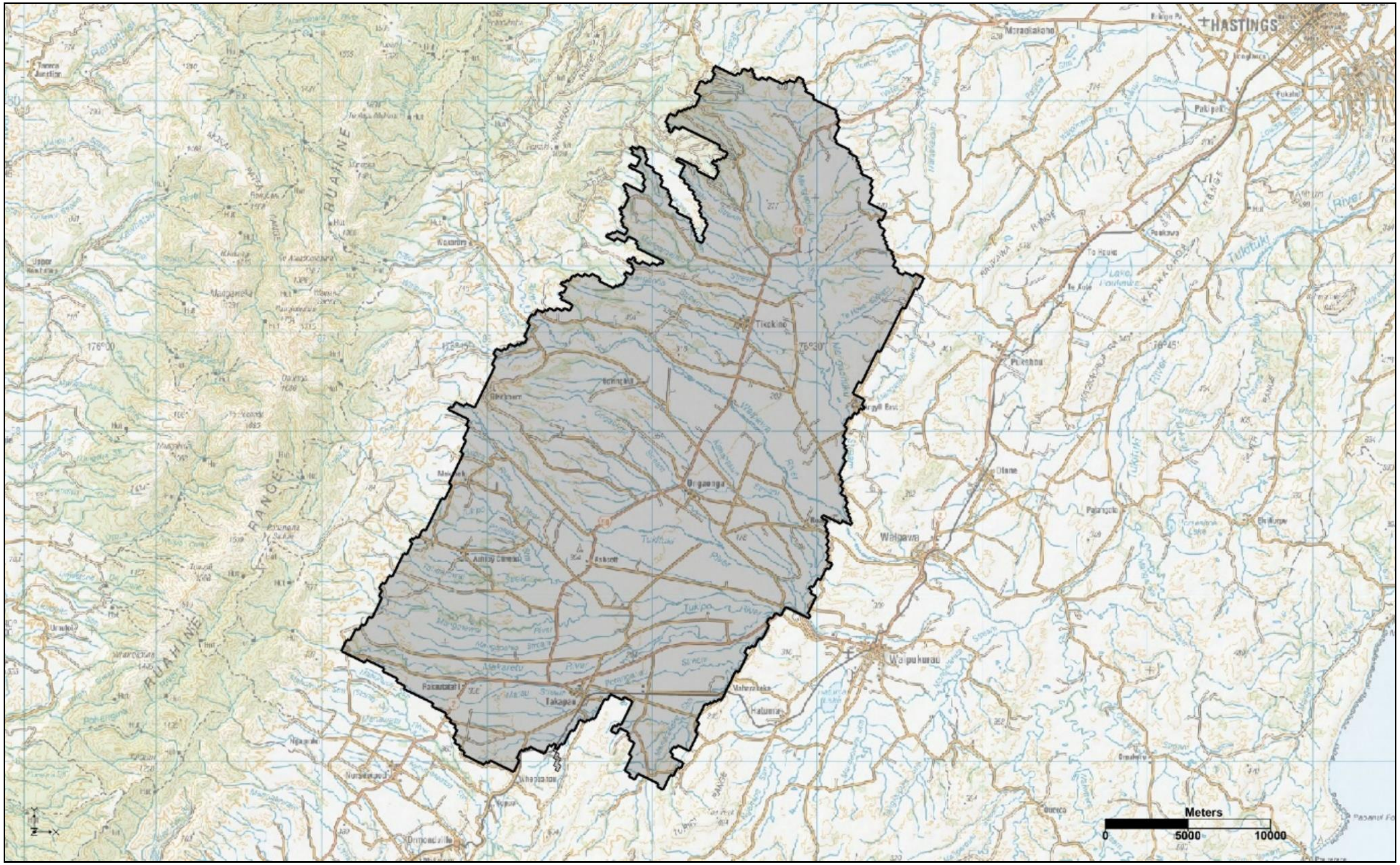


Figure 1: Study area with model extent shown by the shaded polygon

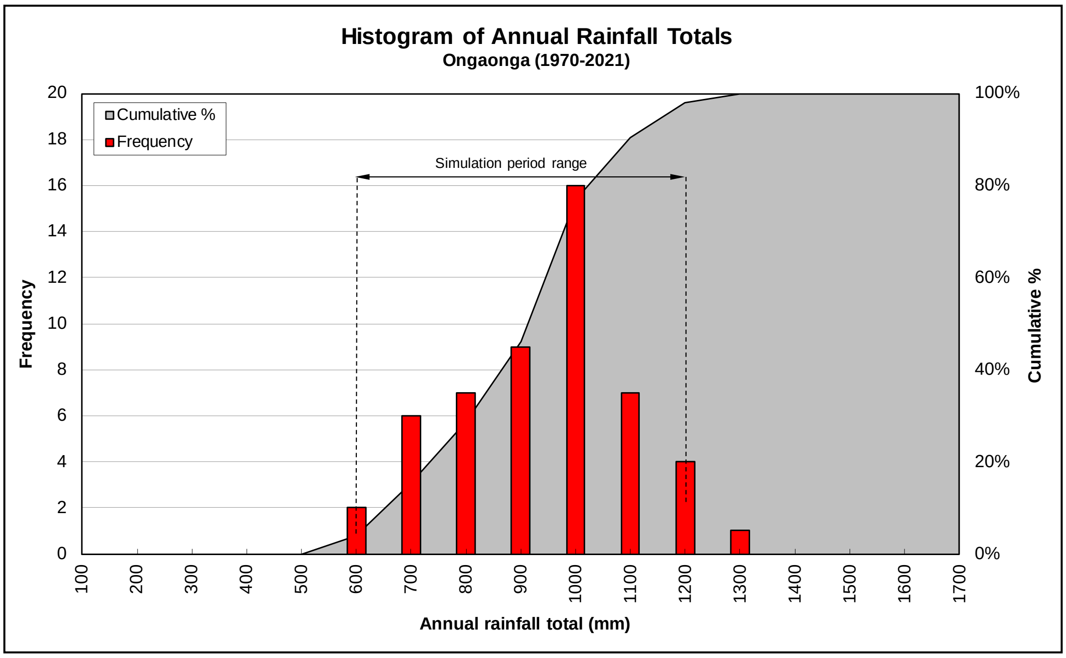


Figure 2: Histogram of annual rainfall totals for Ongaonga (data sourced from NIWA's CliFlow database)

2.1 Model Calibration

To ensure the model appropriately represents reality, the model was calibrated against measured data. This was achieved using a combination of manual trial-and-error methods and automated calibration using the software PEST (Doherty, 2021). Calibration focussed on two key datasets: groundwater levels and river flows. These are discussed in the following paragraphs.

2.1.1 Calibration to Groundwater Levels

During calibration, the modelled groundwater levels in a bore are compared to measured groundwater levels in the same bore, for all of the calibration bores. The difference between the modelled and measured groundwater level is called the 'residual'. If the residuals are all generally positive or negative, then the system is said to be biased. One of the goals during model calibration is to minimise the residuals and bias.

Groundwater level calibration was based on groundwater level measurements (supplied by HBRC) from 72 monitoring bores within the basin (shown in Figure 3).

The transient simulation period spans 1 July 1972 through to 30 June 2012 (40 years). The model was calibrated against any measurements available within this period. Records for some of the more recent calibration bores did not cover the model run period, and therefore less weight was given to fitting these bores.

Both steady-state (average) and transient versions of the model were developed and used for calibration. Due to lack of data and difficulties inherent in predicting historical water use, calibration commenced with a 'No Irrigation' scenario to simulate the groundwater level response under quasi-natural conditions. Here, calibration focussed on matching groundwater levels that were measured during periods that were less influenced by groundwater pumping (i.e. winter levels). The model was then further calibrated for the effects of groundwater abstraction against a 'Status Quo' scenario that simulates the current (2020) level of groundwater abstraction. Here, comparisons focussed on more recent groundwater level measurements that include the response of groundwater pumping. These two scenarios therefore present an envelope of response within which measured data would fall if the model was perfectly calibrated.

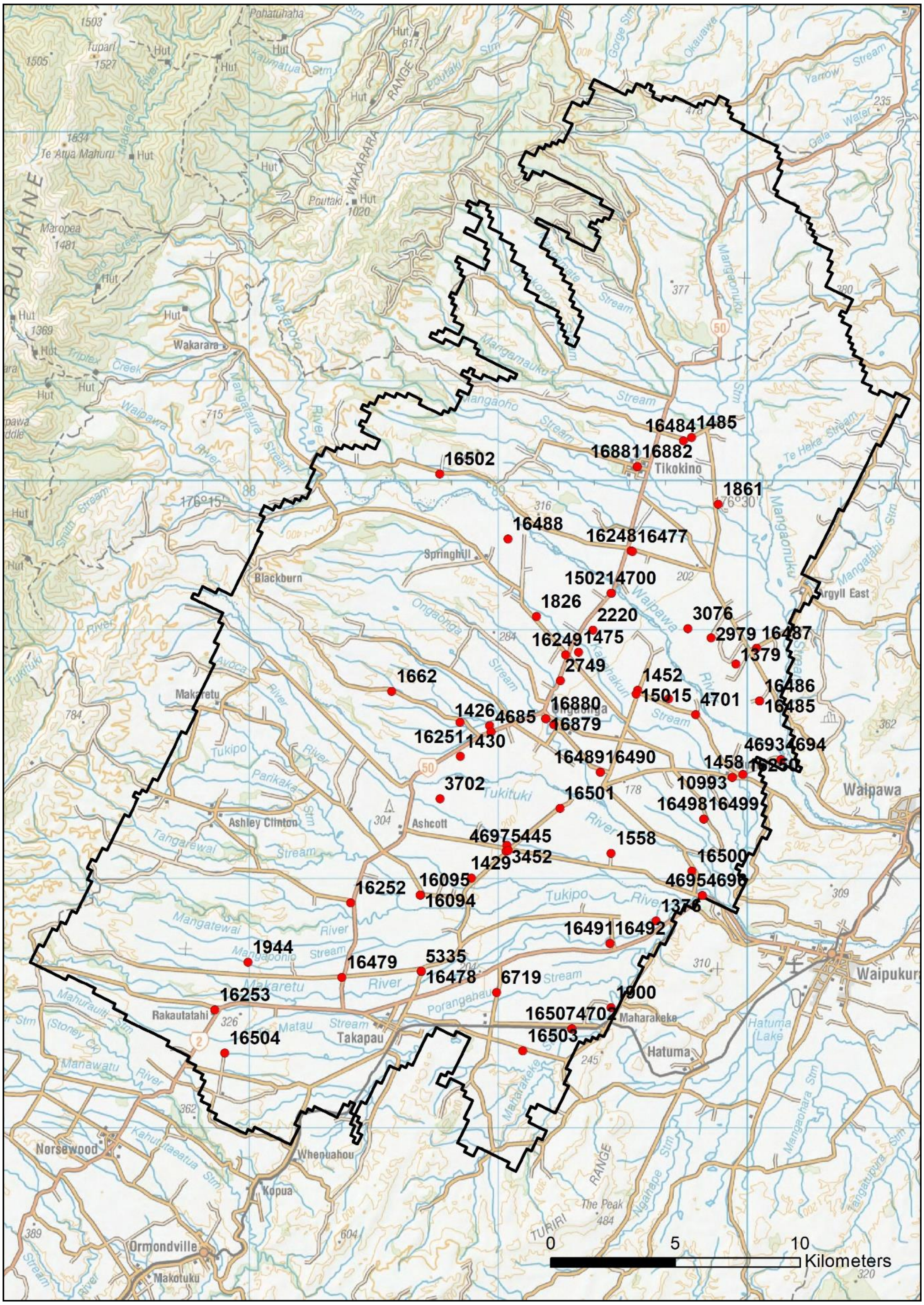


Figure 3: Location of bores used for groundwater level calibration

The model calibrated very well. Plots of measured and modelled groundwater levels in the 72 monitoring bores are presented in Appendix A. The modelled groundwater levels shown on these plots are for the full 40 year simulation period. Most bores have a plotted vertical axis range of 20 m so that a relative comparison between bores can be visualised.

Groundwater level measurements from bores 4697 and 5445 both show variations of over 30 m within each season. This appears to be a local phenomenon resulting from pumping in the bore or from another bore located very nearby. The model is a catchment-scale representation and has not been constructed to simulate these local effects. Hence, differences between measured and modelled groundwater levels are large for these bores. This does not jeopardise the model's ability to predict regional-scale effects.

Figure 4 presents measured versus modelled groundwater levels for both the 'No Irrigation' and 'status Quo' scenarios. For a model perfectly calibrated at every observation bore, all points would lie exactly along the dashed line running diagonally though the plot. The amount of scatter either side of this line provides an indication of the goodness of fit. Some scatter around this line is normal for any model that simplifies a complex real-world system. The scatter occurs as a result of measurement error and model uncertainty. The pumping effects in bores 4697 and 5445 (discussed above) are indicated on this plot.

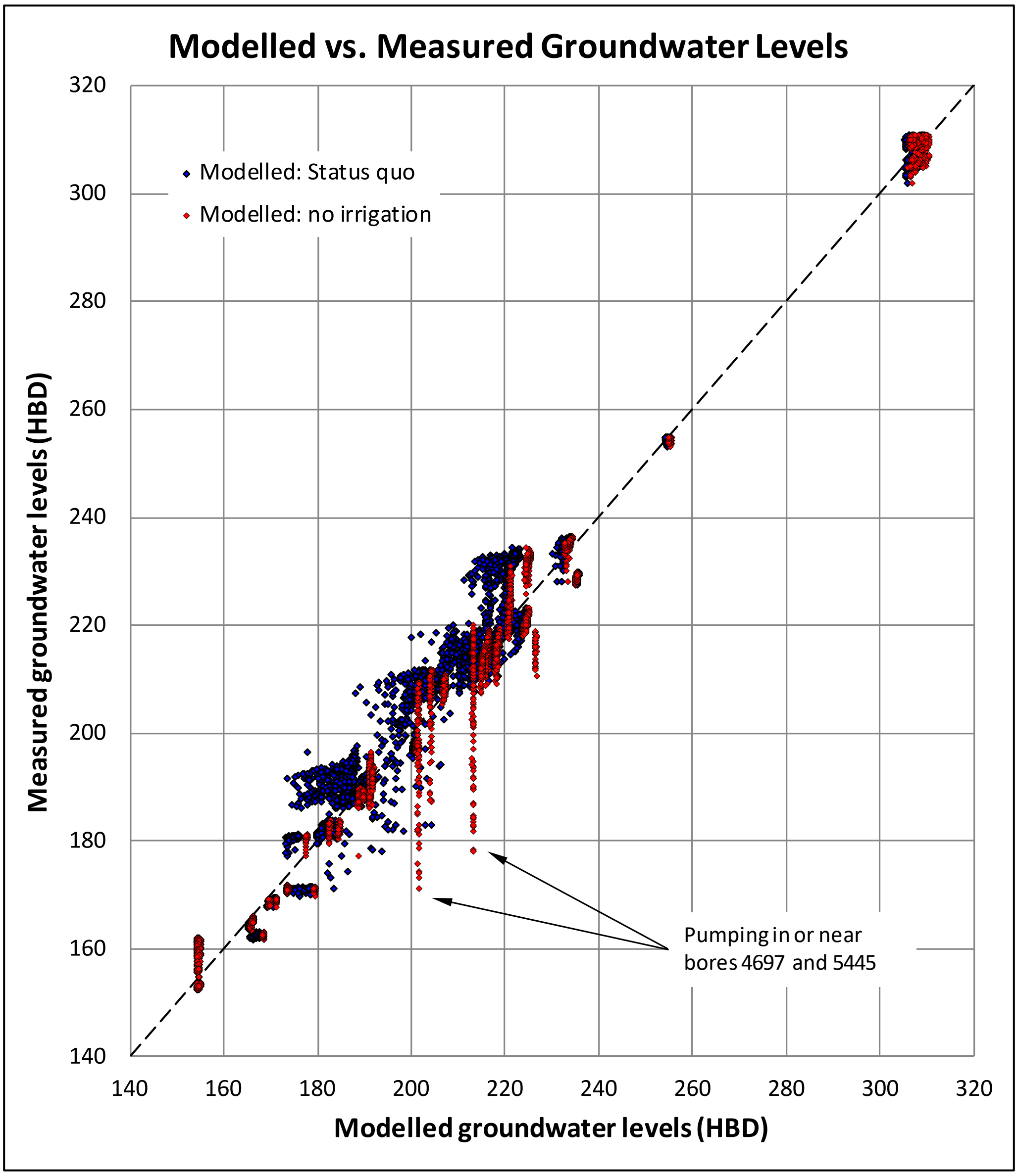


Figure 4: Modelled versus measured groundwater levels

An objective function is a mathematical formula that expresses numerically the goal that is to be achieved during calibration. For the purpose of this model, two objective functions have been considered, as follows:

a. The mean error (ME), which assists in showing the presence of bias (systematic error); and

b. The root mean square error (RMSE), which is a classical measure of model error. The RMSE is usually reported as a percentage of the range within which the measured values vary (this is also referred to as the 'normalised' RMSE).

One of the key goals of model calibration is to minimise the objective functions. Table 1 presents the groundwater level objective function values for the entire 40 year model simulation period. Also in Table 1 are additional statistics that have been generated and a brief description of these statistics.

Table 1: Groundwater level objective function values and other statistics for the calibrated model over the full simulation period (1972-2012)

Objective function or statistic	Scenario		Definition
	No irrigation	Status quo	
Mean error (ME) (m)	1.34	-0.75	Average difference between modelled and measured groundwater level.
Maximum absolute residual (m)	35.2	21.3	Maximum difference between modelled and measured groundwater level.
Minimum absolute residual (m)	0	0	Minimum difference between modelled and measured groundwater level.
Root mean square error (RMSE) (m)	4.4	4.9	Classical measure of error.
Normalised RMSE	2.8%	3.1%	RMSE normalised by the amount that the measured values vary during the simulation period.
R^2 (square of the correlation coefficient)	0.98	0.98	Correlation between measured and modelled values.

The United States Army Corps of Engineers use a rule of thumb for an acceptable normalised RMSE of 10% when considering groundwater flow calibration or verification (Donnell *et al.*, 2004). The 2001 Australian Groundwater Flow Modelling Guidelines indicate that the normalised RMSE should be less than 5% (MDBC, 2001) though the revised 2012 guidelines (Barnett *et al.*) suggest that alternative (larger) values may be acceptable depending on the model scope. The normalised RMSE is 2.8-3.1% for the calibrated model (Table 1). Based on these statistics, the transient model is suitably calibrated.

2.1.2 Calibration to River Flows

River flow calibration primarily focussed on matching low flows, as abstraction potentially causes the greatest stresses to the rivers at these times. In addition, HBRC's management regimes are typically based on low flow statistics (such as the 7-day MALF).

River flow calibration was completed for the Tukituki River, Waipawa River, Mangaonuku River (upstream of the Waipawa confluence) and for the Tukipo River at both SH50 and Ashcott Road. These five sites are shown in Figure 5. Calibration was also undertaken for a series of flow gauging sites located throughout the basin. This is discussed in Section 2.1.3.

River flow calibration data was supplied by HBRC. Measured data was supplied for the Waipawa, Tukituki and Tukipo (at SH50) rivers and the gaugings sites. Synthesised data was supplied for the Tukipo at Ashcott Road and for the Mangaonuku River.

The Tukituki River at Tapairu Road and Waipawa River at RDS/SH2 sites are located 5-11 km downstream of the outlets from the Ruataniwha Basin, as shown in Figure 5. However, for the purposes of model calibration, it has been assumed that river gains and losses between the basin outlets and these flow monitoring sites are negligible (i.e. these sites represent the flows exiting the basin).

Appendix B presents flow duration curves and hydrographs comparing measured (or synthesised) and modelled flows for the five main flow calibration sites. Also included in the hydrographs are river spot gaugings that would have been used by HBRC to synthesise the flow time series (where relevant). The measurement error lines displayed on the flow duration curves have been derived from the findings of McMillan *et al.* (2012). This study reports that total uncertainties at the 95% confidence level for stage-flow ratings vary with flow and can be as high as ±100%. Typically, errors range between 50-100% for low flows and 10-40% for higher flows. A value of 30% has therefore been assign as a mid-range value for the measured sites. For synthesised data (such as Tukipo at Ashcott and Mangaonuku u/s Waipawa), the errors further compound. An error band of 50% has been assumed for these sites.

Table 2 compares flow statistics for the different flow sites. A comparison between measured and modelled low flow (7-day MALF) statistics is shown in Figure 6 and the corresponding objective function (and other calibration statistics) are listed in Table 3.

Table 2: Measured and modelled river flow statistics for the five main river flow sites

Data set	Time period	Tukituki at Tapairu Rd		Waipawa at RDS/SH2		Tukipo at SH50		Tukipo at Ashcott Road		Mangaonuku u/s of SH50	
		Avg. (m^3/s)	7-day MALF (m^3/s)	Avg. (m^3/s)	7-day MALF (m3/s)	Avg. (m^3/s)	7-day MALF (m3/s)	Avg. (m^3/s)	7-day MALF (m3/s)	Avg. (m^3/s)	7-day MALF (m3/s)
Measured	April 1987-June 2012	15.30	2.64	15.26	2.93	1.53	0.17	-	-	-	-
Synthesised		-	-	-	-	-	-	8.16	1.01	7.02	0.93
Modelled No Irrigation		17.44	2.67	15.06	3.24	1.30	0.16	8.54	1.10	6.47	1.03
Modelled Status Quo		17.24	2.25	14.56	2.82	1.30	0.15	8.52	1.06	6.34	0.80
Modelled difference to measured (or synthesised)		+1.9 - +2.1 (+13% - +14%)	-0.4 - +0.03 (-15% - +1%)	-0.2 - -0.7 (-1% - -5%)	-0.11 - +0.3 (-4% - +10%)	-0.2 (-15%)	-0.02 - +0.02 (-6% - -11%)	+0.36 - +0.39 (+4% - +5%)	+0.05 - +0.09 (+5% - +9%)	-0.5 - -0.7 (-1% - -5%)	-0.13 - +0.1 (-14% - +11%)
Modelled No Irrigation	1972-2012	17.91	2.63	15.55	3.23	1.35	0.13	8.85	1.07	6.78	1.04
Modelled Status Quo		17.71	2.18	15.05	2.80	1.34	0.13	8.82	1.02	6.65	0.80

Figure 5: Location of river flow calibration sites

Modelled river flows are consistent with measured (or synthesised) flows for all five sites. However, larger percentage errors are calculated for the smaller rivers due to the relatively small magnitude of flows. Less weight should be given to the sites with synthesised data.

Average flows are also heavily influenced by the higher flows flowing into the basin from the upper catchment. These higher river flows are difficult to synthesise, and flow synthesis has focused on the low flows (as discussed in Section 2). This contributes to the discrepancies in average flows noted in Table 2 but has little influence on the modelled response during low-flow periods.

Considering the 7-day MALF river flow objective function (and other calibration statistic) values presented in Table 3, and allowing for the fact that calibration data for two of the five sites is synthesised, the model is suitably calibrated to low flows.

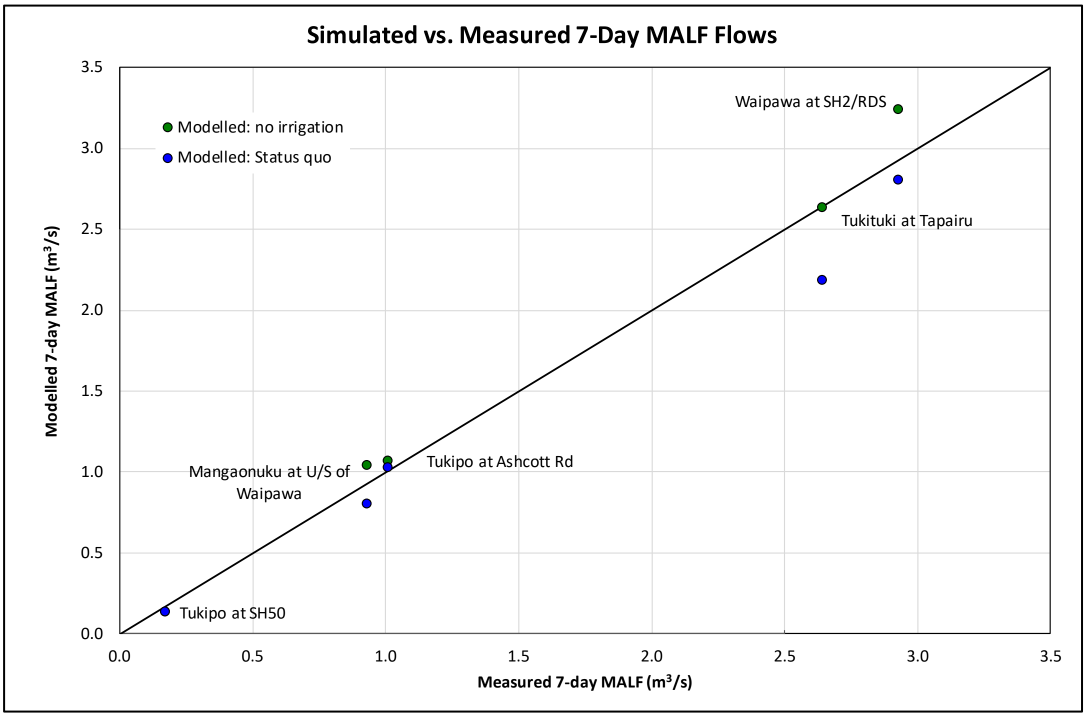


Figure 6: Modelled versus measured 7-day MALF river flows

Table 3: 7-Day MALF river flow objective function values and other statistics for the calibrated model over the full simulation period (1972-2012)

Objective function or statistic	Scenario		Definition
	No irrigation	Status quo	
Mean error (ME) (m^3/s)	0.31	0.13	Average difference between modelled and measured (or synthesised) 7-Day MALF river flow.
Maximum absolute residual (m^3/s)	0.30	0.40	Maximum difference between modelled and measured (or synthesised) 7-Day MALF river flow.
Minimum absolute residual (m^3/s)	0.02	0.02	Minimum difference between modelled and measured (or synthesised) 7-Day MALF river flow.
Root mean square error (RMSE) (m^3/s)	0.15	0.23	Classical measure of error.
Normalised RMSE	5.3%	8.2%	RMSE normalised by the amount that the measured values vary during the simulation period.
R^2 (square of the correlation coefficient)	0.98	0.96	Correlation between measured and modelled values.

2.1.3 Calibration to Gaugings Sites and Patterns of Gaining and Losing Reaches

HBRC have provided individual simultaneous gauging records at 35 sites spread across the Ruataniwha basin spanning the period 1952-2020. The locations of these sites are shown in Figure 7. Modelled flows at these sites have been calibrated to the available data (excluding sites that are used as 'inflows' along the inland model boundary). A comparison of modelled and measured flows is provided in Appendix C. Due to the sporadic nature of the measured data, flow statistics have not been generated for the data with which to compare to the modelled equivalent.

Within the period of data exists a set of 7 simultaneous gauging surveys where all sites within the catchment were measured on the same day. These dates are:

- 17/12/2008
- 21/01/2009
- 04/02/2009
- 04/03/2009
- 18/03/2009
- 01/04/2009
- 24/06/2009

As the majority of these surveys occur during the dry (low flow) summer period when the model's calibration to river flows was targeted, and simultaneously cover all sites in the basin, these dates represent the best data sets to compare to the model. The average flow gains (or losses) over these seven dates have been compared to the average model gains (or losses) over the same seven dates. These comparisons are listed in Table 4 and are plotted in Figure 8 for the 'Status Quo' scenario (which best represents the level of irrigation development at the time of measurements, discussed in Section 3.2).

There is scatter in the comparison, which is expected for any model. However, the model sufficiently replicates the patterns of flow differences, particularly during the drier (low flow) periods plotted towards the centre of Figure 8. Some of the differences may stem from short timing offsets between the instantaneous measured values and daily-averaged modelled values.

Appendix D presents a map of river gaining and losing reaches for the steady state (average) model. This demonstrates where typically rivers gain water from groundwater (gaining reaches) and where the lose to groundwater (losing reaches). This pattern can change over time, and therefore flow differences from the transient model have been compared with measured differences where this data is available. The flow differences between measurement sites include flow gains and losses as a result of interactions with groundwater (the combined result of river bed conductance and relative water levels) and river inflow from, and outflows to, tributary reaches.

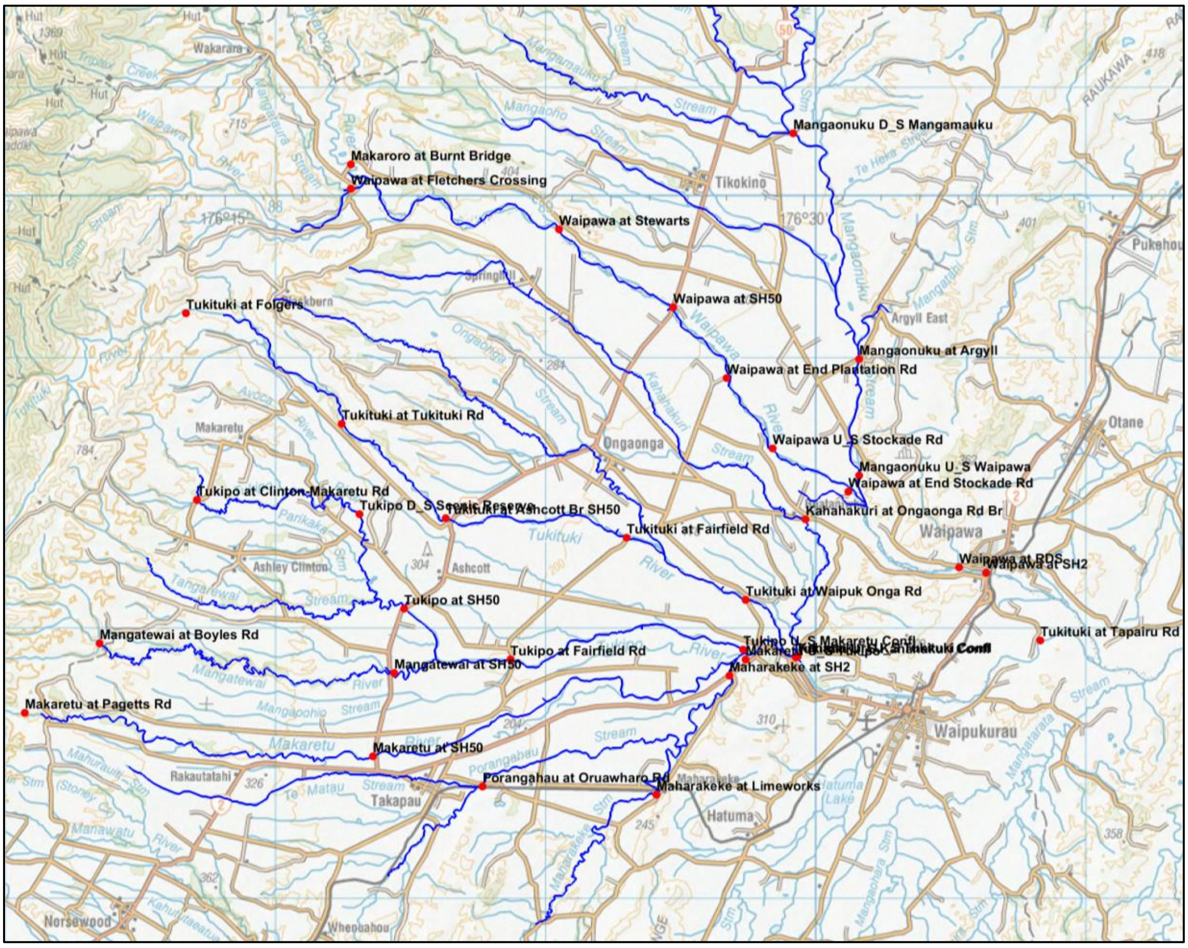


Figure 7: Location of river flow individual gauging sites

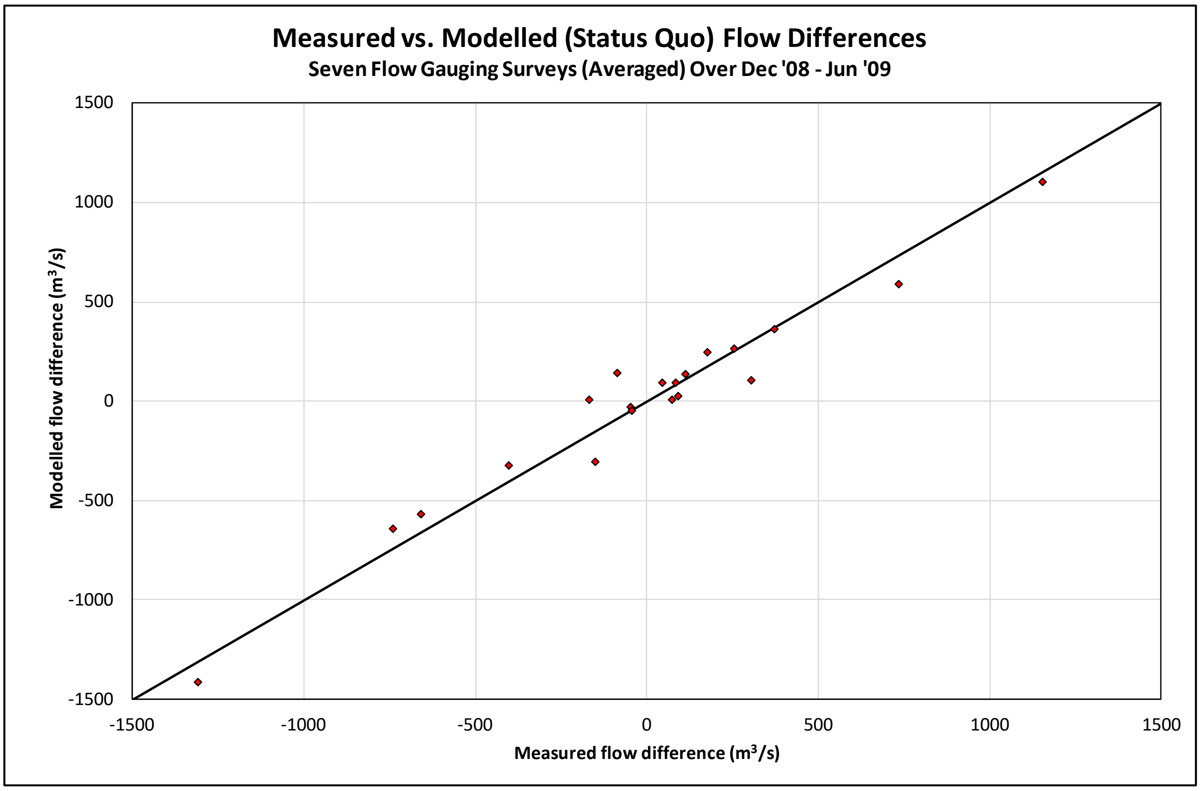


Figure 8: Measured versus modelled river flow differences

Table 4: Measured and modelled river flow differences over the period December 2008-June 2009 for the 'Status Quo' scenario

River	Sites	Flow difference (l/s)		Comment
		Measured	Modelled (status quo)	
Mangaonuku Stream	Between D/S Mangamauku and Argyle	305	108	Several tributaries, some not modelled
Mangaonuku Stream	Between Argyle and U/S Waipawa	1,153	1,105	
Waipawa River	Between Fletchers + Makaroro at Burnt Brigs, and Stewarts	-152	-305	Includes two tributaries
Waipawa River	Between Stewarts and SH50	114	135	
Waipawa River	Between SH50 and End Plantation Rd	-1,310	-1,414	
Waipawa River	Between End Plantation Rd and U/S Stockade Rd	-742	-639	
Waipawa River	Between U/S Stockade Rd and Stockade Rd	372	363	
Kahahakuri Stream	Between Ongaonga Rd Br and U/S Tukituki Confl	737	592	
Tukituki River	Between Folgers and Tukituki Rd	-46	-31	
Tukituki River	Between Tukituki Rd and Ashcott/SH50	83	92	
Tukituki River	Between Ashcott/SH50 and Fairfield Rd	-660	-568	
Tukituki River	Between Fairfield Rd and Onga Rd	-403	-323	
Tukipo River	Between Clinton-Makaretu Rd and Scenic Reserve	93	28	
Tukipo River	Between Scenic Reserve and SH50	254	265	
Tukipo River	Between SH50 + Mangatewai at SH50 and Farfield Rd	-45	-47	Includes two tributaries
Tukipo River	Between Farfield Rd and U/S Makaretu Confluence	178	245	
Mangatewai Stream	Between Boyles Rd and SH50	73	5	
Makaretu Stream	Between Ragetts Rd and SH50	-169	8	
Makaretu Stream	Between SH50 + Maharakeke at SH2 and U/S Tukipo	-86	141	Several tributaries
Maharakeke Stream	Between Limeworks + Porangaha at Oruawharo Rd and State Highway 2 Br	46	91	Several tributaries

2.2 Calibrated Model Parameters

Aquifer horizontal conductivity, vertical conductivity and specific storage were assigned by interpolating between a series of points (called 'pilot points'). This resulted in spatially variable properties. Where available, aquifer test values were assigned individual fixed pilot points. Additional pilot points were then added between these values and varied throughout model calibration. River bed parameters were assigned as single values for each of 27 specific river reaches assigned throughout the model.

Specific storage (defined as the aquifer storage divided by the saturated thickness) for layer 1 was assigned separately to layers 2 and below to simulate the different hydraulic response of shallow unconfined/semi-confined aquifers compared to the deeper more confined layers.

Maps of horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storages (for both layer 1 and also layers 2 and below) and river bed conductivities are shown in Appendix E.

Subsurface flows under the two rivers at the outlets of the basin are relatively unknown but are expected to be small in comparison to river flows. The magnitude of these flows has been estimated by multiplying the groundwater gradient at these locations (based on nearby measured groundwater levels) with nearby aquifer transmissivities (reported by PDP, 2018), given the width of the groundwater opening. This yielded a total flow of approximately 0.06 m^3/s combined through the two subsurface outlets. This equates to less than 0.2% of the average measured river flow.

The conductances of the general head boundaries at these outlets were adjusted so that the modelled subsurface flows over these boundaries approximately equalled the estimated flows.

2.3 Model Flow Budgets

As noted in Section 2.1.1, both 'No Irrigation' and 'Status Quo' scenarios were used for model calibration. Average groundwater flow budgets (derived from the transient models) for each of these scenarios is shown in Table 5.

Table 5: Long-term (average) groundwater balances

Flow (m^3/s)	Storage	Recharge	Streams	Pumping	General heads	Total
No Irrigation						
Inflows	5.5	3.8	4.9	-	0	14.2
Outflows	5.4	-	8.8	-	0	14.2
Inflow-outflow	0.1	3.8	-3.9	-	0	0
Status Quo						
Inflows	6.0	3.9	5.1	-	0	15.0
Outflows	5.9	-	8.3	0.8	0	15.0
Inflow-outflow	0.1	3.9	-3.2	-0.8	0	0

The increased groundwater abstraction as a result of the proposed Tranche 2 irrigation and augmentation takes is rebalanced by both an increase in recharge from rivers (along their losing reaches) and a reduction of discharge to rivers (along their gaining reaches). The additional recharge from the increased irrigated areas is relatively small. Hence, the effects of pumping are largely rebalanced by changes in river gains and losses and by changes in aquifer storage.

From the transient models, model flow balance errors are less than 1% for all time steps and average approximately 0.2% over the full 40 year simulation. This implies that the model has sufficiently accurately accounted for all water movements.

2.4 Parameter Sensitivities

A sensitivity analysis of a model determines which parameters are most important for model calibration and therefore for determining aquifer behaviour. This in turn provides focus for additional field investigations and monitoring. A sensitivity analysis for the Ruataniwha Basin model has been generated by PEST (Doherty, 2021). PEST uses the following objective function (Φ) to consider the sensitivity of various model parameters:

$$\Phi = \sum_{i=1}^{n} [w\ (H_i - h_i)\ ]^2 \qquad (1)$$

Where: H_i = measured groundwater level

h_i = calculated groundwater level

w = observation weight

n = the total number of observations

The objective function is a measure of how well the modelled values compare to measurements. In brief, PEST determines how the objective function varies relative to changes in model parameters. If the objective function changes significantly with small changes in a particular parameter, then model predictions overall are considered to be sensitive to that parameter. Similarly, if the objective function does not change significantly with large changes in a particular parameter, then model predictions are considered overall to be relatively insensitive to that parameter.

Figure 9 provides a summary of the sensitivities of the single value (block) model parameters. Sensitivity maps for all pilot points are provided in Appendix F.

Considering the single-value parameters, most contribute to model calibration, except for the bed conductivity of the upper Maharakeke River. Considering the Kh pilot point sensitivities presented in Appendix F, overall model calibration is sensitive to most of the points located centrally and to the south of the study areas. This is likely because there is good coverage of monitoring bores in these areas. There are fewer observation bores located to the north and therefore parameter sensitivities are lower in this area. Model calibration is generally less sensitive to parameters located near the outlet of the basin as this is where water is forced to the surface regardless of the aquifer parameters. This is logical.

The sensitivities of Kv parameters are more variable, but tend to be less sensitive towards the basin outlet and more so in the inland areas. Again this is logical. There are no obvious spatial patterns in the sensitivity of storage parameters for either the shallow or deep layers.

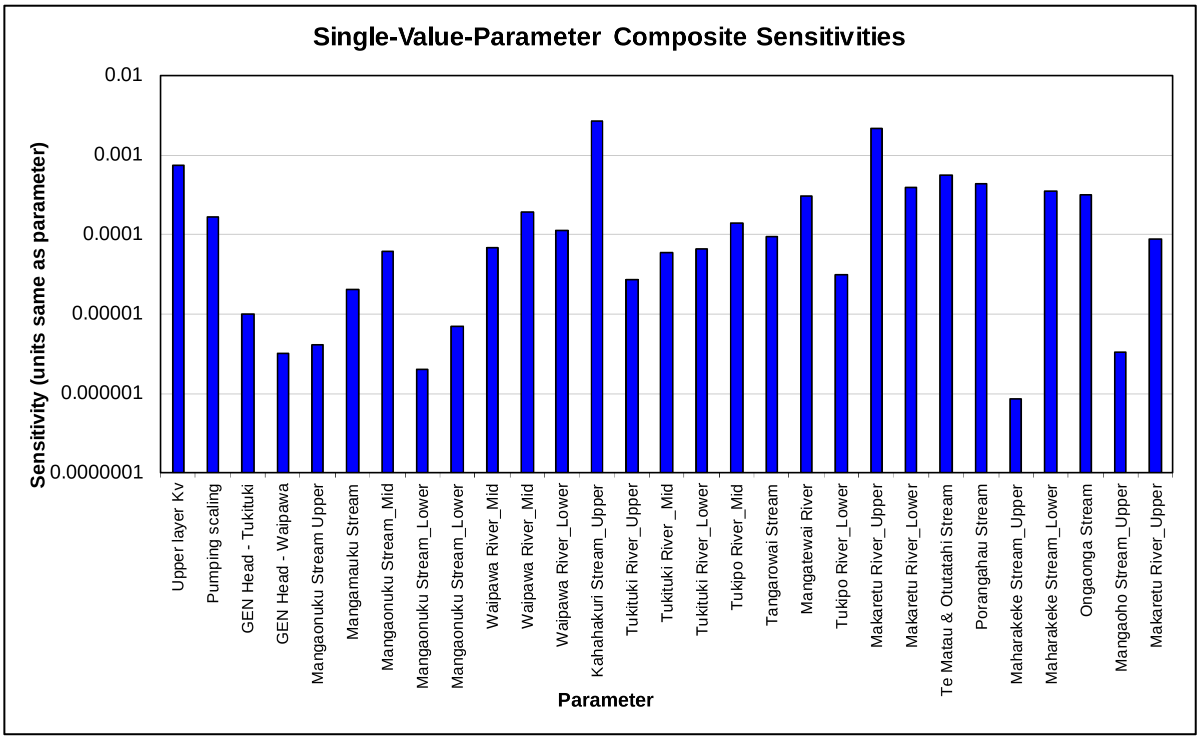


Figure 9: Sensitivities for single-value parameters

Manual parameter sensitivity scenarios have also been conducted to ascertain how the predicted responses in river flows change due to the proposed Tranche 2 activities under different parameter sets. These sensitivity scenarios are discussed in Section 3.16.

2.5 Predictive Uncertainty Analyses

Modern groundwater modelling techniques often include an assessment of predictive uncertainty. It is helpful to consider the uncertainty and parameter sensitivities associated with the model predictions in context of the water management decisions being made. However, uncertainty analyses should not be treated as a substitute for robust model construction. When taken to an extreme, uncertainty results can confuse decision makers by muddying the information needed to make key decisions (uncertainty analyses are themselves often uncertain), particularly given the subjective nature of some of the inputs to the uncertainty assessments. Comprehensive predictive uncertainty techniques also take a long time to generate and require substantial computing power. A balance is therefore needed between theory and practical application.

The Ruataniwha basin groundwater model has been developed thoroughly over many years and is a sound simulator of past response (particularly low river flows). Furthermore, using the model to predict *changes* in river flows (rather than absolute values) removes much of the model uncertainty (differences between measured and modelled *absolute* values are removed, leaving behind the much smaller differences between the scenarios being compared).

However, simple predictive uncertainty analyses have been completed on the transient (status quo) model to provide an approximate scale of the uncertainty expected from the predictions of absolute groundwater levels and river flows during dry periods.

The uncertainty in model predictions can be estimated as a function of:

1. The estimated parameter variability prior to calibration; and
2. The reduction in this parameter variability achieved by calibrating to measured data.

Prior estimates of the uncertainty of the calibration parameters were estimated based on the variability of the calibrated values (which includes measured data). The standard deviations applied are as follows:

- For locations with test data: 20% of the test value
- For locations without test data: 50% of the calibrated value

Uncertainty in the rate of groundwater abstraction has been accommodated by a universal scaling factor applied to all groundwater takes. This maintains the modelled *timing* of abstraction but scales the *magnitude* of the rate of take. The status quo scenario includes full development of existing irrigation (discussed in Section 3.2). Based on recent monitoring data presented in Figure 1 of HBRC (2022), historical peak actual groundwater use was approximately 80% of the total allocation volume (this occurred in 2019/20 season). Therefore, actual groundwater abstraction is likely to be lower than modelled for most years. To accommodate this in the uncertainty analyses, the scaling factor for groundwater abstraction has been allowed to vary within the range 0.80-1.05. The upper limit has been set at 5% higher than the modelled maximum to allow for measurement error.

Using these estimates of prior parameter variance, the scaling of groundwater abstraction, the model residuals, and the calculated model sensitivities, estimates of the relative reduction in predictive uncertainty achieved through calibration were derived using a linear parameter uncertainty assessment provided by the suite of utilities within the 'GENLINPRED' tool by Doherty (2021). Due to limitations with the GMS (2022) software, a full suite of uncertainty analyses was difficult to achieve and required scripting to further incorporate uncertainties in modelled river flows (in addition to groundwater levels). However, this has been completed.

Given the more uncertain nature of river sites with synthesised flows, these measurements have been given a lower measurement confidence (and therefore a lower weighting) than sites with measured data.

As can be observed in Figure 3, some of the inland areas of the model domain do not have nearby observation bores with which to tightly 'tie-down' model calibration in these areas. The uncertainty in these areas is therefore greater than elsewhere. To quantify this, seven additional 'dummy' observation bores (with no observed data) have been added to the model (in the shallow aquifer) for the uncertainty analyses. The locations of these dummy bores is shown in Figure 10 along with the original observation bores used for calibration.

Results of relative observation uncertainty reductions from the linear uncertainty analyses are depicted in Figure 11 for low groundwater levels and in Figure 12 for low river flows. The first graph in Figure 12 presents the uncertainty reduction for HBRC's five river flow restriction sites, and the second graph presents the equivalent results for 22 of the sites shown in Figure 7 (excluding 'inflow' sites along the inland model boundary).

All measurements experience a moderate or significant reduction in uncertainty as a result of calibration, with most sites notably improved. Those measurements that were most sensitive to parameter variations incurred the greatest reduction in uncertainty via the calibration process (i.e. those with very low post-calibration uncertainty). In contrast, those observations that were least sensitive still reduced overall predictive uncertainty, but not as large a proportion as the more sensitive observations. The observations that experienced the least reductions in predictive uncertainty were typically the dummy observation bores and also those bores that had a low pre-calibration uncertainty. Regardless, all observations have contributed to reducing the calibration uncertainty, some significantly.

The linear uncertainty assessment generates prediction standard deviations as a measure of uncertainty. As noted in Table 6, the post-calibration prediction standard deviations for low groundwater levels range between 0.07-1.5 m (with an average of approximately 0.4 m). This equates to 0.03-0.8% of the absolute values. For low river flows at the five low-flow restriction sites listed in Table 7, the post-calibration standard deviation ranges between approximately 0.001-0.008 m^3/s (with an average of approximately 0.004 m^3/s). This equates to approximately 0.2-0.7% of the absolute values (with an average of 0.3%). Similarly from Table 7 for the gauging sites, the post-calibration standard deviation ranges between approximately zero and 0.01 m^3/s (with an average of approximately 0.001 m^3/s). This equates to approximately 0.1-5.2% of the absolute values (with an average of 1.1%).

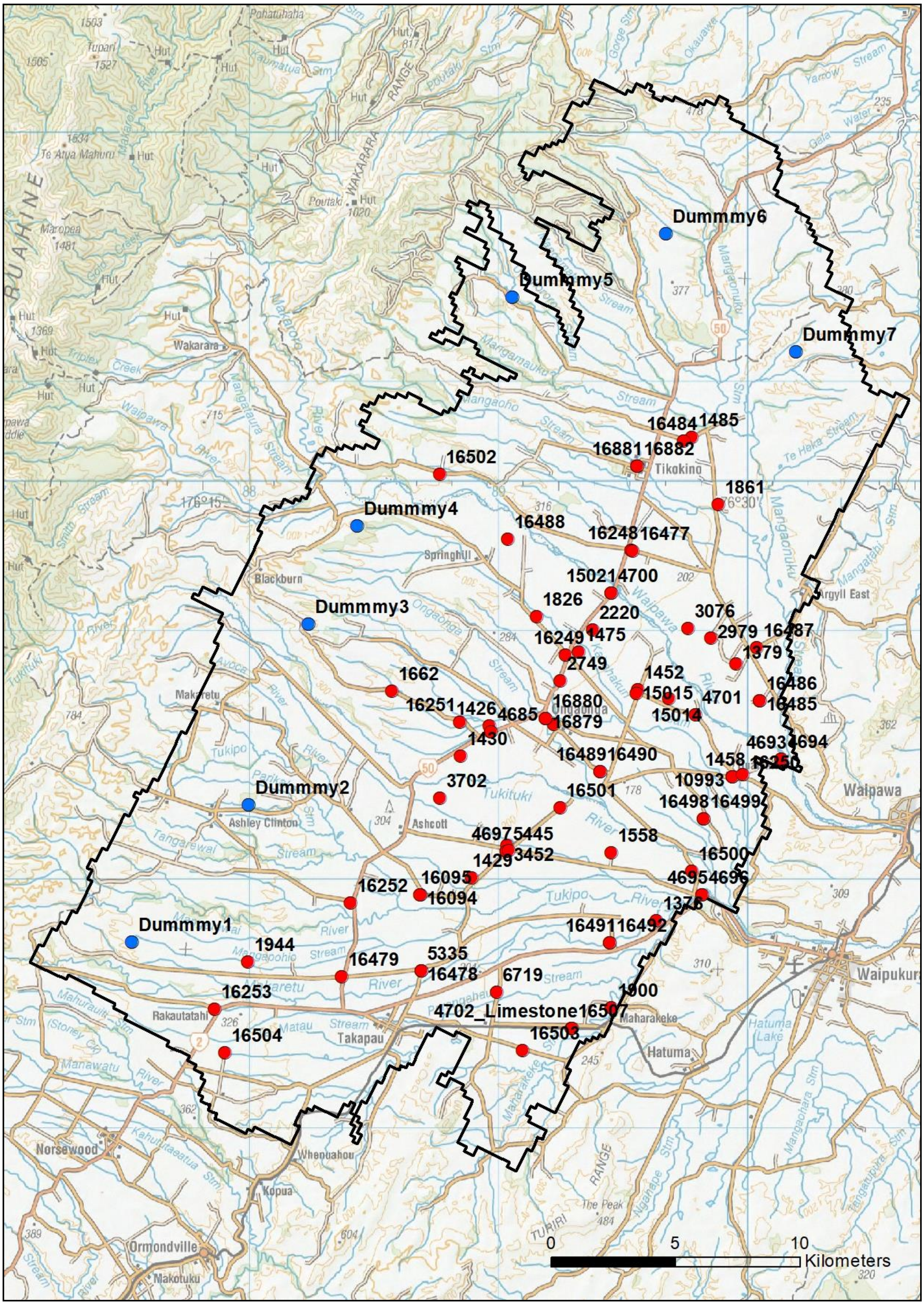
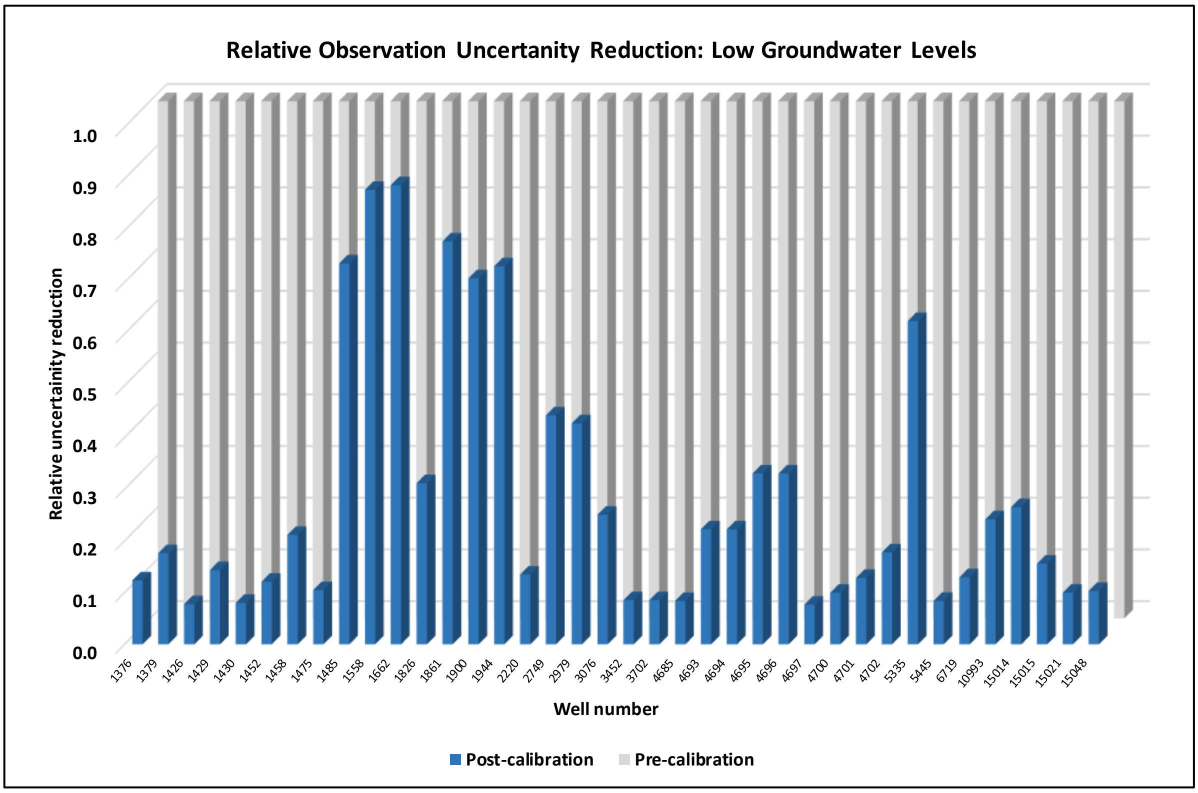


Figure 10: Location of observation and dummy bores used for groundwater level uncertainty analyses



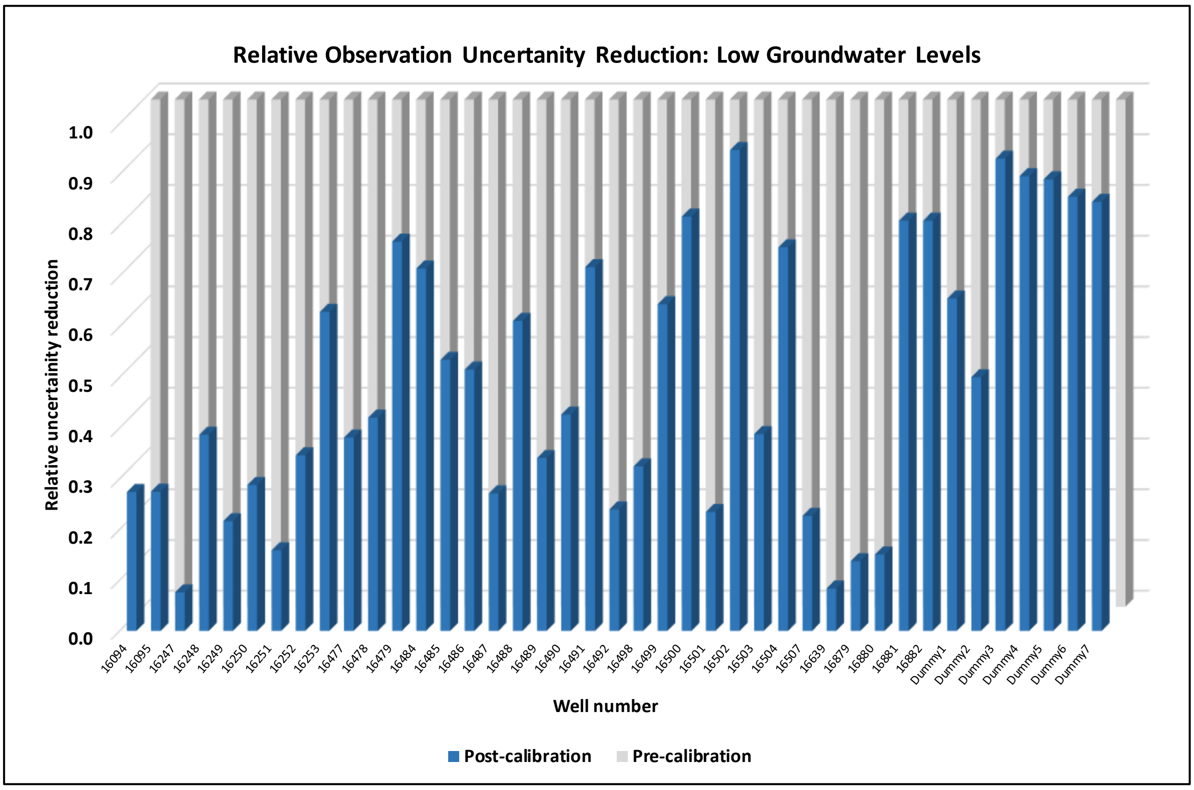
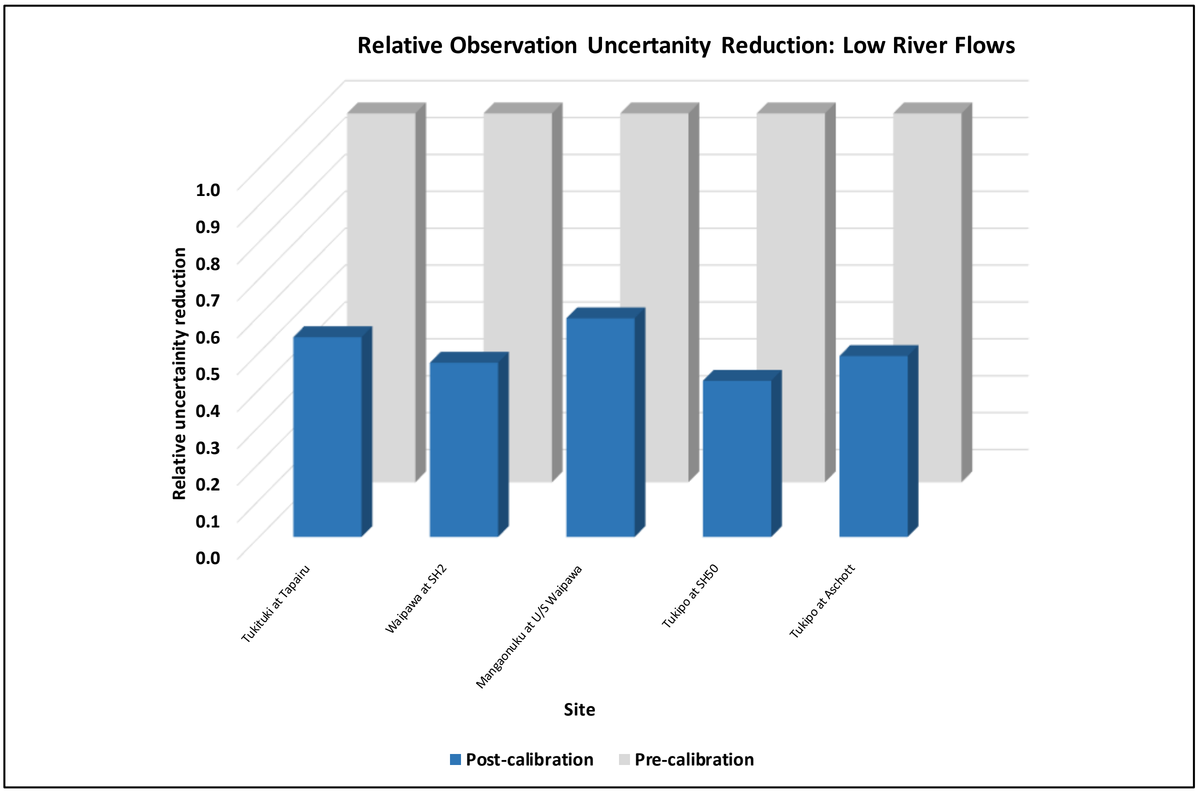


Figure 11: Relative observation uncertainty reduction for measured groundwater levels



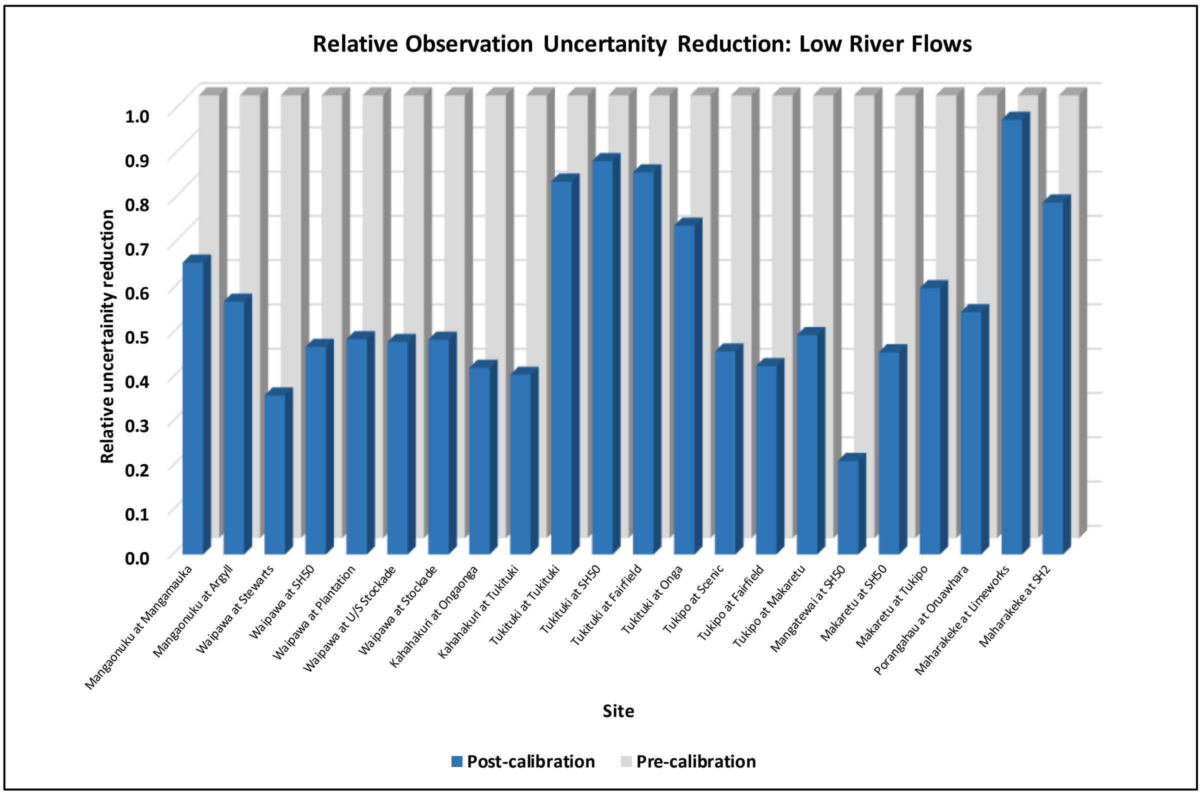


Figure 12: Relative observation uncertainty reduction for river flows

Table 6: Contribution to total predictive uncertainty for groundwater levels

Bore	Post- calibration standard deviation (m of total head)
1376	0.18
1379	0.24
1426	0.20
1429	0.36
1430	0.23
1452	0.19
1458	0.13
1475	0.19
1485	1.14
1558	0.08
1662	0.07
1826	0.26
1861	1.38
1900	1.36
1944	0.26
2220	0.15
2749	0.72
2979	0.53
3076	0.18
3452	0.19
3702	0.26
4685	0.21
4693	0.11
4694	0.11
4695	0.11
4696	0.11
4697	0.19
4700	0.12
4701	0.16
4702	0.18
5335	0.15
5445	0.19
6719	0.31
10993	0.13
15014	0.38
15015	0.25
15021	0.12

Bore	Post- calibration standard deviation (m of total head)
15048	0.18
16094	0.80
16095	0.80
16247	0.19
16248	0.60
16249	0.37
16250	0.17
16251	0.39
16252	1.52
16253	0.28
16477	0.59
16478	1.31
16479	0.24
16484	0.75
16485	0.27
16486	0.37
16487	0.39
16488	0.54
16489	0.42
16490	0.52
16491	1.47
16492	0.28
16498	0.33
16499	0.35
16500	0.50
16501	0.39
16502	0.24
16503	0.68
16504	0.24
16507	0.28
16639	0.21
16879	0.24
16880	0.28
16881	1.09
16882	1.09

Bore	Post- calibration standard deviation (m of total head)
Dummy1	0.68
Dummy2	0.10
Dummy3	0.26
Dummy4	0.17
Dummy5	0.25
Dummy6	0.27
Dummy7	0.15

Table 7: Contribution to total predictive uncertainty for river flows

Site	7-Day MALF (m^3/s)		Post-calibration standard deviation m^3/s	Contribution to uncertainty						
	Value	Measured or modelled		Kh	Kv	Ss deep	Ss shallow	Pumping	River bed Kv	GEN heads
HBRC's low-flow restriction sites										
Waipawa at SH2	2.93	Measured	0.006	53%	9%	2%	2%	0%	34%	0%
Tukituki at Tapairu Rd	2.64	Measured	0.008	47%	14%	1%	1%	3%	35%	0%
Tukipo at SH50	0.17	Measured	0.001	18%	3%	0%	1%	0%	77%	0%
Tukipo at Ashcott Rd	1.01	Synthesised	0.002	1%	0%	0%	0%	0%	98%	0%
Mangaonuku u/s Waipawa	0.93	Synthesised	0.003	24%	2%	1%	2%	2%	70%	0%
Gauging sites (located in Figure 7, excluding 'inflow' sites along the inland model boundary)										
Mangaonuku d/s Mangamauku	0.02	Modelled	~ 0	14%	1%	0%	1%	1%	82%	0%
Mangaonuku at Argyll	0.07	Modelled	0.001	14%	2%	0%	2%	0%	81%	0%
Waipawa at Stewarts	0.82	Modelled	0.001	79%	7%	1%	2%	6%	6%	0%
Waipawa at SH50	0.20	Modelled	0.001	49%	6%	2%	1%	3%	40%	0%
Waipawa at End Plantation Rd	0.09	Modelled	0.001	49%	7%	1%	1%	4%	38%	0%
Waipawa u/s Stockade Rd	0.02	Modelled	~ 0	50%	8%	1%	1%	3%	37%	0%
Waipawa at End Stockade Rd	0.01	Modelled	~ 0	49%	8%	1%	1%	4%	37%	0%
Kahahakuri at Ongaonga Rd	0.11	Modelled	0.003	29%	7%	0%	0%	0%	64%	0%
Kahahakuri u/s Tukituki confl.	0.65	Modelled	0.01	23%	8%	1%	1%	0%	68%	0%
Tukituki at Tukituki Rd	0.12	Modelled	~ 0	3%	0%	0%	1%	3%	92%	0%
Tukituki at SH50	0.10	Modelled	~ 0	2%	0%	0%	3%	0%	94%	0%
Tukituki at Fairfield Rd	0.02	Modelled	~ 0	3%	0%	0%	4%	0%	93%	0%
Tukituki at Waipuk-Onga Rd	0.02	Modelled	~ 0	5%	1%	0%	1%	0%	93%	0%
Tukipo d/s Scenic Reserve	0.04	Modelled	~ 0	2%	0%	0%	0%	0%	98%	0%
Tukipo at Fairfield Rd	0.24	Modelled	0.001	1%	0%	0%	0%	0%	99%	0%
Tukipo u/s Makaretu confl.	0.57	Modelled	0.002	25%	1%	1%	1%	0%	71%	0%
Mangatewai at SH50	0.01	Modelled	0.005	88%	4%	0%	0%	3%	5%	0%
Makaretu at SH50	0.01	Modelled	0.005	4%	0%	0%	2%	0%	93%	0%
Makaretu u/s Tukipo	0.48	Modelled	0.002	25%	2%	0%	2%	5%	66%	0%
Porangahau at Oruawharo Rd	0.02	Modelled	~ 0	1%	0%	0%	0%	0%	99%	0%
Maharakeke at Limeworks	0.08	Modelled	~ 0	20%	1%	0%	1%	4%	74%	0%
Maharakeke at SH2	0.16	Modelled	0.001	25%	4%	0%	3%	6%	63%	0%

The observation standard deviations can be used to assign 95% confidence intervals around the model predictions, where two standard deviations accommodate approximately 95% of the predictive uncertainty (or in other words where almost all of the predictions are expected to fall). In all cases, the 95% confidence intervals are very narrow indicating that uncertainty in the predictions is small.

The GENLINPRED suite of utilities provided by Doherty (2021) also calculates the contribution of specific parameters to total predictive uncertainty at specific sites. The relative contribution to total uncertainty from the various parameter groups for all river flow sites are listed in Table 7. These results demonstrate that the majority of predictive uncertainty associated with river flows is associated with horizontal hydraulic conductivity (Kh) and river bed conductance.

Similar results for individual groundwater level observations are too numerous to reproduce here, but are heavily dominated by the aquifer horizontal conductivity (71% on average) followed by aquifer vertical hydraulic conductivity (13% on average). River bed conductivity accounts for approximately 7% of the predictive uncertainty, deeper layer storage approximately 5% and shallow layer storage approximately 3%.

It is worth another reminder that the model has been used to predict the *change* in groundwater levels and river flows as a result of the proposed Tranche 2 activities. As noted in Section 1, by using the model to predict the change (rather than absolute values), then the model's predictive uncertainty is largely eliminated, particularly so given the relatively low uncertainty values reported. The predictive uncertainty associated with modelled changes is discussed in Section 3.17.

3 SCENARIOS

The calibrated flow model has been used to run multiple scenarios of future takes to quantify the net change in river flows. The following scenarios have been simulated:

- Status quo: This includes all existing takes, but no proposed Tranche 2 activities.
- Scenarios 1-8: One model run for each of the eight proposed Tranche 2 applicants. These models are all founded on the 'Status Quo' scenario, but with each applicant's proposed full irrigation needs at their proposed location. The results of these scenarios (compared to status quo) have then been used to determine the timing of the augmentation requirement (for mitigating stream depletion effects of the irrigation take alone) that would feed into subsequent augmentation scenarios.
- Augmentation Scenarios: Initially, a combined model scenario including all applicants' takes and with each applicant's augmentation operating. Then additional scenarios that balance environmental flows and irrigated areas.

Further details of these scenarios are provided below along with a brief discussion on each applicant's proposed activity and their water use. An overview of the applicants' farm locations, augmentation locations and key flow monitoring sites is provided in Figure 13.

Each of these model scenarios commence with initial groundwater levels set from outputs of a steady state model of the equivalent scenario (using long-term average inputs). Therefore, the effects of the proposed activities are included in the model right from the beginning of the transient scenario. Each transient scenario also runs continuously (with daily stress periods) over the 40-year simulation period, and therefore any residual effect from one year to the next will be automatically included in the results.

3.1 Scenario Modelling and Augmentation Rationale

When the Tranche 2 applications were lodged, it was unclear how the Tukituki PC6 provisions should be interpreted and implemented. The reason being that the Tranche 2 regime was developed by the Tukituki Board of Inquiry and not by HBRC. For example, it was unclear whether or not the effects of the deep groundwater augmentation abstractions on surface flows would themselves need to be offset by further augmentation, and so on. Some applicants (including Te Awahohonu Forest Trust and Springhill Dairies) assumed that would be the case while others did not.

Consequently, the approach taken here is to focus on the total amount of Tranche 2 water sought by each applicant and the total irrigable area applied for.

Irrigation demand is then calculated for the irrigable areas applied for using Aqualinc's soil-water balance model, IrriCalc, assuming the water supply is unrestricted. From these calculations, the 90 percentile (or 9 in 10 years) irrigation demand has been calculated, assuming full development of each property. Once the irrigation demand is calculated, then the irrigation volume is deducted from the total volume applied for to yield a volume of water available for augmentation. Various scenarios are then modelled to assess the effects of each applicants' take (singularly and in combination with all other applicants) and the optimum timing for the commencement and duration of the augmentation takes. Consequently, the division between irrigation and augmentation use varies depending on the scenarios being modelled, but the total volume of water taken will not exceed that originally applied for. However, in some cases the original irrigable area needed to be reduced to either enable sufficient water to be available for augmentation purposes (e.g. for Papawai Partnership) or to ensure that the total volume of Tranche 2 water available (15 million m^3) was not exceeded (e.g. for Purunui).

The assessments described herein assume that all Tranche 2 irrigation water is used for new irrigation. If only some Tranche 2 water is used to fill in gaps when Tranche 1 water is unavailable, then the overall effects will be less than assessed: less Tranche 2 water will be taken for irrigation and augmentation will remain the same.

3.2 Status Quo Scenario

The 'Status Quo' scenario represents the currently irrigated area of approximately 9,100 ha within the basin. This comprises a combination of surface water-sourced and groundwater-sourced water.

Surface water takes are restricted based on the relevant low flow abstraction rules in HBRC's Regional Resource Management Plan (RRMP). This scenario has been used as a baseline against which other scenarios have been compared to quantify changes in river flows and groundwater levels.

The 'Status Quo' scenario includes an annual average demand of 0.8 m^3/s (Table 5). Assuming this occurs over a typical irrigation season of 150 days with peak on-farm applicant rates of 0.5 l/s/ha, then this rate equates to full irrigation of approximately 3,900 ha from groundwater (with the remaining irrigated area sourced from surface water). However, if a lesser peak application rate is assumed (say by irrigating the same water over a larger area), then a larger irrigated area will be supplied from groundwater. This difference has no implications to the groundwater take. The same annual volume is assumed to be used regardless of the area irrigated.

Dark (2020) presents surveys of irrigated areas for all of New Zealand, mapped in 2020 but with source data relevant to a period spanning 2015-2020 in the Ruataniwha basin. From this work, the total irrigated area (from both groundwater and surface water combined) is approximately 8,800 ha, which is similar to the total irrigated area modelled.

Therefore, the 'Status Quo' scenario includes all existing irrigated areas, and this has been applied retrospectively over the full simulation period 1972-2012. In other words, the most recent irrigated area has been included back in time through all years. This past climate includes some extended and very dry periods (such as the summer of 1997/98). Updated flow data recently supplied by HBRC (Appendix B) suggests that flows in the Tukituki and Waipawa rivers over the summer of 2019/20 were the lowest on record, and the last 9 years (since the end of the model run period) has experienced one or two extreme dry years. However, the likely occurrence of restrictions in any year has not changed significantly. Furthermore, HBRC allocate in a 9 in 10 year event. Therefore, irrigators would likely have had insufficient water to fully irrigate and augment during the one or two years with lowest records post 2011/12 in the Tukituki and Waipawa rivers and would have therefore ceased take or rationed their use throughout the season.

For simplicity, it has been assumed that all existing and future irrigated land use is pasture, which typically has a larger seasonal water demand than other land uses. Irrigation return water is realised as an increase in land surface recharge (compared to dryland).

If land uses other than pasture are applied (e.g. cropping, or mixed pasture and cropping), then the seasonal water use and associated recharge will be less for the same irrigated area, or a larger area could be irrigated for the same seasonal volume. In these cases, the modelled effects on river flows will be either less or similar (respectively) than the assessments presented below.

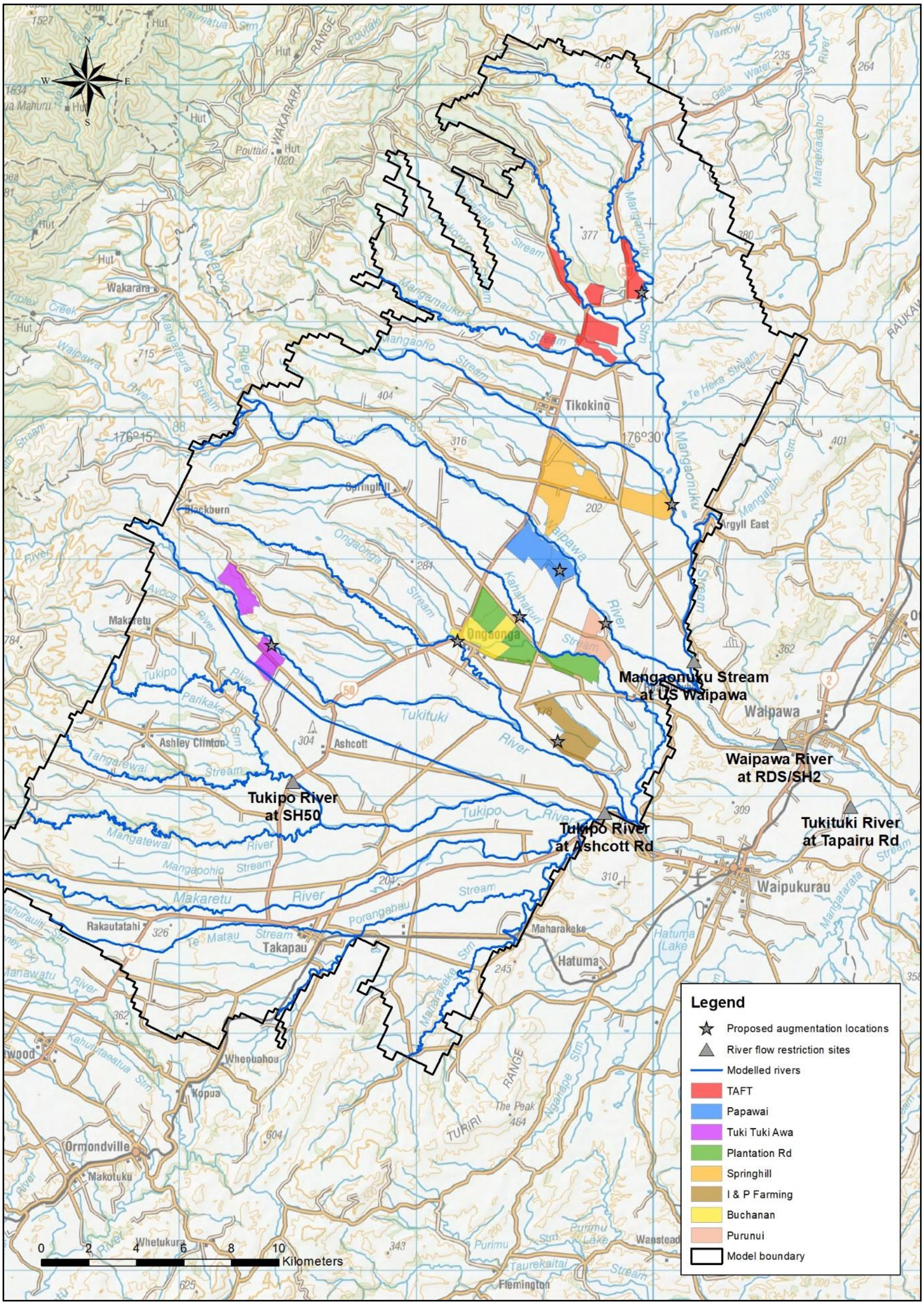


Figure 13: Tranche 2 applicants' farm locations, proposed augmentation discharge locations and key river flow monitoring sites

3.3 Te Awahohonu Forest Trust (TAFT)

Te Awahohonui Forest Trust (TAFT) have applied to take up to **4,914,920 m^3/year** of Tranche 2 groundwater from deep bores located around their Gwavas Station property, Tikokino. The proposed take is intended to irrigate 540 ha of pasture (assumed), or a larger area of less water-intensive crops or horticulture, and provide river augmentation to the Mangaonuku Stream.

The location of the bores (existing and proposed) from which TAFT have proposed to take groundwater, and the approximate locations of the augmentation take bore and the discharge site, are shown in Figure 14.

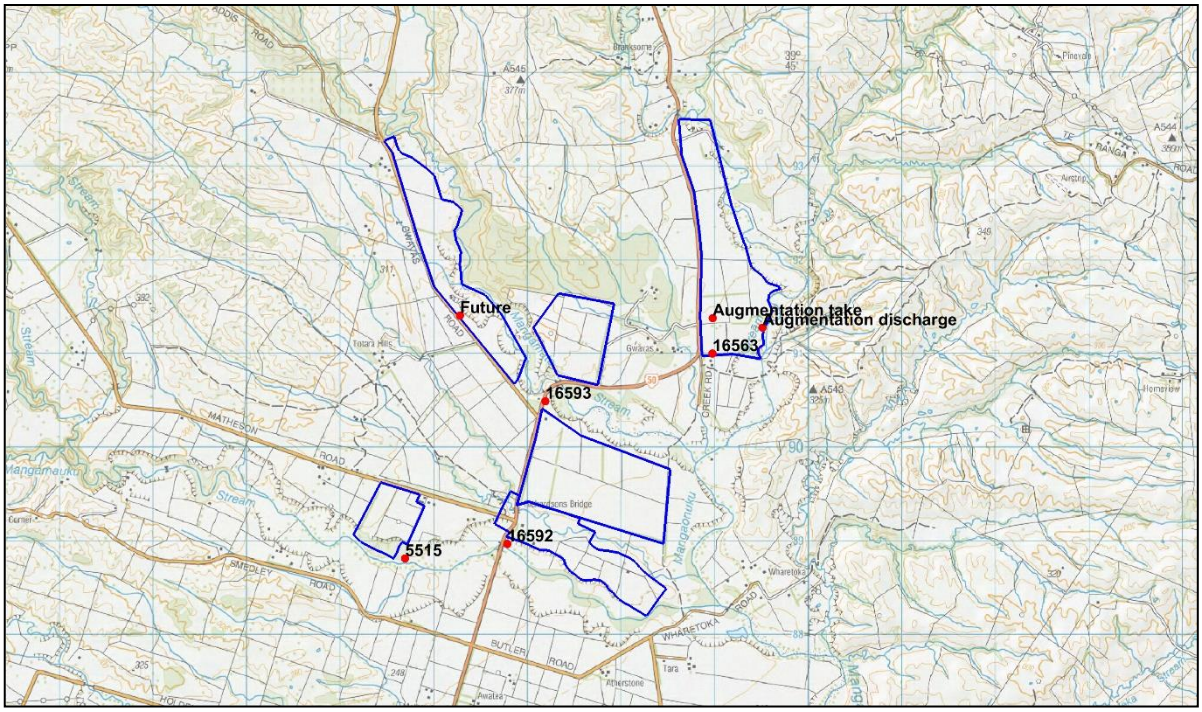


Figure 14: TAFT's proposed bore and augmentation locations (proposed irrigation areas are shown as blue outlines)

Key infrastructure for TAFT's proposed Tranche 2 take are summarised in Table 8.

Table 8: TAFT's proposed Tranche 2 infrastructure

Site	Use and/or status	Current status	Depth (m bgl)	Approx. irrigated area (ha)
Bore 16563	Irrigation	Existing	162.2	130
Bore 16592	Irrigation	Exploratory well	220.8	100
Bore 16593	Irrigation	Exploratory bore	222.3	110
Bore 5515	Irrigation	Existing	66.0	50
Future bore	Irrigation	Proposed	~ 200	150
Augmentation take	Augmentation take	Proposed	~160	-
Augmentation discharge	Discharge to Mangaonuku Stream	Proposed	-	-

3.3.1 Irrigation Demand

Irrigation demand has been modelled using Aqualinc's IrriCalc soil-water balance model. The 90 percentile water demand for pasture is calculated to be approximately 580 mm/year, which over an irrigated area of 540 ha equates to an annual volume of 3.1 million m^3/year.

The IrriCalc modelling provides a daily time series of crop water demand (assuming an unrestricted supply) and resulting daily time series of land surface recharge (LSR). The crop water demand has been modelled from the bores proposed to supply the property, as listed in Table 8, in proportion to the listed irrigated areas. Furthermore, new irrigation results in additional LSR compared to dryland. This has also been incorporated into the model by exchanging previously dryland LSR with irrigated LSR for the proposed irrigated areas shown in Figure 14.

3.3.2 Modelling Results for TAFT

The model has been run with daily outputs generated from 1 July 1972 through to 30 June 2012. Time series of river flows at each of the flow restriction sites shown in Figure 13 have been processed to generate changes in flow statistics due to TAFT's irrigation take alone. Changes in these flow statistics compared to status quo are summarised in Table 9. Although the results are presented to the nearest litre per second, the model's accuracy is not that precise. Therefore, these results represent the approximate scale and direction of effect.

Table 9: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to TAFT's irrigation take alone (no augmentation)

Scenario	Site				
	Waipawa at SH2	Tukituki at Tapairu Rd	Tukipo at SH50	Tukipo at Ashcott Rd	Mangaonuku u/s Waipawa
Change in average flow (l/s)					
TAFT's irrigation take only	-65	-18	0	-2	-32
Change in mean 7-day annual low flow (MALF) (l/s)					
TAFT's irrigation take only	-63	-16	0	-2	-46

From Table 9, irrigation alone (with no augmentation) results in a reduction in river flows throughout much of the basin. The largest changes occur in the Waipawa catchment and tributaries, as this is the catchment within which Gwavas Station is located. However, small scale effects do propagate over to the lower Tukituki catchment and tributaries.

Changes in flows allowing for all Tranche 2 applicants' irrigation takes, augmentation takes and augmentation discharges are presented later.

3.4 Papawai Partnership

Papawai Partnership have submitted two applications to take Tranche 2 groundwater. An original application was submitted to take up to 423,062 m^3/year of groundwater, and a new application has recently been submitted to take up to 1,052,455 m^3/year of groundwater. These combine to a total of **1,475,517 m^3/year** and comprises 1,161,000 m^3/year for irrigation and 314,517 m^3/year for augmentation. The applications seek to take groundwater from an existing deep bore (16508) located on their property, adjacent to the Waipawa River, and provide river augmentation to this river. The irrigation component of the proposed Tranche 2 take will supplement an existing consented take of 608,212 m^3/year to provide adequate irrigation of 320 ha of pasture (assumed) or a larger area of less water-intensive crops or horticulture, from both bores 16508 and 1859 (combined).

Papawai Partnership have proposed to inject the augmentation water into an existing unused shallow bore located approximately 300 m from the Waipawa River. They have advised that they believe this shallow bore is directly connected to the nearby Waipawa River, though this will be confirmed prior to commencing augmentation. For the purpose of augmentation modelling, it will be assumed that the water will be discharge directly into the Waipawa River immediately adjacent to the shallow injection bore. Due to the fast hydraulic response between the Waipawa River and nearby shallow groundwater, this will make little difference to the modelled effects.

The location of existing bore 16508, from which Papawai Partnership have proposed to take the additional Tranche 2 groundwater, and the approximate location of the augmentation discharge site are shown in Figure 15. Also shown is the location of the other irrigation bore 1859.

Key infrastructure for Papawai Partnership's proposed Tranche 2 take are summarised in Table 10.

Table 10: Papawai Partnership's proposed Tranche 2 infrastructure

Site	Use and/or status	Current status	Depth (m bgl)	Approx. irrigated area (ha)
Bore 16508	Irrigation & augmentation take	Existing	119.6	160
Bore 1859	Irrigation	Existing	87.5	160
Augmentation discharge	Discharge to groundwater adjacent to Waipawa River	Existing	Unknown (shallow)	-

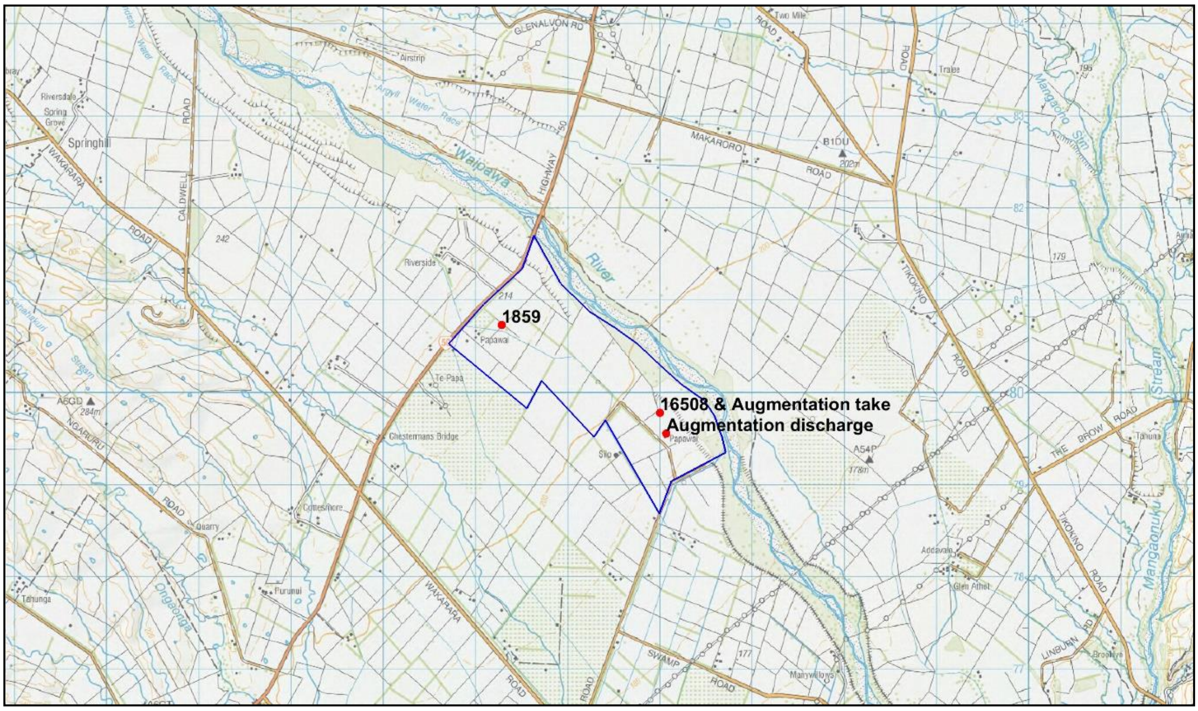


Figure 15: Papawai Partnership's existing bores and proposed and augmentation location (the total irrigated area is shown as a blue outline)

3.4.1 Irrigation Demand

Irrigation demand has been modelled using Aqualinc's IrriCalc soil-water balance model. The 90 percentile water demand for pasture is calculated to be approximately 560 mm/year, which over an irrigated area of 320 ha equates to an annual volume of 1.8 million m^3/year. In combination with their existing consented take, this is consistent with the total volume of water sought by Papawai Partnership. The Tranche 2 groundwater applied for is adequate to irrigate approximately 207 ha of pasture.

The IrriCalc modelling provides a daily time series of crop water demand (assuming an unrestricted supply) and resulting daily time series of land surface recharge (LSR). The Tranche 2 crop water demand has been modelled from bores 1859 and 16508 (listed in Table 10), in proportion to the listed irrigated areas. Furthermore, new irrigation results in additional LSR compared to dryland. This has also been incorporated into the model by exchanging previously dryland LSR with irrigated LSR.

3.4.2 Modelling Results for Papawai Partnership

The model has been run with daily outputs generated from 1 July 1972 through to 30 June 2012. Time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics due to Papawai Partnership's irrigation take alone. Changes in these flow statistics compared to status quo are summarised in Table 11. Although the results are presented to the nearest litre per second, the model's accuracy is not that precise. Therefore, these results represent the approximate scale and direction of effect.

Table 11: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to Papawai Partnership's irrigation take alone (no augmentation)

Scenario	Site				
	Waipawa at SH2	Tukituki at Tapairu Rd	Tukipo at SH50	Tukipo at Ashcott Rd	Mangaonuku u/s Waipawa
Change in average flow (l/s)					
Papawai's irrigation take only	-26	-8	0	-1	-9
Change in mean 7-day annual low flow (MALF) (l/s)					
Papawai's irrigation take only	-18	-8	0	-1	-12

From Table 11, irrigation alone (with no augmentation) results in a reduction in river flows throughout much of the basin. The largest changes occur in the mid-lower Waipawa catchment and tributaries, as this is the catchment within which Papawai Partnership is located. However, small scale effects do propagate over to the lower Tukituki catchment and tributaries.

Changes in flows allowing for all applicants' irrigation takes, augmentation takes and augmentation discharges are presented later.

3.5 Tuki Tuki Awa

Tuki Tuki Awa initially applied to take up to **952,400 m^3/year** of Tranche 2 groundwater from four proposed deep bores located on their southern irrigated property, adjacent to the Tukituki River. The irrigation component of the proposed Tranche 2 take is intended to gap fill and/or replace their existing surface supply for reliable and adequate irrigation of up to 135 ha of pasture (assumed) or a larger area of less water-intensive crops or horticulture.

Tuki Tuki Awa plan to maintain their surface water take and abstract only some of the proposed Tranche 2 groundwater to provide full reliability when their surface water take is on low-flow restrictions. However, the assessment described below has been modelled as though all water is sourced from Tranche 2 groundwater to replace their surface water take. This presents a worst-case scenario of effects. Any other combination of water supply from mixed sources (balancing surface and groundwater supplies) will result in smaller effects on river flows.

Tuki Tuki Awa propose to abstract Tranche 2 augmentation water from a series of new bores planned on their southern block, and discharge this directly into the Tukituki River adjacent to the block. The approximate location of the proposed new irrigation bores on the southern block, the proposed new augmentation abstraction bore, and the approximate location of the augmentation discharge site are shown in Figure 16. It is not proposed to irrigate the northern run-off block.

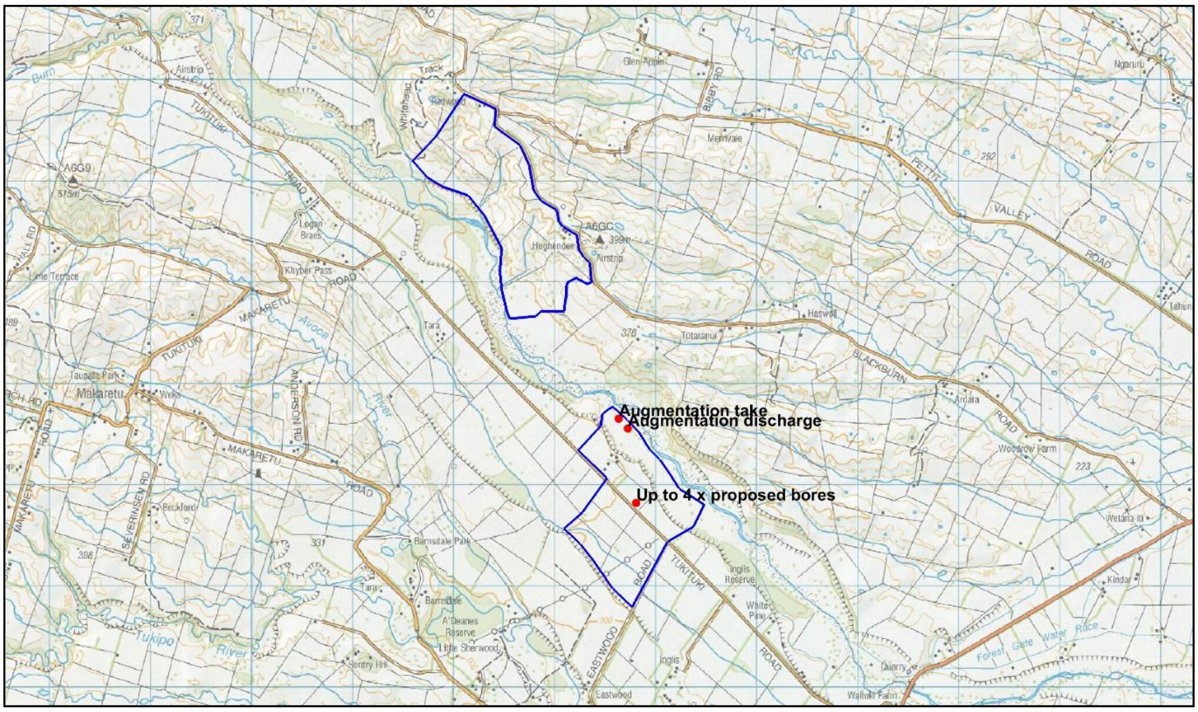


Figure 16: Tuki Tuki Awa's proposed bores and augmentation locations (the property boundaries are shown as blue outlines)

Key infrastructure for Tuki Tuki Awa's proposed Tranche 2 take are summarised in Table 12.

Table 12: Tuki Tuki Awa's proposed Tranche 2 infrastructure

Site	Use and/or status	Current status	Depth (m bgl)	Approx. irrigated area (ha)
Proposed bores x 4	Irrigation	Proposed	50 +	136
Augmentation take	Augmentation take	Proposed	50 +	-
Augmentation discharge	Discharge to Tukituki River	Proposed	-	-

3.5.1 Irrigation Demand

Irrigation demand has been modelled using Aqualinc's IrriCalc soil-water balance model. The 90 percentile water demand for pasture is calculated to be approximately 450 mm/year, which over an irrigated area of 135 ha equates to 607,000 m^3/year. This is less than the volume of water sought by Tuki Tuki Awa for irrigation purposes (which was 882,800 m^3/year) and suggests that not all of the water applied for would be used, except during extreme dry years. Alternatively, more Tranche 2 water could be used for augmentation than indicated in the application (if permitted).

The IrriCalc modelling provides a daily time series of crop water demand (assuming an unrestricted supply) and resulting daily time series of land surface recharge (LSR). The Tranche 2 crop water demand has been modelled from the location of the proposed bores (as listed in Table 12). Although irrigation results in additional LSR compared to dryland, the proposed Tranche 2 groundwater is sought to replace existing irrigation sourced from surface water. Hence, there will be no change to the irrigated area (and resulting LSR); the only change is from where the water is sourced.

3.5.2 Modelling Results for Tuki Tuki Awa

The model has been run with daily outputs generated from 1 July 1972 through to 30 June 2012. Time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics due to Tuki Tuki Awa's irrigation take alone. Changes in these flow statistics compared to status quo are summarised in Table 13. Although the results are presented to the nearest litre per second, the model's accuracy is not that precise. Therefore, these results represent the approximate scale and direction of effect.

Table 13: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to Tuki Tuki Awa's irrigation take alone (no augmentation)

Scenario	Site				
	Waipawa at SH2	Tukituki at Tapairu Rd	Tukipo at SH50	Tukipo at Ashcott Rd	Mangaonuku u/s Waipawa
Change in average flow (l/s)					
Tuki Tuki Awa's irrigation take only	-10	-9	0	-3	-2
Change in mean 7-day annual low flow (MALF) (l/s)					
Tuki Tuki Awa's irrigation take only	-3	-6	0	-2	-2

From Table 13, irrigation alone (with no augmentation) results in a reduction in river flows throughout much of the basin. The largest changes occur in the mid-lower Tukituki catchment and tributaries, as this is the catchment within which Tuki Tuki Awa is located. However, effects do propagate over to the lower Waipawa catchment and tributaries. The overall effects are relatively small compared to some other applicants because the total scale of the proposed Tranche 2 take is also relatively small.

Changes in flows allowing for all applicants' irrigation takes, augmentation takes and augmentation discharges are presented later.

3.6 Plantation Road Dairies

Plantation Road Dairies originally applied to take 6,000,000 m^3/year of Tranche 2 groundwater. After their application was lodged, they changed their proposal and reduced the volume of groundwater sought. The 'released' Tranche 2 groundwater was therefore available to fulfil the unmet volume applied by the last person in the Tranche 2 applicant queue at the time, and then for additional allocation under new applications. The volume of Tranche 2 groundwater that Plantation Road Dairies have now applied for is **3,751,225 m^3/year** from deep bores around their property, located in the lower basin between the Waipawa and Tukituki rivers. Approximately 26% of the volume has been assigned to augmentation, though this may change (discussed later under different scenarios). The remaining irrigation component of the proposed Tranche 2 take (2,775,914 m^3/year) will be used to irrigate up to 459 ha of pasture (assumed), or a larger area of less water-intensive crops or horticulture.

The location of the bores (existing and proposed), from which Plantation Road Dairies have proposed to take Tranche 2 groundwater, are shown in Figure 17. The proposed augmentation discharge site is also shown in this figure. It is proposed to take the additional augmentation water from a proposed new bore located in adjacent land also owned by Planation Road Dairies and discharge directly into the Kahahakuri Stream immediately beside this location.

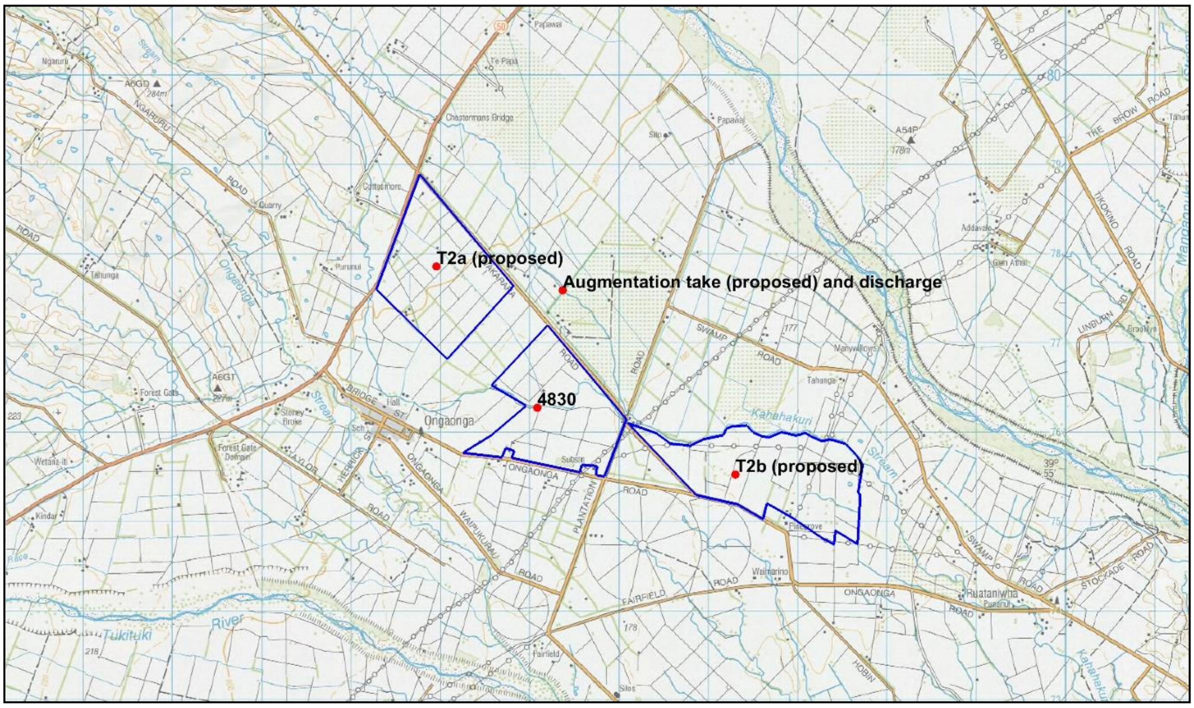


Figure 17: Plantation Road Dairies existing and proposed bores and augmentation locations (irrigation areas are shown as blue outlines)

Key infrastructure for Plantation Road Dairies proposed Tranche 2 take are summarised in Table 14.

Table 14: Plantation Road Dairies proposed Tranche 2 infrastructure

Site	Use and/or status	Current status	Depth (m bgl)	Approx. irrigated area (ha)
4830	Irrigation	Existing	137	144
T2a	Irrigation	Proposed	~ 100	155
T2b	Irrigation	Proposed	~ 100	160
Augmentation take	Augmentation take	Proposed	~ 100	-
Augmentation discharge	Discharge to Kahahakuri Stream	Proposed	-	-

3.6.1 Irrigation Demand

Irrigation demand has been modelled using Aqualinc's IrriCalc soil-water balance model. The 90 percentile water demand for pasture is calculated to be approximately 600 mm/year, which over an irrigated area of 459 ha equates to a volume of approximately 2.75 million m^3/year. This is similar to the total volume of irrigation water initially sought by Plantation Road Dairies for irrigation purposes (2,775,914 m^3/year).

The IrriCalc modelling provides a daily time series of crop water demand (assuming an unrestricted supply) and resulting daily time series of land surface recharge (LSR). The crop water demand has been modelled from the bores proposed to supply the property, as listed in Table 14, in proportion to the listed irrigated areas. Furthermore, new irrigation results in additional LSR compared to dryland. This has also been incorporated into the model by exchanging previously dryland LSR with irrigated LSR for the areas that were previously unirrigated.

3.6.2 Modelling Results for Plantation Road Dairies

The model has been run with daily outputs generated from 1 July 1972 through to 30 June 2012. Time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics due to Plantation Road Dairies' irrigation take alone. Changes in these flow statistics compared to status quo are summarised in Table 15. Although the results are presented to the nearest litre per second, the model's accuracy is not that precise. Therefore, these results represent the approximate scale and direction of effect.

Table 15: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to Plantation Road Dairies' irrigation take alone (no augmentation)

Scenario	Site				
	Waipawa at SH2	Tukituki at Tapairu Rd	Tukipo at SH50	Tukipo at Ashcott Rd	Mangaonuku u/s Waipawa
Change in average flow (l/s)					
Plantation Road Dairies' irrigation take only	-45	-24	0	-4	-13
Change in mean 7-day annual low flow (MALF) (l/s)					
Plantation Road Dairies' irrigation take only	-38	-24	0	-3	-19

From Table 15, irrigation alone (with no augmentation) results in a reduction in river flows throughout much of the basin. The largest changes occur in the Waipawa catchment and tributaries, though effects do propagate over to the lower Tukituki catchment and tributaries.

Changes in flows allowing for all applicants' irrigation takes, augmentation takes and augmentation discharges are presented later.

3.7 Springhill Dairies

Springhill Dairies (formerly Ingleton Farms) have applied to take up to **1,005,213 m^3/year** of Tranche 2 groundwater from deep bores located around their property. The proposed Tranche 2 take will supplement existing consented takes with a combined volume of approximately 4,029,077 m^3/year to provide adequate irrigation of 702 ha of pasture (assumed), or a larger area of less water-intensive crops or horticulture, from bores 1518, 3870, 4122, 4593, 5497 and 5167 (combined). It is proposed to provide augmentation directly into the Mangaonuku Stream.

The location of the bores from which Springhill Dairies have proposed to take groundwater, and the approximate locations of the augmentation take bore and the discharge site, are shown in Figure 18.

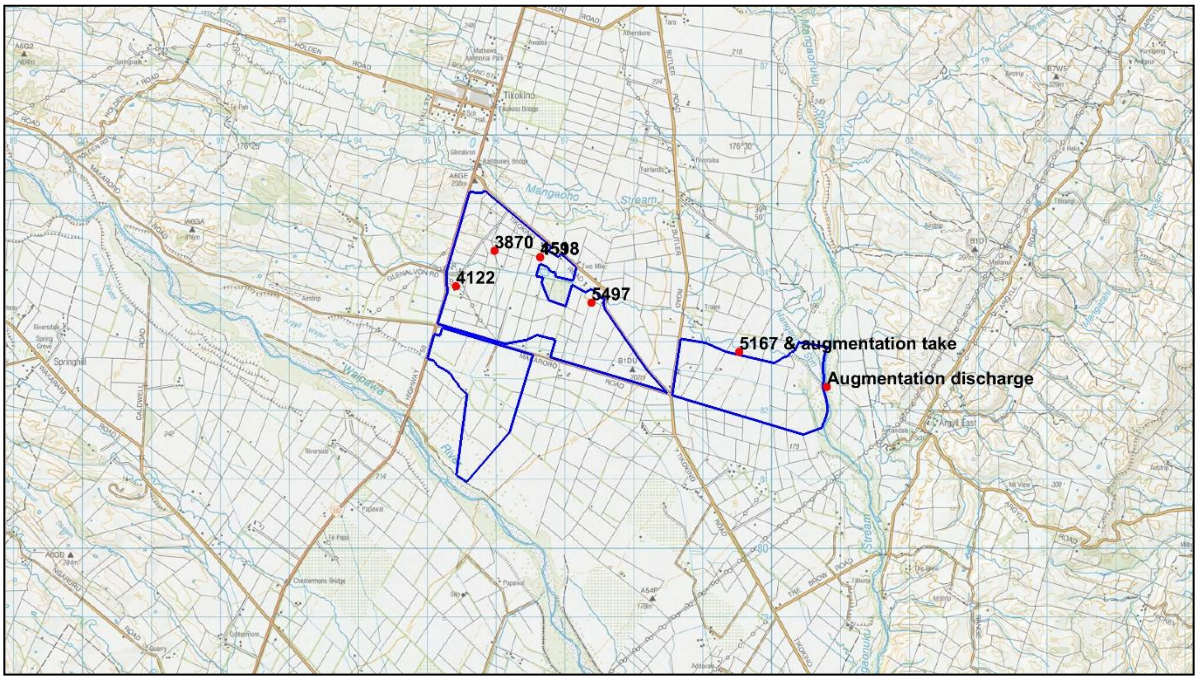


Figure 18: Springhill Dairies' bores and augmentation locations (irrigation areas are shown as blue outlines)

Key infrastructure for Springhill Dairies' proposed takes are summarised in Table 16.

Table 16: Springhill Dairies' proposed infrastructure

Site	Use and/or status	Current status	Depth (m bgl)
Bore 5167	Irrigation & augmentation take	Existing bore and irrigation take; proposed augmentation take	124.6
Bore 4593	Irrigation	Existing	84.7
Bore 1518	Irrigation	Existing	152.9
Bore 3870	Irrigation	Existing	144.7
Bore 4122	Irrigation	Existing	134.2
Bore 5497	Irrigation	Existing	56.1
Augmentation discharge	Discharge to Mangaonuku Stream	Proposed	-

For the purposes of this assessment, it has been assumed that the additional Tranche 2 water is extracted from bores 3870 and 5167.

3.7.1 Irrigation Demand

Irrigation demand has been modelled using Aqualinc's IrriCalc soil-water balance model. The 90 percentile annual water demand for pasture is calculated to be approximately 480 mm/year, which over an irrigated area of 702 ha equates to 3.4 million m^3/year. The irrigation demand is able to be met by utilising a combination of the exiting consented takes and a portion of the Tranche 2 volume applied for, whilst leaving a reasonable volume of Tranche 2 water available for augmentation purposes. The irrigation volume initially applied for (597,997 m^3/year) would be adequate to irrigate approximately 125 ha.

The IrriCalc modelling provides a daily time series of crop water demand (assuming an unrestricted supply) and resulting daily time series of land surface recharge (LSR). The crop water demand has been modelled from the bores proposed to supply the property, as listed in Table 16. Furthermore, new irrigation results in additional LSR compared to dryland. This has also been incorporated into the model by exchanging previously dryland LSR with irrigated LSR for the new irrigated areas.

3.7.2 Modelling Results for Springhill Dairies

The model has been run with daily outputs generated from 1 July 1972 through to 30 June 2012. Time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics due to Springhill Dairies' irrigation take alone. Changes in these flow statistics compared to status quo are summarised in Table 17. Although the results are presented to the nearest litre per second, the model's accuracy is not that precise. Therefore, these results represent the approximate scale and direction of effect.

Table 17: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to Springhill Dairies' irrigation take alone (no augmentation)

Scenario	Site				
	Waipawa at SH2	Tukituki at Tapairu Rd	Tukipo at SH50	Tukipo at Ashcott Rd	Mangaonuku u/s Waipawa
Change in average flow (l/s)					
Springhill Dairies' irrigation take only	-13	-4	0	0	-5
Change in mean 7-day annual low flow (MALF) (l/s)					
Springhill Dairies' irrigation take only	-10	-3	0	0	-7

From Table 17, irrigation alone (with no augmentation) results in a reduction in river flows throughout much of the basin. The largest changes occur in the Waipawa catchment and tributaries, as this is the catchment within which Springhill Dairies is located. However, small scale effects do propagate over to the lower Tukituki catchment and tributaries. The overall effects are relatively small compared to some other applicants because the total scale of the proposed Tranche 2 take is also relatively small.

Changes in flows allowing for all applicants' irrigation takes, augmentation takes and augmentation discharges are presented later.

3.8 I&P Farming

I&P Farming have submitted two applications to take Tranche 2 groundwater. An original application was submitted to take up to 477,122 m^3/year of Tranche 2 groundwater, and a new application has recently been submitted to take up to 722,888 m^3/year of groundwater. These combine to a total of **1,200,010 m^3/year** and comprises 913,862 m^3/year for irrigation and 286,148 m^3/year for augmentation. The applications seek to take groundwater from new deep bores (likely two new bores) located on their property. The irrigation rate applied for is intended to fully irrigate approximately 184 ha of pasture (assumed), or a larger area of less water-intensive crops or horticulture.

The general location of the bores from which I&P Farming have proposed to take groundwater, and the approximate location of the augmentation discharge site, are shown in Figure 19. It is proposed to discharge water into an existing unnamed small stream that joins the Tukituki River less than 1 km below the downgradient boundary of the property. This unnamed stream is not included in the model, and therefore it has been assumed that the augmentation discharge occurs at the confluence of this stream with the Tukituki River, as indicated in Figure 19. This site is a little higher up-catchment than the site originally proposed by I&P Farming in their initial application.

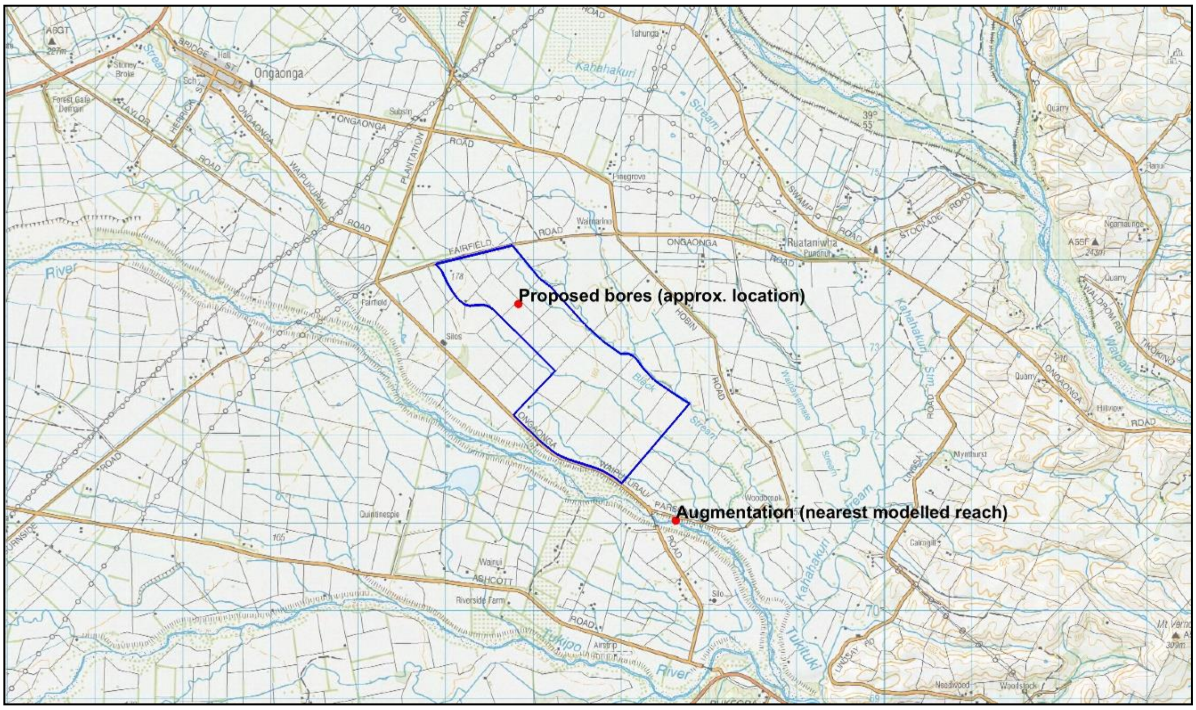


Figure 19: I&P Farming's bore and augmentation locations
(irrigation areas are shown as blue outlines)

Key infrastructure for I&P Farming's proposed take are summarised in Table 18.

Table 18: I&P Farming's proposed infrastructure

Site	Use and/or status	Current status	Depth (m bgl)
Proposed bore	Irrigation & augmentation take	Proposed	60 m min (assumed)
Augmentation discharge	Discharge to unnamed stream, tributary of Tukituki River	Proposed	-

3.8.1 Irrigation Demand

Irrigation demand has been modelled using Aqualinc's IrriCalc soil-water balance model. The 90 percentile annual water demand for pasture is calculated to be approximately 550 mm/year. The irrigation volume applied is therefore adequate to irrigate approximately 166 ha of pasture, which is a little less than the 184 ha intended for mixed cropping. The smaller area of pasture will be assumed for modelling purposes.

The IrriCalc modelling provides a daily time series of crop water demand (assuming an unrestricted supply) and resulting daily time series of land surface recharge (LSR). The crop water demand has been modelled from the proposed bore to supply the property, as listed in Table 18. Furthermore, new irrigation results in additional LSR compared to dryland. This has also been incorporated into the model by exchanging previously dryland LSR with irrigated LSR for the new irrigated areas.

3.8.2 Modelling Results for I&P Farming

The model has been run with daily outputs generated from 1 July 1972 through to 30 June 2012. Time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics due to I&P Farming's irrigation take alone. Changes in these flow statistics compared to status quo are summarised in Table 19. Although the results are presented to the nearest litre per second, the model's accuracy is not that precise. Therefore, these results represent the approximate scale and direction of effect.

Table 19: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to I&P Farming's irrigation take alone (no augmentation)

Scenario	Site				
	Waipawa at SH2	Tukituki at Tapairu Rd	Tukipo at SH50	Tukipo at Ashcott Rd	Mangaonuku u/s Waipawa
Change in average flow (l/s)					
I&P Farming's irrigation take only	-9	-15	0	-2	-2
Change in mean 7-day annual low flow (MALF) (l/s)					
I&P Farming's irrigation take only	-5	-13	0	-2	-2

From Table 19, irrigation alone (with no augmentation) results in a reduction in river flows throughout much of the basin.

Changes in flows allowing for all applicants' irrigation takes, augmentation takes and augmentation discharges are presented later.

3.9 Buchanan Trust No 2 (Buchanan)

Buchanan have applied to take up to 1,631,018 m^3/year of Tranche 2 groundwater from existing and proposed new deep bores located around their property. However, at the time of their original application, only **1,145,794 m^3/year** was available from the Tranche 2 volume available. This equates to approximately 70% of the water applied for.

Assuming augmentation volume is 20% of the total take (this may be adjusted in subsequent scenarios, discussed later), then the Tranche 2 volume remaining for Buchanan would be made up of 915,894 m^3/year for irrigation and a further 229,900 m^3/year for augmentation. This reduced volume has been applied to the modelling scenarios and is adequate to fully irrigate 153 ha of pasture (assumed) or a larger area of less water-intensive crops or horticulture.

The location of the bores from which Buchanan have proposed to take groundwater, and the approximate location of the augmentation discharge site, are shown in Figure 20. It is proposed to discharge water into the nearby reach of Ongaonga Stream, which converges with Tukituki River approximately 4 km below the property.

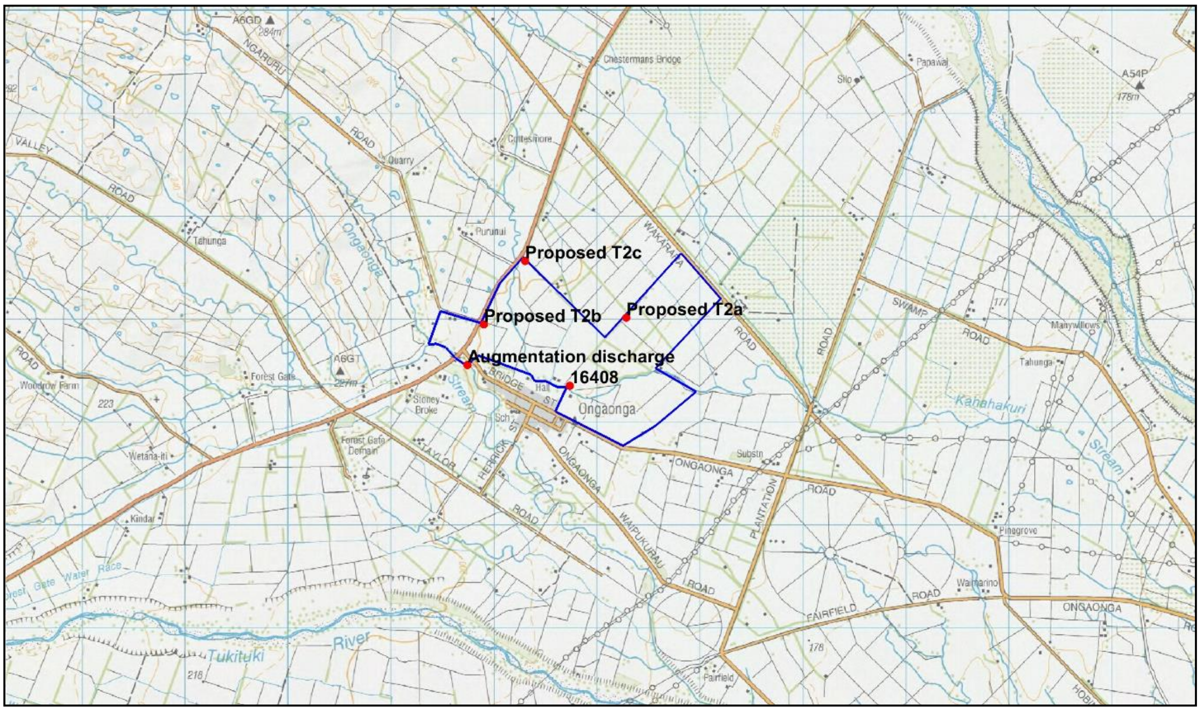


Figure 20: Buchanan's bores and augmentation locations (irrigation areas are shown as blue outlines)

Key infrastructure for Buchanan's proposed take are summarised in Table 20.

Table 20: Buchanan's proposed infrastructure

Site	Use and/or status	Current status	Depth (m bgl)
16408	Irrigation & augmentation take	Existing	119.8
Proposed T2a	Irrigation & augmentation take	Proposed	~ 110 m (assumed)
Proposed T2b	Irrigation & augmentation take	Proposed	
Proposed T2c	Irrigation & augmentation take	Proposed	
Augmentation discharge	Discharge to Ongaonga Stream	Proposed	-

3.9.1 Irrigation Demand

Irrigation demand has been modelled using Aqualinc's IrriCalc soil-water balance model. The 90 percentile annual water demand for pasture is calculated to be approximately 600 mm/year. This results in the 153 ha of pasture being fully irrigable from the 915,894 m^3/year volume.

The IrriCalc modelling provides a daily time series of crop water demand (assuming an unrestricted supply) and resulting daily time series of land surface recharge (LSR). The crop water demand has been modelled from the proposed bore to supply the property, as listed in Table 20. Furthermore, new irrigation results in additional LSR compared to dryland. This has also been incorporated into the model by exchanging previously dryland LSR with irrigated LSR for the new irrigated areas.

3.9.2 Modelling Results for Buchanan

The model has been run with daily outputs generated from 1 July 1972 through to 30 June 2012. Time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics due to Buchanan's irrigation take alone. Changes in these flow statistics compared to status quo are summarised in Table 21. Although the results are presented to the nearest litre per second, the model's accuracy is not that precise. Therefore, these results represent the approximate scale and direction of effect.

Table 21: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to Buchanan's irrigation take alone (no augmentation)

Scenario	Site				
	Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
Change in average flow (l/s)					
Buchanan's irrigation take only	-17	-10	0	-2	-4
Change in mean 7-day annual low flow (MALF) (l/s)					
Buchanan's irrigation take only	-11	-9	0	-2	-5

From Table 21, irrigation alone (with no augmentation) results in a reduction in river flows throughout much of the basin. The largest changes occur in the Waipawa catchment.

Changes in flows allowing for all applicants' irrigation takes, augmentation takes and augmentation discharges are presented later.

3.10 Purunui Trust

Purunui Trust have applied to take up to 1,575,000 m^3/year of Tranche 2 groundwater from three deep bores located around their property, near Ongaonga. The annual volume applied for is comprised of:

- 1,050,000 m^3/year (at a volume not exceeding 252,000 m^3 within any 28 day period) for irrigation of up to 175 ha (assumed all pasture), capped at meeting full water demand up to a one-in-ten year drought; and
- An additional 525,000 m^3/year (at volume not exceeding 126,000 m^3 within any 28 day period) to provide river augmentation to mitigate the effects of the irrigation take during dry periods.

Due to their position as last in the queue of Tranche 2 groundwater applications, the full volume applied for by Purunui Trust is not available due to the 15,000,000 m^3/year cap on the combined Tranche 2 takes (RRMP Table 5.9.5). Instead, a total volume of **554,921 m^3/year** is available, which equates to approximately 35% of the water applied for. Assuming both the irrigation and augmentation volume is scaled equally, then the Tranche 2 volume remaining for Purunui Trust would be made up of 369,944 m^3/year for irrigation and a further 184,977 m^3/day for augmentation. This reduced volume has been applied to the modelling scenarios and is adequate to fully irrigate approximately 62 ha of pasture (assumed), or a larger area of less water-intensive crops or horticulture.

The location of the bores (existing and proposed) from which Purunui Trust have proposed to take groundwater, and the approximate locations of the augmentation take bore and the discharge site, are shown in Figure 21. It is proposed to provide river augmentation into the Waipawa River via an existing unused large-diameter shallow bore located approximately 200-300 m from the river. Purunui Trust have advised that they believe this shallow bore is directly connected to the nearby Waipawa River, though this will be confirmed prior to commencing augmentation. For the purpose of augmentation modelling, it will be assumed that the water will be discharge directly into the Waipawa River immediately adjacent to the existing shallow bore. Due to the fast hydraulic response between the Waipawa River and nearby shallow groundwater, this will make little difference to the modelled effects.

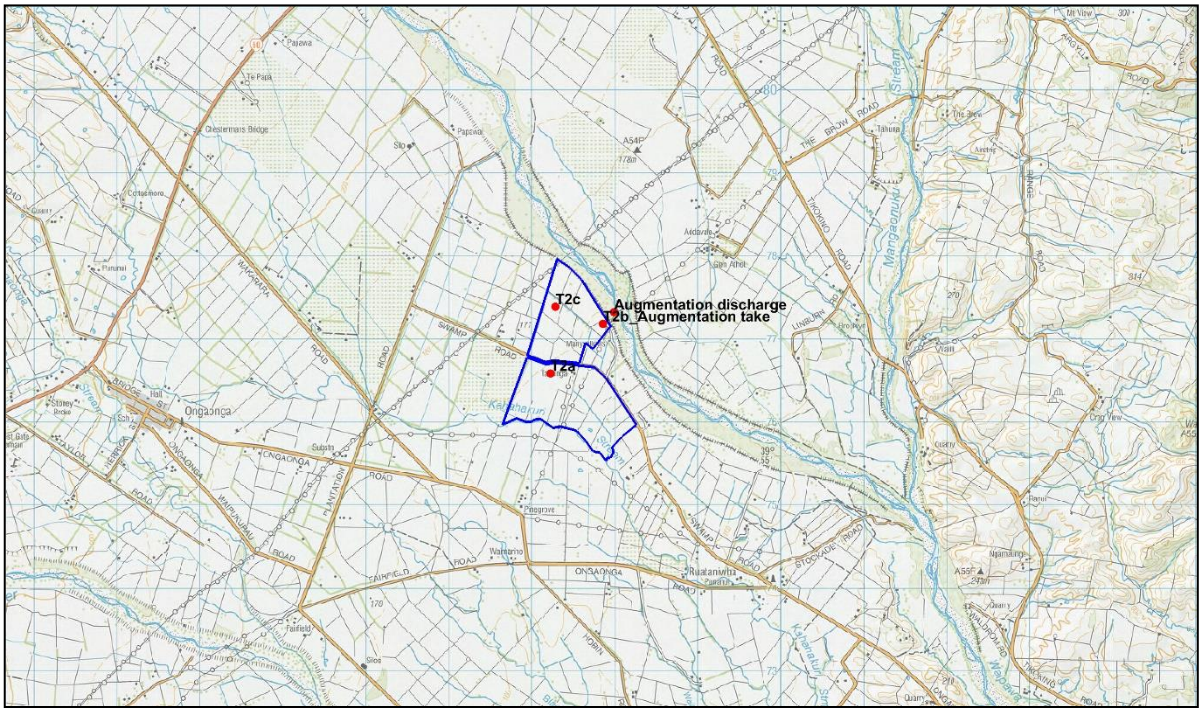


Figure 21: Purunui Trust's proposed bore and augmentation locations (proposed irrigation areas are shown as blue outlines)

Key infrastructure for Purunui Trust's proposed Tranche 2 take are summarised in Table 22.

Table 22: Purunui Trust's proposed Tranche 2 infrastructure

Site	Use and/or status	Current status	Depth (m bgl)	Approx. irrigated area (ha)
T2a	Irrigation	Proposed	50 m min (assumed)	31
T2b	Augmentation	Proposed		-
T2c	Irrigation	Proposed		31
Augmentation discharge	Discharge to Waipawa River	Proposed	-	-

3.10.1 Irrigation Demand

Irrigation demand has been modelled using Aqualinc's IrriCalc soil-water balance model. The 90 percentile water demand for pasture is calculated to be approximately 600 mm/year, which over an irrigated area of 62 ha equates to an annual volume of 372,000 million m^3/year.

The IrriCalc modelling provides a daily time series of crop water demand (assuming an unrestricted supply) and resulting daily time series of land surface recharge (LSR). The crop water demand has been modelled from the bores proposed to supply the property, as listed in Table 22, in proportion to the listed irrigated areas. Furthermore, new irrigation results in additional LSR compared to dryland. This has also been incorporated into the model by exchanging previously dryland LSR with irrigated LSR for the proposed irrigated areas shown in Figure 21.

3.10.2 Modelling Results for Purunui Trust

The model has been run with daily outputs generated from 1 July 1972 through to 30 June 2012. Time series of river flows at each of the flow restriction sites shown in Figure 13 have been processed to generate changes in flow statistics due to Purunui Trust's irrigation take alone. Changes in these flow statistics compared to status quo are summarised in Table 23. Although the results are presented to the nearest litre per second, the model's accuracy is not that precise. Therefore, these results represent the approximate scale and direction of effect.

Table 23: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to Purunui Trust's irrigation take alone (no augmentation)

Scenario	Site				
	Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
Change in average flow (l/s)					
Purunui Trust's irrigation take only	-6	-3	0	0	-2
Change in mean 7-day annual low flow (MALF) (l/s)					
Purunui Trust's irrigation take only	-5	-4	0	0	-2

From Table 23, irrigation alone (with no augmentation) results in a reduction in river flows throughout much of the basin. The largest changes occur in the Waipawa catchment and tributaries, as this is the catchment within which Purunui Trust's property is located. However, small scale effects do propagate over to the lower Tukituki catchment and tributaries.

Changes in flows allowing for all Tranche 2 applicants' irrigation takes, augmentation takes and augmentation discharges are presented later.

3.11 Augmentation Scenarios: All Takes Combined Plus Augmentation

The effects from individual applicants are summarised below. Following this, several scenarios have been developed that consider the combined effects of all applicants together with augmentation.

3.11.1 Summary of Individual Effects

Effects for individual applicants are summarised in Table 24.

Table 24: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due for all proposed Tranche 2 irrigation takes (no augmentation)

Applicant	Site				
	Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
Change in average flow (l/s)					
TAFT	-65	-18	0	-2	-32
Papawai	-26	-8	0	-1	-9
Tuki Tuki Awa	-10	-9	0	-3	-2
Plantation Rd Dairies	-45	-24	0	-4	-13
Springhill Dairies	-13	-4	0	0	-5
I&P Farming	-9	-15	0	-2	-2
Buchanan	-17	-10	0	-2	-4
Purunui	-6	-3	0	0	-2
Total	**-126**	**-91**	**0**	**-14**	**-69**
Change in mean 7-day annual low flow (MALF) (l/s)					
TAFT	-63	-16	0	-2	-46
Papawai	-18	-8	0	-1	-12
Tuki Tuki Awa	-3	-6	0	-2	-2
Plantation Rd Dairies	-38	-24	0	-3	-19
Springhill Dairies	-10	-3	0	0	-7
I&P Farming	-5	-13	0	-2	-2
Buchanan	-11	-9	0	-2	-5
Purunui	-5	-4	0	0	-2
Total	**-153**	**-83**	**0**	**-12**	**-95**

From the above table, the changes in river flows statistics are concentrated in the Waipawa catchment where most of the new takes are located. However, effects do also occur in the lower Tukituki sites. No noticeable effect is predicted in the Tukipo River at SH50 as no properties are sited near or above this location.

3.11.2 Restrictions

To provide a reliable supply for irrigation, it is proposed that the Tranche 2 takes are operated unrestricted (supplying crop water demand as needed, day to day). To then mitigate stream depletion effects caused by the irrigation takes and to maintain reliability for existing users, surface water augmentation (sourced from groundwater) is proposed when rivers reach minimum flows. For the

Ruataniwha basin, the river flow restrictions were initially based on the following sites and flows, as specified in RRMP Table 5.9.3: Tukituki Catchment Minimum Flows framework:

- Waipawa at RDS/SH2: 2,500 l/s
- Tukituki River at Tapairu Road: 2,300 l/s
- Tukipo at SH50: 150 l/s
- Tukipo at Ashcott: 1,043 l/s
- Mangaonuku at u/s Waipawa confluence 1,170 l/s

The locations of these flow restriction sites are shown in Figure 13.

The daily river flow time series used to generate a time series of restrictions has been modified for the base case by a time series of changes in flows resulting from all applicants (combined) taking their irrigation takes alone. This was generated by the individual scenarios discussed in Section 3.3 through to Section 3.10.

A further flow restriction site exists on the Tukituki River at Red Bridge, down catchment from the Ruataniwha basin outlet. This is below the model's extent and therefore the flow monitoring sites on the Waipawa at SH2 and Tukituki at Tapairu Road have been considered to represent this site. So long as the combined 7-day MALF at the SH2 and Tapairu sites are maintained (or improved), then the downstream low flows at Red Bridge will not be adversely affected by the proposed Tranche 2 activities. This is discussed in Section 3.12.

It has been assumed that the full augmentation rate is taken (sourced from Tranche 2 water) and discharged at the locations described above for each applicant whenever restrictions on any one of the above RMP Table 5.9.3 minimum flow sites occurs. Furthermore, as all Tranche 2 applicants are operating collaboratively, and effects from any one take potentially propagate across several streams, it has been assumed that augmentation will occur by all of the applicants if any one of the RRMP Table 5.9.3 minimum flow sites experiences a low-flow restriction.

3.11.3 Augmentation Scenario 1

Scenario 1 assumes that augmentation occurs only when irrigation from Tranche 2 groundwater is occurring on each applicant's property. However, as outlined above, if one of the RRMP Table 5.9.3 minimum flow sites is triggered then augmentation commences from all Tranche 2 applicants, but also only occurs when they are each irrigating. The model has been run with the combined applicants' proposed irrigation takes and augmentation, for the period 1 July 1972 through to 30 June 2012. Time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics (compared to status quo), which are summarised in Table 25. Again, the results are presented to the nearest litre per second, but the model's accuracy is not that precise. Therefore, these results represent the approximate scale and direction of effect.

Table 25: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to all applicants' irrigation takes with augmentation scenario 1

Site				
Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
Change in average flow (l/s)				
-194	-63	-1	-9	-99
Change in mean 7-day annual low flow (MALF) (l/s)				
-90	+89	-1	-7	-66

Calculated augmentation volumes for each applicant are summarised in Table 26. Also included in this table for comparison is a summary of the total Tranche 2 groundwater volumes applied for each applicant.

Table 26: Calculated seasonal augmentation volumes for augmentation scenario 1

Applicant	Approx. area irrigated from Tranche 2 groundwater (ha) [1]	Modelled 90 percentile annual volumes (m^3/year) (1972-2012)			Tranche 2 GW volume applied (m^3/year)
		For irrigation	For augmentation (% of total)	Total	
TAFT	540	3,100,000	894,100 (18%)	3,994,100	4,914,920
Papawai	207	1,161,000	121,100 (8%)	1,282,100	1,475,517
Tuki Tuki Awa	135	612,000	108,200 (11%)	720,200	952,400
Plantation Rd Dairies	459	2,754,000	546,900 (15%)	3,300,900	3,751,225
Springhill Dairies	125 [2]	597,997 [2]	171,400 (17%)	769,397	1,005,213
I&P Farming	166 [3]	913,862	67,100 (6%)	980,962	1,200,010
Buchanan	153 [3]	915,894	222,000 (19%)	1,137,894	1,145,794 [3]
Purunui	62 [3]	448,121	62,900 (11%)	511,021	554,921 [3]
	Total	**10,502,874**	**2,193,700 (15%)**	**12,696,574**	**15,000,000**

(1) These areas are based on the assumption that pasture is irrigated. However, larger areas of less intensive crops or horticulture can be irrigated within the same yearly volumes used by pasture, with little-to-no difference in the hydraulic effect.

(2) The Tranche 2 water will supplement existing takes to irrigate a larger area of land than can be irrigated from the Tranche 2 water alone. Therefore, it has been assumed above that all of the Tranche 2 irrigation water applied for is utilised.

(3) Less than applied for.

A map of groundwater level difference between status quo and augmentation scenario 1 is presented in Figure 22 for the dry period of 1 March 2011. This is during a time of typically lowest groundwater levels (in most monitored wells). This demonstrates how groundwater levels are predicted to change spatially during dry periods. Temporal changes in groundwater are discussed in Section 3.15.

From Figure 22, the greatest changes in shallow groundwater levels occur west (upgradient) of the take locations. This is because shallow groundwater level changes in areas downgradient of the take locations are mitigated (or partially mitigated) by the river augmentation; areas upgradient (and also deeper layers, not shown) do not receive the full benefit of the augmentation.

The following key observations are derived from the above results:

- Augmentation benefits most the catchment below where it is directly discharged.
- From Table 24, the proposed irrigation takes combined (without augmentation) are predicted to result in a total reduction in the 7-day MALF out of the basin of approximately 236 l/s (-153 l/s from the Waipawa and -83 l/s from the Tukituki). From Table 25, with augmentation, the equivalent change in the combined 7-day MALF out of the basin is a reduction of approximately 1 l/s (-90 l/s in the Waipawa and +89 l/s in the Tukituki). Reductions in flows are also predicted for the Mangaonuku River and the two Tukipo River sites.
- Therefore, the augmentation trialled under this scenario is having a partial mitigating effect, but it is insufficient to fully mitigate the effects of the proposed new Tranche 2 takes, for the scenario tested.
- From Figure 22, shallow groundwater levels are predicted to lower up to a maximum of 0.7 m under augmentation scenario 1. This maximum change is focussed in the vicinity of greatest abstraction (the applicants' properties). Elsewhere, shallow groundwater levels are predicted to change less than 0.2 m.

The augmentation volumes in Table 26 were derived by summing (for each year) the proposed augmentation rate applied whenever it is triggered, and calculating the 90%ile annual volume. The total volume of Tranche 2 water abstracted (approximately 12.7 million m^3) is less than that available (15.0 million m^3). At face value, this might suggest that a greater volume of groundwater could be abstracted for irrigation. However, this is not the case as the effects on surface flows set out in Table 25 need to be further mitigated, and that can only occur by taking more deep groundwater for augmentation purposes and/or taking less water for irrigation. This leads into Scenario 2.

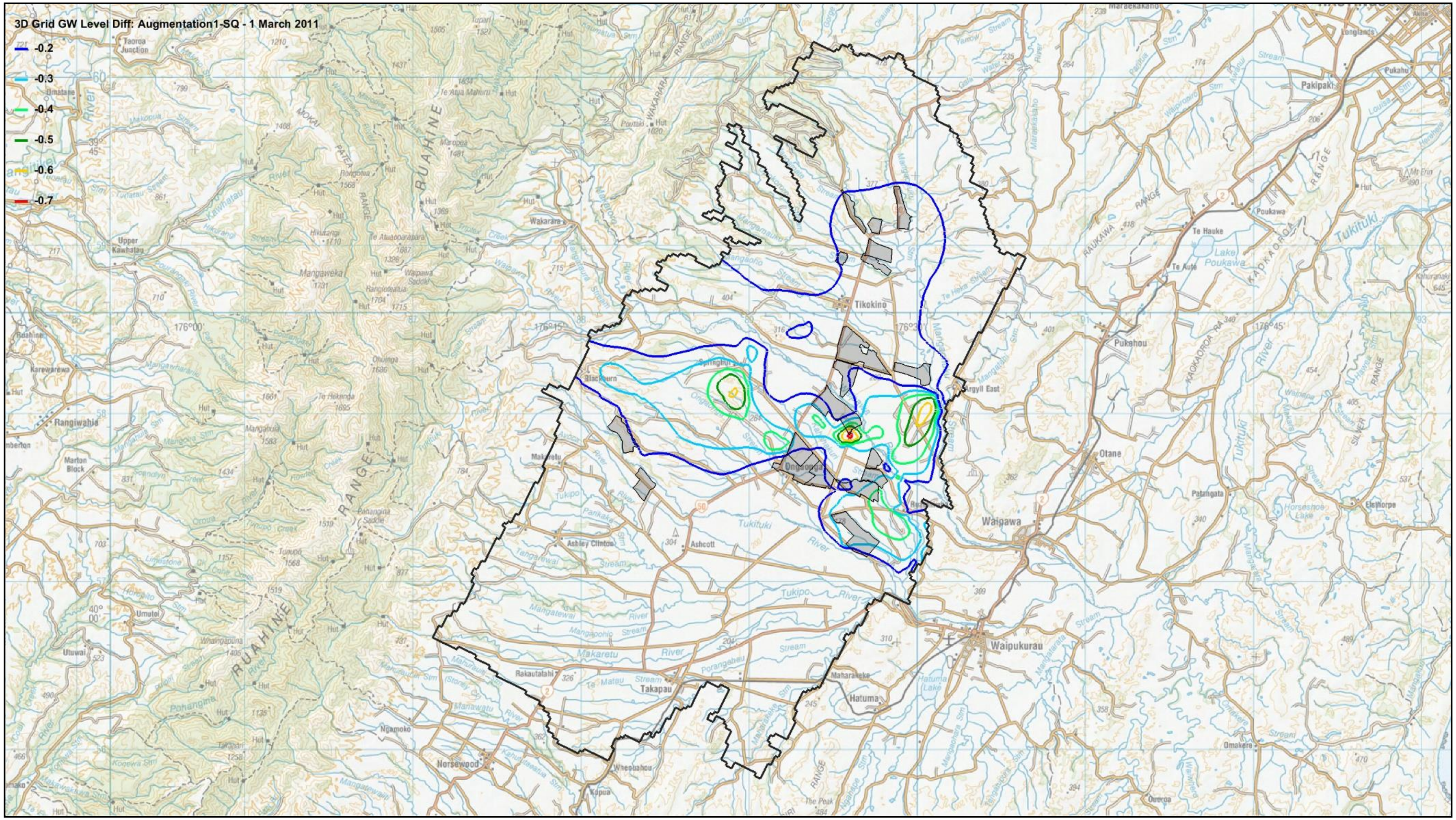


Figure 22: Difference in shallow (layer 1) groundwater levels at 1 March 2011 between status quo and augmentation scenario 1

3.11.4 Augmentation Scenario 2

From the above model results, augmentation is not predicted to fully mitigate the effects on low flows at some river sites. Therefore, an alternative augmentation regime has been trialled. Scenario 2 assumes augmentation occurs whenever RRMP Table 5.9.3 minimum flows are reached throughout the year, regardless of whether or not irrigation is occurring. This scenario aims to better mitigate the temporal effects of the takes during low-flow periods through more frequent augmentation. This in turn results in a greater volume of Tranche 2 water taken for augmentation, and in some cases means individual applicants are forecasted to take more than their applied volume. Therefore, some irrigated areas (and therefore irrigation volumes) have been reduced to counter this.

This scenario has been modelled, and time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics (compared to status quo) which are summarised in Table 27.

Table 27: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to all applicants' irrigation takes with augmentation scenario 2

Site				
Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
Change in average flow (l/s)				
-180	-38	-1	-10	-48
Change in mean 7-day annual low flow (MALF) (l/s)				
+19	+229	-1	-7	+1

Calculated augmentation volumes for each applicant are summarised in Table 28 along with irrigation volumes and the necessary reduced irrigated areas, compared to the total Tranche 2 groundwater volumes and irrigated areas applied for.

Table 28: Calculated seasonal augmentation volumes for augmentation scenario 2

Applicant	Approx. area irrigated from Tranche 2 groundwater (ha) (1)		Modelled 90 percentile annual volumes (m^3/year) (1972-2012)			Tranche 2 GW volume applied (m^3/year)
	As applied	Adjusted to annual volume	For irrigation	For augmentation (% of total)	Total	
TAFT	540	453	2,627,120	2,016,700 (41%)	4,643,820	4,914,920
Papawai	207	207	1,161,000	256,100 (17%)	1,417,100	1,475,517
Tuki Tuki Awa	135	135	607,000	266,800 (28%)	873,800	952,400
Plantation Rd Dairies	459	380	2,280,525	1,296,400 (35%)	3,576,925	3,751,225
Springhill Dairies	125 (2)	114	545,213	405,500 (40%)	950,713	1,005,213
I&P Farming	166 (3)	166	913,862	234,700 (20%)	1,148,562	1,200,010
Buchanan	153 (3)	89	533,294	539,900 (47%)	1,073,194	1,145,794 (3)
Purunui	62 (3)	62	381,831	152,600 (27%)	534,431	554,921 (3)
		Total	**9,049,845**	**5,168,700 (33%)**	**14,218,545**	**15,000,000**

(1) These areas are based on the assumption that pasture is irrigated. However, larger areas of less intensive crops or horticulture can be irrigated within the same yearly volumes used by pasture, with little-to-no difference in the hydraulic effect.

(2) The Tranche 2 water will supplement existing takes to irrigate a larger area of land than can be irrigated from the Tranche 2 water alone. Therefore, it has been assumed above that all of the Tranche 2 irrigation water applied for is utilised.

(3) Less than applied for.

A map of groundwater level difference between status quo and augmentation scenario 2 is presented in Figure 23 for 1 March 2011. This demonstrates how groundwater levels are predicted to change spatially during dry periods. Temporal changes in groundwater are discussed in Section 3.15.

The following key observations are derived from these results:

- Compared to augmentation scenario 1, the more frequent augmentation provides additional benefit to the low flows exiting the catchment.
- As previously noted in Table 24, the combined effects from the proposed irrigation takes alone are predicted to result in a total reduction in the 7-day MALF out of the basin of approximately 236 l/s (-183 l/s from the Waipawa and -83 l/s from the Tukituki). From the alternative augmentation scenario 2 results in Table 27, the combined 7-day MALF out of the basin is expected to increase by 248 l/s, a result of a +19 l/s (increase) in the Waipawa and +229 l/s (increase) in the Tukituki.
- Overall, alternative augmentation scenario 2 is having a much larger positive effect on the 7-day MALF exiting the basin, but does not fully mitigate the effects in the Tukipo River at Aschott Rd.
- Shallow groundwater levels are predicted to lower up to a maximum of 0.7 m under augmentation scenario 2. Again, this maximum change is focussed in the areas of greatest abstraction (near the applicants' properties). Elsewhere, shallow groundwater levels are predicted to change less than 0.2 m.

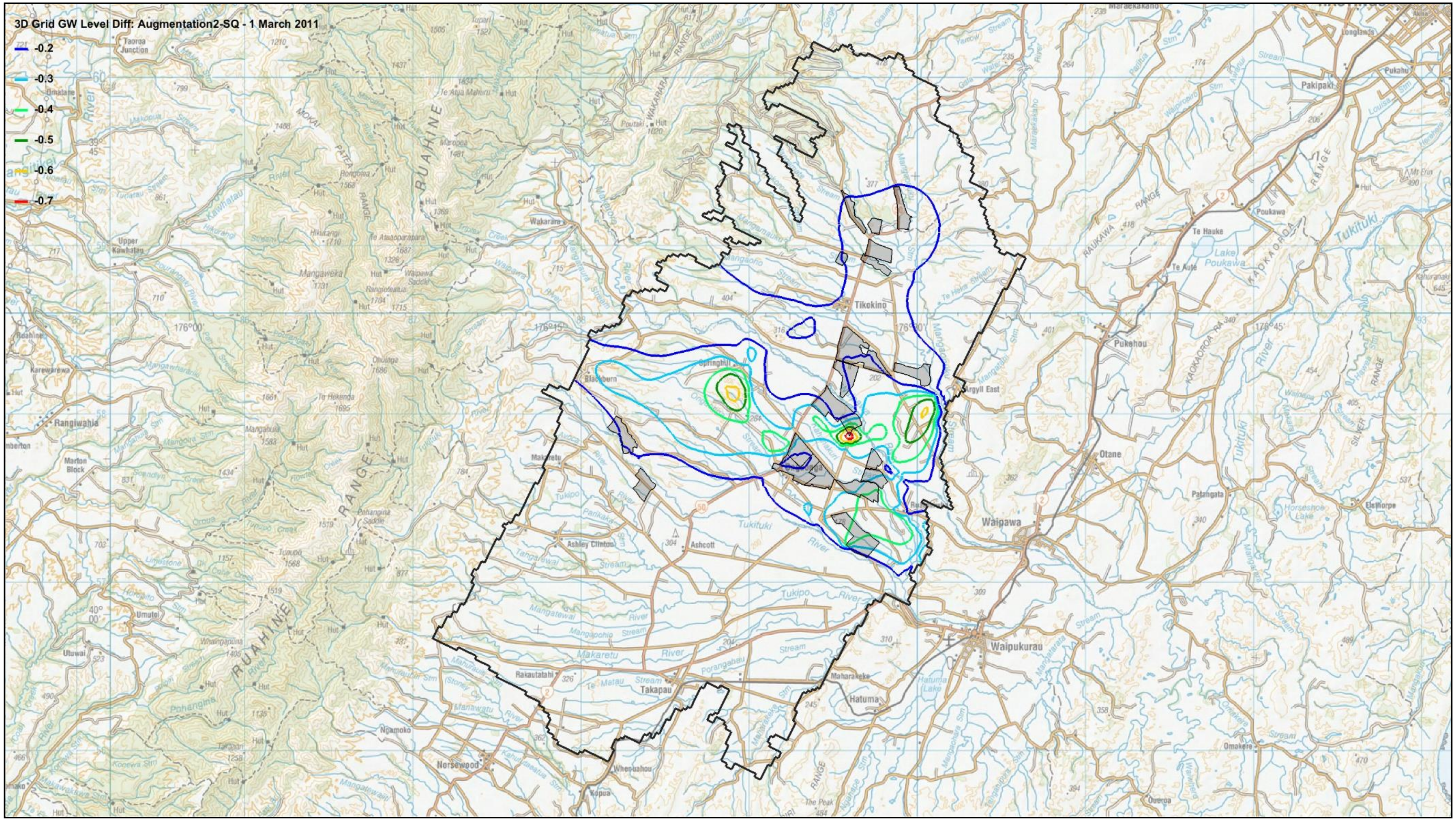


Figure 23: Difference in shallow (layer 1) groundwater levels at 1 March 2011 between status quo and augmentation scenario 2

3.11.5 Augmentation Scenario 3

An alternative augmentation time series has been trialled whereby low-flow restrictions (and therefore augmentation) are assumed to occur sooner (at higher flow rates) than those listed in Section 3.11.2. HBRC have previously indicated that they would consider this more favourable than operating on the low-flow restriction trigger values set out in RRMP Table 5.9.3. The following rationale has been applied to generate an alternative set of low flow trigger values when augmentation would commence:

- Waipawa at RDS/SH2: 2,500 l/s current flow trigger
  + 153 l/s low flow reduction due to takes (Table 24)
  + 50% additional reduction for augmentation take
  Round up to **2,730 l/s**
- Tukituki River at Tapairu Road: 2,300 l/s current flow trigger
  + 83 l/s low flow reduction due to takes (Table 24)
  + 50% additional reduction for augmentation take
  Round up to **2,425 l/s**
- Tukipo at SH50: 150 l/s current flow trigger
  + 0 l/s low flow reduction due to takes (Table 24)
  + 50% additional reduction for augmentation take
  Round up to **150 l/s (assume 155 l/s)**
- Tukipo at Ashcott: 1,043 l/s current flow trigger
  + 12 l/s low flow reduction due to takes (Table 24)
  + 50% additional reduction for augmentation take
  Round up to **1,065 l/s**
- Mangaonuku at u/s Waipawa confluence: 1,170 l/s current flow trigger
  + 95 l/s low flow reduction due to takes (Table 24)
  + 50% additional reduction for augmentation take
  Round up to **1,315 l/s**

These raised low-flow trigger values have been applied to the augmentation takes regardless of whether or not irrigation is occurring on the day (as was the case for augmentation scenario 2, augmentation is assumed to occur even if the applicant is not irrigating). This scenario 3 aims to better maintain existing users' reliability by triggering augmentation at higher river flows. In turn, this (again) results in a greater volume of Tranche 2 water taken for augmentation, which pushes some applicants total take beyond their applied volumes. So some irrigated areas (and therefore irrigation volumes) have been further reduced to counter this.

This scenario 3 has been modelled, and time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics (compared to status quo) which are summarised in Table 29.

Table 29: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to all applicants' irrigation takes with augmentation scenario 3

Site				
Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
Change in average flow (l/s)				
-177	-33	-1	-10	-44
Change in mean 7-day annual low flow (MALF) (l/s)				
+32	+251	-1	-8	+15

Calculated augmentation volumes for each applicant are summarised in Table 30 along with irrigation volumes and the necessary reduced irrigated areas, compared to the total Tranche 2 groundwater volumes and irrigated areas applied for.

Table 30: Calculated seasonal augmentation volumes for augmentation scenario 3

Applicant	Approx. area irrigated from Tranche 2 groundwater (ha) (1)		Modelled 90 percentile annual volumes (m^3/year) (1972-2012)			Tranche 2 GW volume applied (m^3/year)
	As applied	Adjusted to annual volume	For irrigation	For augmentation (% of total)	Total	
TAFT	540	427	2,475,320	2,140,800 (46%)	4,616,120	4,914,920
Papawai	207	207	1,165,717	271,800 (19%)	1,437,517	1,475,517
Tuki Tuki Awa	135	135	629,700	283,200 (31%)	912,900	952,400
Plantation Rd Dairies	459	364	2,182,925	1,376,200 (39%)	3,559,125	3,751,225
Springhill Dairies	125 (2)	107	514,713	430,400 (46%)	945,113	1,005,213
I&P Farming	166 (3)	166	916,010	249,200 (21%)	1,165,210	1,200,010
Buchanan	153 (3)	82	492,594	573,200 (54%)	1,065,794	1,145,794 (3)
Purunui	62 (3)	62	370,321	162,400 (30%)	532,721	554,921 (3)
		Total	**8,474,300**	**6,252,700 (39%)**	**14,234,500**	**15,000,000**

(1) These areas are based on the assumption that pasture is irrigated. However, larger areas of less intensive crops or horticulture can be irrigated within the same yearly volumes used by pasture, with little-to-no difference in the hydraulic effect.

(2) The Tranche 2 water will supplement existing takes to irrigate a larger area of land than can be irrigated from the Tranche 2 water alone. Therefore, it has been assumed above that all of the Tranche 2 irrigation water applied for is utilised.

(3) Less than applied for.

A map of groundwater level difference between status quo and augmentation scenario 3 is presented in Figure 24 for 1 March 2011. This demonstrates how groundwater levels are predicted to change spatially during dry periods. Temporal changes in groundwater are discussed in Section 3.15.

The following key observations are derived from these results:

- Compared to augmentation scenario 2, the more frequent and earlier-commenced augmentation provides additional benefit (again) to the 7-Day MALF of to the Waipawa and Tukituki rivers exiting the catchment.
- As previously noted in Table 24, the combined effects from the proposed irrigation takes alone are predicted to result in a total reduction in the 7-day MALF out of the basin of approximately 236 l/s (-153 l/s from the Waipawa and -83 l/s from the Tukituki). Under augmentation scenario 3 (Table 29), the combined 7-day MALF out of the basin is expected to increase by 283 l/s as a result of a +32 l/s (increase) in the Waipawa and +251 l/s (increase) in the Tukituki.
- Overall, the alternative augmentation scenario is having a larger positive effect on the 7-day MALF exiting the basin, but again does not fully mitigate the effects in the Tukipo River at Ashcott Rd.
- Similar to previous scenarios, shallow groundwater levels are predicted to lower up to a maximum of 0.7 m under augmentation scenario 3, focussed near the applicants' properties. Elsewhere, shallow groundwater levels are predicted to change less than 0.2 m.

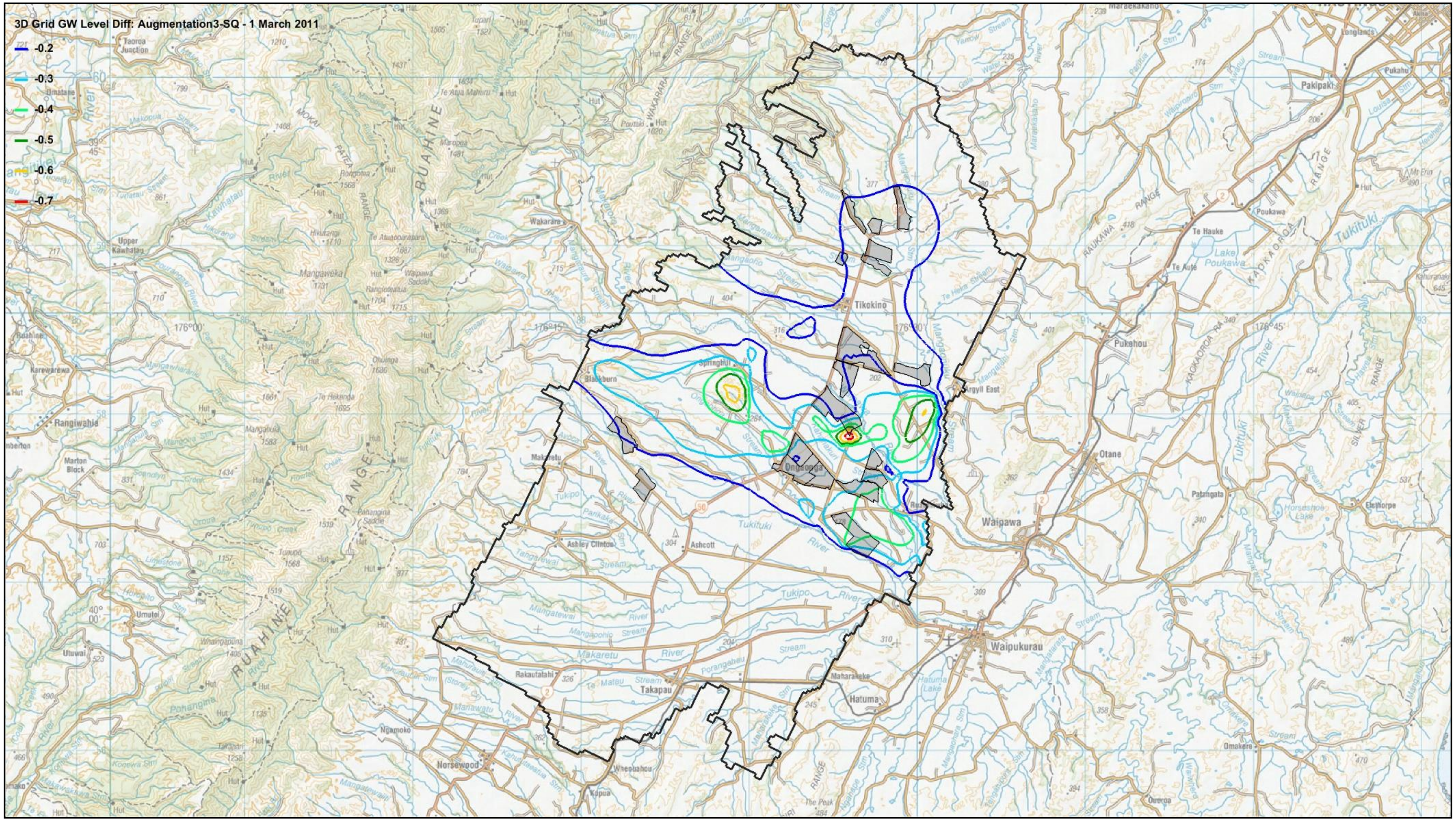


Figure 24: Difference in shallow (layer 1) groundwater levels at 1 March 2011 between status quo and augmentation scenario 3

Although there is a residual effect for the Tukipo River at Ashcott Rd of -8 l/s (Table 29), this equates to less than 1% of the minimum flow for this site (1,043 l/s). It could be argued that this is a minor adverse effect, as based on the modelled hydraulic response for this site, it is estimated that low-flow restrictions might commence hours (rather than days) earlier than might otherwise occur, as demonstrated in Figure 25. The green line shows how the flow in the Tukipo would recede under scenario 3 compared to the case if no Tranche 2 activities were occurring (the blue line).

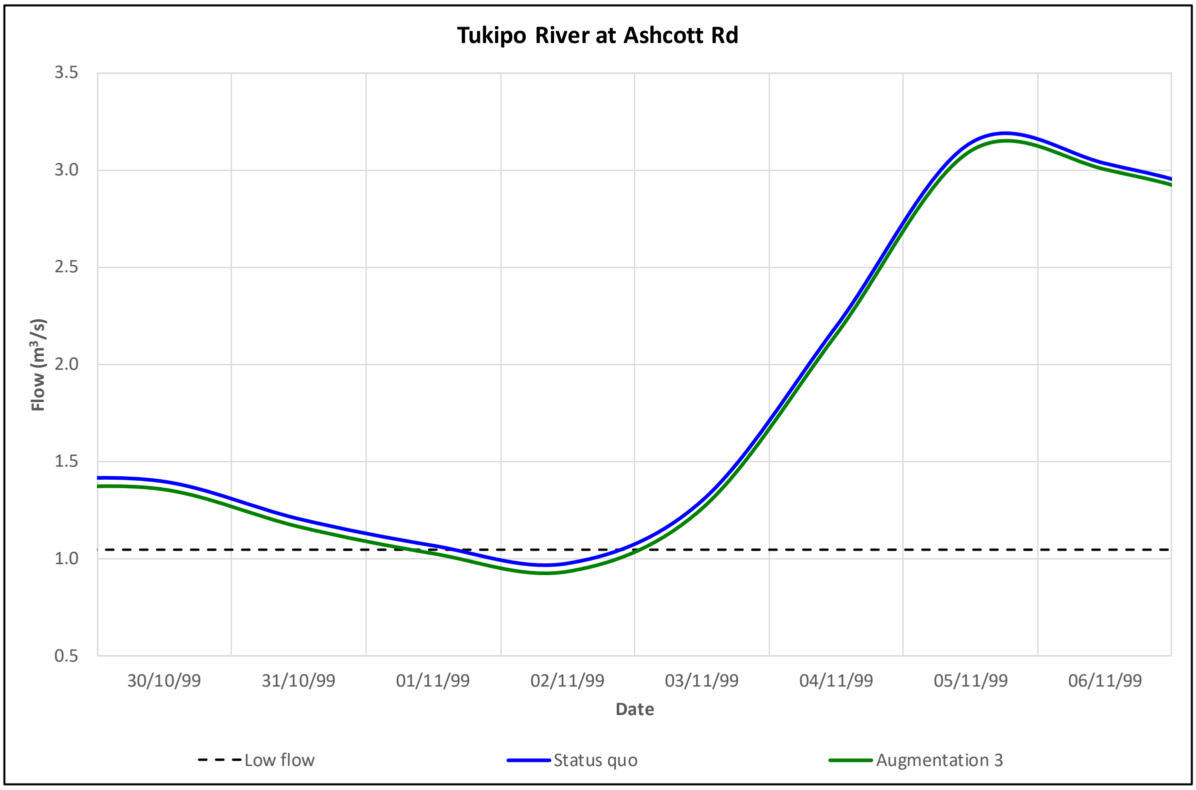


Figure 25: Example of hydraulic timing of modelled river flows in the Tukipo River at Ashcott Rd

Nevertheless, a further scenario has been explored with the aim being to avoid, or minimise to the extent practicable, the residual adverse effect on the Tukipo at Ashcott Rd. This, along with additional balancing of augmentation and irrigated area, is scenario 4 that is discussed next.

3.11.6 Augmentation Scenario 4

Based on the results of augmentation scenario 3, changes in flow in the Tukipo River at Aschott Rd are not fully mitigated. Yet low flows exiting the basin are over compensated. Therefore, augmentation scenario 4 rebalances each applicant's augmentation discharge rate and irrigated area such that the effects on low flows are adequately mitigated (where possible) while ensuring that the total volume of Tranche 2 groundwater proposed for each applicant is no more than the volume applied and the areas to be irrigated do not exceed the irrigable areas sought in the original Tranche 2 applications.

Scenario 4 has been modelled, and time series of river flows at each of the flow restriction sites have been processed to generate changes in flow statistics (compared to status quo) which are summarised in Table 31.

Table 31: Modelled changes in flow statistics (over the period 1972-2012) compared to status quo due to all applicants' irrigation takes with augmentation scenario 4

Site				
Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
Change in average flow (l/s)				
-188	-37	-1	-5	-50
Change in mean 7-day annual low flow (MALF) (l/s)				
+15	+218	-1	-3	+7

Calculated augmentation volumes for each applicant are summarised in Table 32 along with irrigation volumes and the reduced irrigated areas, compared to the total Tranche 2 groundwater volumes and irrigated areas applied for.

Table 32: Calculated seasonal augmentation volumes for augmentation scenario 4

Applicant	Approx. area irrigated from Tranche 2 groundwater (ha) (1)		Modelled 90 percentile annual volumes (m^3/year) (1972-2012)			Tranche 2 GW volume applied (m^3/year)
	As applied	Adjusted to annual volume	For irrigation	For augmentation (% of total)	Total	
TAFT	540	490	2,842,000	2,065,900 (42%)	4,907,900	4,914,920
Papawai	207	181	1,013,500	459,400 (31%)	1,472,900	1,475,517
Tuki Tuki Awa	135	135	607,500	342,600 (36%)	950,100	952,400
Plantation Rd Dairies	459	403	2,418,000	1,328,000 (35%)	3,746,000	3,751,225
Springhill Dairies	125 (2)	123	588,500	415,400 (41%)	1,003,900	1,005,213
I&P Farming	166 (3)	166	913,000	286,600 (24%)	1,199,600	1,200,010
Buchanan	153 (3)	131	786,000	355,400 (31%)	1,141,400	1,145,794 (3)
Purunui	62 (3)	62	372,000	181,400 (33%)	553,400	554,921 (3)
		Total	**9,540,500**	**5,434,700 (36%)**	**14,975,200**	**15,000,000**

(1) These areas are based on the assumption that pasture is irrigated. However, larger areas of less intensive crops or horticulture can be irrigated within the same yearly volumes used by pasture, with little-to-no difference in the hydraulic effect.

(2) The Tranche 2 water will supplement existing takes to irrigate a larger area of land than can be irrigated from the Tranche 2 water alone. Therefore, it has been assumed above that all of the Tranche 2 irrigation water applied for is utilised.

(3) Less than applied for.

A map of groundwater level difference between status quo and augmentation scenario 4 is presented in Figure 26 for 1 March 2011. This demonstrates how groundwater levels are predicted to change spatially during dry periods. Temporal changes in groundwater are discussed in Section 3.15.

The following key observations are derived from these results:

- As previously noted in Table 24, the combined effects from the proposed irrigation takes alone are predicted to result in a total reduction in the 7-day MALF out of the basin of approximately 236 l/s (-153 l/s from the Waipawa and -83 l/s from the Tukituki). Under augmentation scenario 4 (Table 31), the combined 7-day MALF out of the basin is expected to increase by approximately 233 l/s as a result of +15 l/s (increase) in the Waipawa and +218 l/s (increase) in the Tukituki.
- Overall, augmentation scenario 4 is having a positive effect on the 7-day MALF exiting the basin, and also fully or nearly mitigates the effects on low flows in both the Mangaonuku and Tukipo rivers.
- Similar to previous scenarios, shallow groundwater levels are predicted to lower up to a maximum of 0.7 m under augmentation scenario 4, focussed near the applicants' properties. Elsewhere, shallow groundwater levels are predicted to change less than 0.2 m.

From the above, augmentation scenario 4 provides a reasonable balance between irrigation and augmentation while providing a positive benefit to low flows out of the catchment (low flows increase compared to status quo scenario where no Tranche 2 water is taken). In other words, the adverse effects of the Tranche 2 takes on surface water low flows exiting the basin are over-compensated under scenario 4. The very small residual negative changes to 7-day MALFs in the Tukipo River at both the SH50 and Ashcott Rd sites are smaller than both model uncertainty and measurement precision.

Additional model outputs have been generated and presented in the following sections. Where relevant, these results are from augmentation scenario 4 (i.e. not from augmentation scenarios 1-3).

3.12 Effects at Red Bridge

Due to the large distance between the basin outlet and Red Bridge and the associated complexity of the hydrogeology along the Heretaunga Plains, the effects at Red Bridge as a result of the proposed Tranche 2 activities is very difficult to derive. That is why the proposed Tranche 2 activity targets full mitigation of low-flows out of the basin. Given this, the low-flow reliability of downstream users would not be made worse by the proposed Tranche 2 activities.

However, assuming that the change in flow out of the basin is seen directly at Red Bridge then an estimate of effects on flows at Red Bridge has been made under the augmentation scenario 4. This is shown in Appendix G. Here, the sum of the flow differences in the Tukituki River at Tapairu and Waipawa River at RDS/SH2 (i.e. the flow differences exiting the basin) have been subtracted off the measured river flows at Red Bridge. Due to the long distance between the basin exit and Red Bridge, the flow differences have been off-set (delayed) by one day to approximate the travel time between the two sites.

Although the finer details are difficult to distinguish in Appendix G, the adjusted flows at Red Bridge do not drop below the PC6 low flow trigger more frequently as a result of the Tranche 2 activities, apart from briefly (by 1-3% of the trigger flow) on the following six individual days:

- 13/03/1973
- 23/03/1977
- 30/03/1978
- 24/11/1984
- 11/01/1985
- 26/02/2003

This suggests that the Tranche 2 activities would have an unnoticeable adverse effect at Red Bridge. Conversely, there are approximately 132 days over the 40-year simulation period where augmentation out of the basin is predicted to prevent flows at Red Bridge reaching the low-flow trigger (during dry periods). These results suggest that the proposed Tranche 2 activities would have either a positive or unnoticeable effect at Red Bridge.

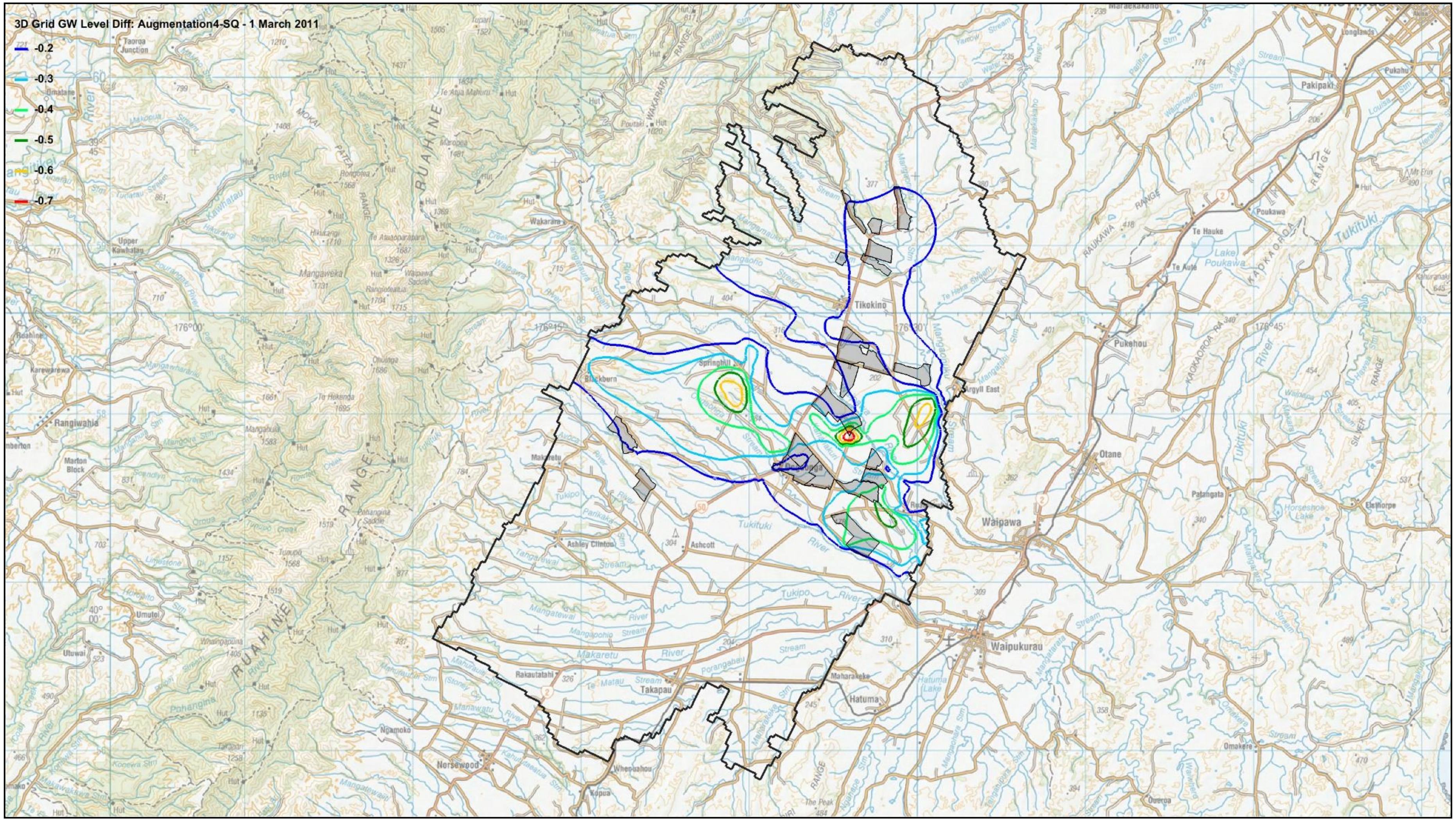


Figure 26: Difference in shallow (layer 1) groundwater levels at 1 March 2011 between status quo and augmentation scenario 4

3.13 Potential Effects at Other Streams and Rivers

All of the existing or proposed Tranche 2 bores are (or will be) screened at or below 50 m below ground level. At these depths, the takes will not be directly stream depleting, but effects will develop slowly and will be spread over a wide area. This is simulated by the numerical model, but due to the catchment scale of the model, not every single stream is represented in the model. Therefore, the model has been used to predict the change in flow in the modelled streams throughout the basin (other than the five key low-flow sites) as a result of the proposed Tranche 2 activities and (where relevant) has been used to derive an estimate of change in the other small streams not modelled.

All river sites gauged by HBRC within the basin (noted in Figure 7) are located on rivers that have been included in the model and used for model calibration. Of the sites that naturally dry, the general modelling results suggest that flows in these streams might be dry a few days (1-3 days) earlier with the Tranche 2 takes, and similarly flows would likely return a few days later. As these streams are dry during the very dry periods, further stream depletion assessments are not sensible.

The following streams that are not represented in the model have been identified that are likely to remain flowing along some, or all, of their reaches:

- Black Stream (near I&P Farming); and
- Avoca River (near Tuki Tuki Awa).

Depletion in these two streams have been interpolated based on the modelled depletion from relevant nearby streams. This assessment is provided in Table 33 and focusses on sites where the maximum change is expected (e.g. just above and below augmentation locations). From these results, the following conclusions are drawn:

- Flow differences are both positive and negative. Negative differences are typically located above reaches that receive augmentation water.
- The negative flow differences are very small (1-10 l/s), typically less than model and measurement precision. The larger differences typically occur in the rivers with the larger flows (such as the Waipawa River) and hence the flow differences will be a much smaller percentage of the flow.

Table 33: Summary of modelled stream depletion augmentation scenario 4 for river and stream sites not included in model calibration

Property	River	Location	Modelled flow change in 7-day MALF due to Tranche 2 activities (l/s)	Comment
TAFT	Mangaonuku	u/s augmentation site	-1	
	Mangaonuku	d/s property	+2	
	Mangamate	u/s Mangaonuku	-1	
	Mangamauku	u/s Mangaonuku	-1	
Papawai	Waipawa	u/s augmentation site	-4	
	Waipawa	d/s augmentation site	+14	
Tuki Tuki Awa	Tukituki	u/s augmentation site	0	
	Tukituki	d/s augmentation site	+10	
	Avoca	u/s Tukipo	0	Estimated from effect on Tukipo
PRD	Kahahakuri	u/s augmentation site	0	
	Kahahakuri	d/s property	+1	
	Ongaonga	u/s Tukituki	-2	
Springhill	Mangaoho	u/s Mangaonuku (u/s augmentation)	-10	
	Mangaonuku	d/s Mangaoho (d/s augmentation)	+7	
	Waipawa	u/s Papawai augmentation site	-4	Same site as Papawai
I&P	Tukituki	u/s augmentation site	+20	
	Tukituki	d/s augmentation site	+24	
	Black Stream	d/s property	0	Estimated from effect on Ongaonga
Buchanan	Ongaonga	u/s augmentation site	0	
	Ongaonga	d/s augmentation site	0	
	Kahahakuri	u/s PRD augmentation site	0	Same site as PRD
Purunui	Waipawa	u/s augmentation site	+11	
	Waipawa	d/s augmentation site	+12	
	Kahahakuri	d/s PRD property	+1	Same site as PRD

3.14 Reduction in Aquifer Volume

The proposed Tranche 2 takes are expected to lower groundwater levels (as do existing takes). In doing so, the total volume of water stored in the groundwater system is also expected to reduce, but only marginally compared to the total volume of water stored in the aquifer system. Within the basin's area (approximately 78,000 ha), the existing (status quo) total volume of water in the groundwater system is in the order of 15 billion m^3 (assuming an average depth of 200 m and porosity of 0.1). The proposed Tranche 2 takes are predicted to lower groundwater levels by 0-0.7 m, with a spatially-averaged maximum change of approximately 0.2-0.3 m. This equates to a volume of water of approximately 0.01-0.02 billion m^3 which is 0.07-0.13% of the total volume.

3.15 Temporal Response in Calibration Wells

Appendix H provides groundwater level hydrographs comparing status quo with augmentation scenario 4. Generally, the wells that respond less to climate and groundwater abstraction are shallower wells that are screened in the shallow unconfined aquifer that has higher storage coefficients compared to deeper wells. Groundwater levels in these shallower wells are also moderated by streams. Deeper wells experience greater seasonal variation and greater response to the additional Tranche 2 takes. However, there is no obvious temporal variation (over multiple years) to suggest that groundwater will be mined and continue to decline. Groundwater levels simply oscillate at a lower dynamic equilibrium.

For wells that are obviously influenced by pumping, the seasonal response (the saw-tooth effect) as a result of the additional Tranche 2 takes is smaller than that currently experienced from existing takes. Bore 1426 presents one example of this. Figure 27 (reproduced from Appendix A) plots the modelled groundwater level time series in this bore under both the 'No Irrigation' and 'Status Quo' scenarios. Measured groundwater levels are also plotted.

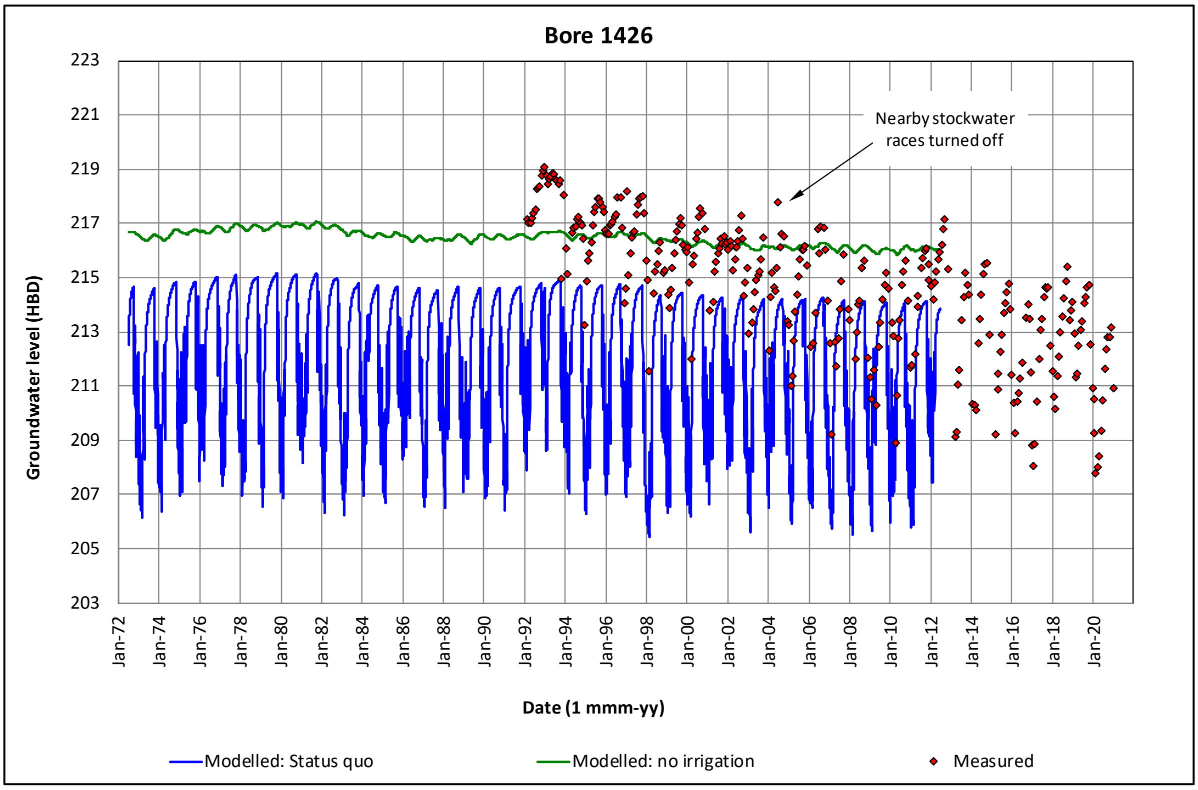


Figure 27: Modelled and measured groundwater levels in bore 1426 (reproduced from Appendix A)

Existing pumping (from nearby irrigation bores) is modelled to be having a clear seasonal effect in this bore, in the order of 8 m. Groundwater levels do not recover to the 'unpumped' state – they reach a new lower dynamic equilibrium and oscillate along there, but do not continue to decline so long as the scale of irrigation remains the same. There is a clear 'saw tooth' effect from seasonal irrigation pumping (pumps turn on during the irrigation season and off out of season). This effect is superimposed onto the longer-term response from climate (the top of the blue line is roughly parallel (but lower) to the green line which shows similar seasonal variability over multiple years). Other bores in the area exhibit a similar response, as demonstrated in Appendix A.

The predicted responses in bore 1426 under both the 'Status Quo' scenario and augmentation scenario 4 are shown in Figure 28. Here, the Tranche 2 takes are predicted to lower the low groundwater levels in this well by approximately 1-2 m further compared to existing pumping. This is approximately an order of magnitude smaller than the effects of existing pumping.

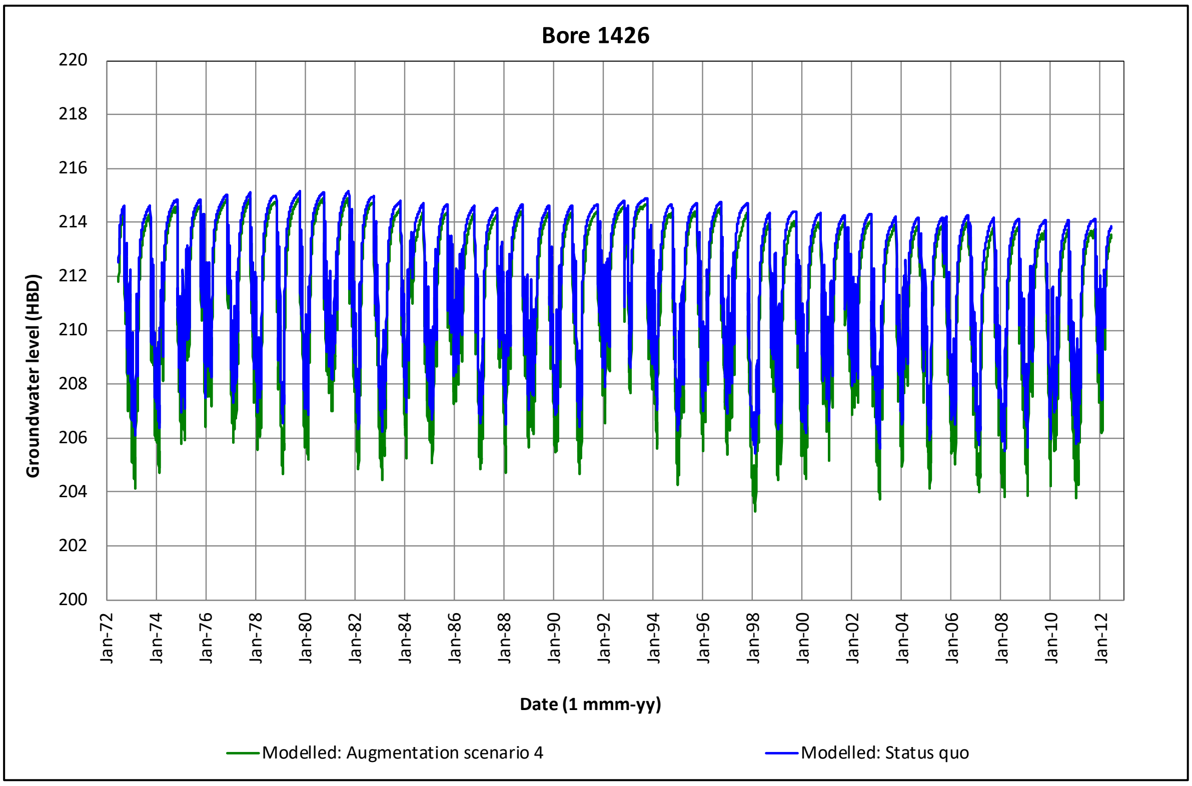


Figure 28: Modelled groundwater levels in bore 1426 (reproduced from Appendix H)

As indicated in Figure 27, stock water races in the area were turned off in approximately 2005. This has contributed to the groundwater level decline in this bore and in other bores (as indicated in Appendix H) but has not been accommodated in the modelling.

3.15.1 Timing of Change

To quantify the length of time for groundwater levels to fully change as a result of the proposed Tranche 2 activities, augmentation scenario 4 has been rerun but with initial conditions set as the same as the 'Status Quo' scenario. In other words, the model starts at the status quo state and then immediately progresses with the additional proposed Tranche 2 irrigation takes and augmentation discharges. Figure 29 shows an example of how groundwater levels move from status quo to the lower transient equilibrium under augmentation scenario 4 for one example calibration bore (3076).

The time for the new groundwater level equilibrium to be reached varies depending on location and depth. Appendix I summarises the modelled time for each calibration well to reach approximately 0.05 m[1] of the augmentation scenario 2 levels and also to reach 90% of the total difference at the start. There is a wide range of predicted times, with both states being reached at times ranging between zero and 40+ years. On average, the full effects are predicted to be reached within approximately 10 years and 90% within approximately 7 years.

[1] A value of 0.05 m has been used to represent the full effects of change as this is a level that is typically less than groundwater level measurement precision.

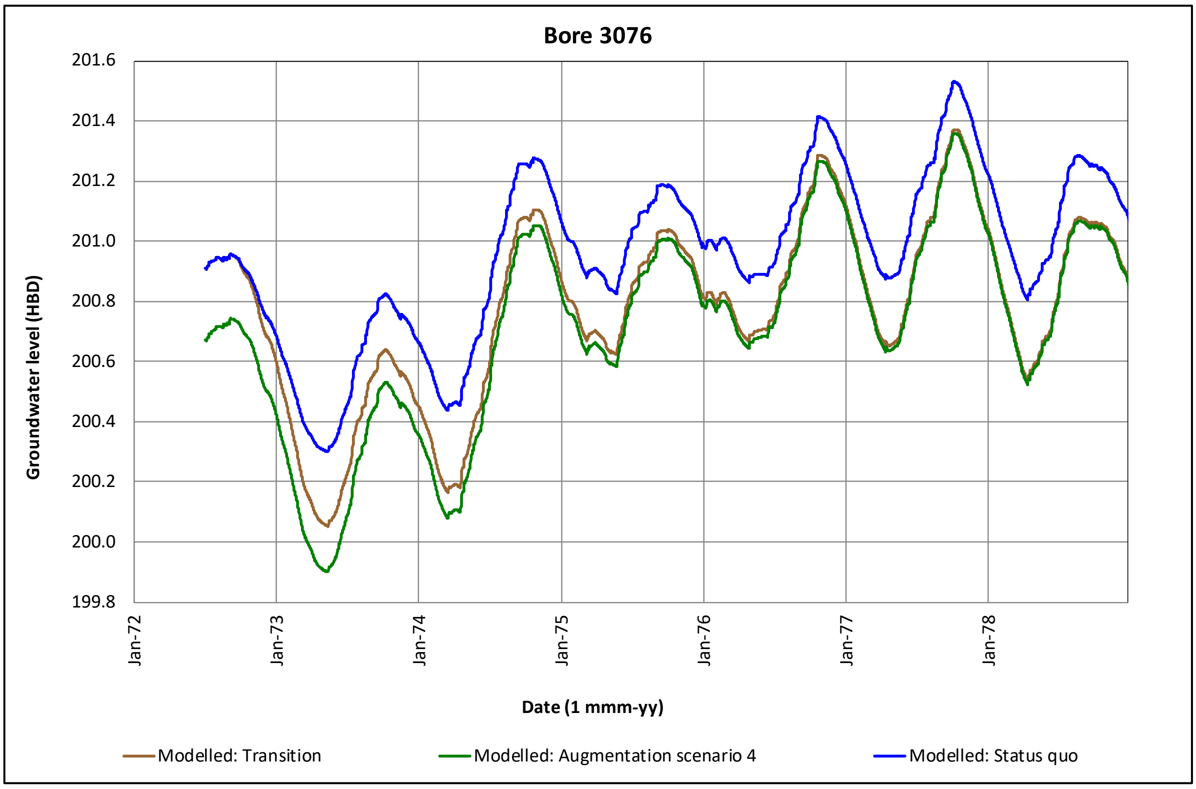


Figure 29: Example of the timing of change for bore 3076

3.16 Manual Parameter Sensitivity Scenarios

To provide a feel for how the changes in river flows due to Tranche 2 activities are affected by model parameters, simple manual sensitivity scenarios have been run where all riverbed conductances and aquifer horizontal and vertical hydraulic conductivities are adjusted. The subsequent changes in river flows as a result of the Tranche 2 activities are then compared to the equivalent outputs from the calibrated model.

Initially, sensitivity scenarios were trialled where parameters were simultaneously increased by one order of magnitude (x10), and then reduced by one order of magnitude (x0.1). However, the x10 scenario became numerically unstable and model flows were not balanced (the model numerically created and/or lost water). Furthermore, the very high aquifer conductivities resulted in very low groundwater levels (several tens of metes lower than calibrated). Because of this, some wells went dry and MODFLOW turned these wells off. Therefore, there was less pumping. Consequently, results from this ‘x10’ scenario were meaningless and could not be compared to other scenarios.

Similar numerical instability was also found when parameters increased by a factor of 5. Increasing parameters by a factor of 2 was numerically stable, and the absolute magnitude of parameter changes are similar to the x0.1 scenario (but in the opposite direction). This presents a more balanced assessment of parameter response (compared to the more extreme x10 and x5 scenarios).

Changes in river flows as a result of the proposed Tranche 2 takes and augmentations have then been compared to the original calibrated model results. This has been completed for augmentation scenario 4 as this represents the likely operation of the proposed Tranche 2 activities. Results are presented in Table 34.

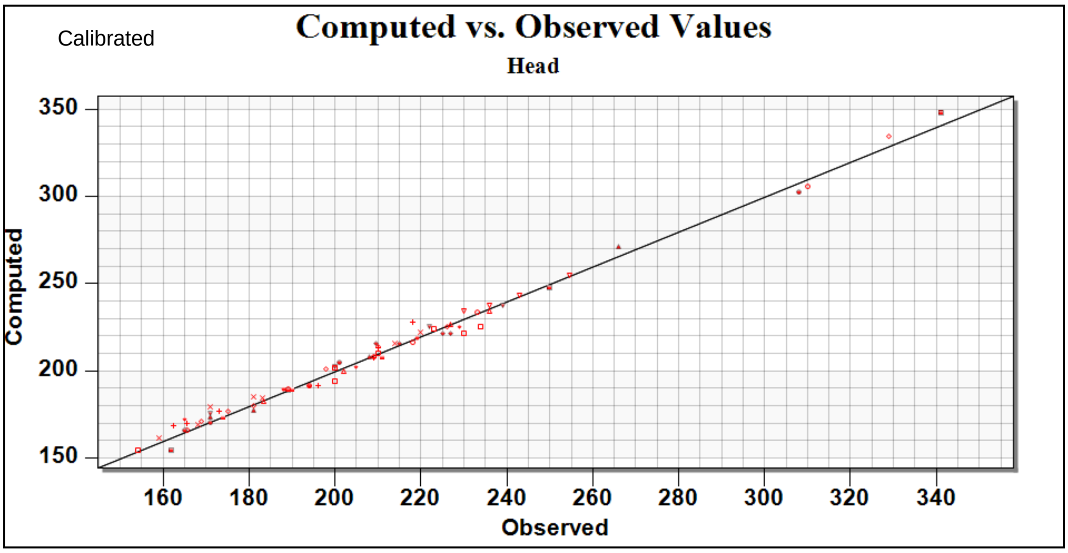
Table 34: Modelled changes in flow statistics (over the period 1972-2012) between status quo and augmentation scenario 4 for different manual parameter sensitivity scenario

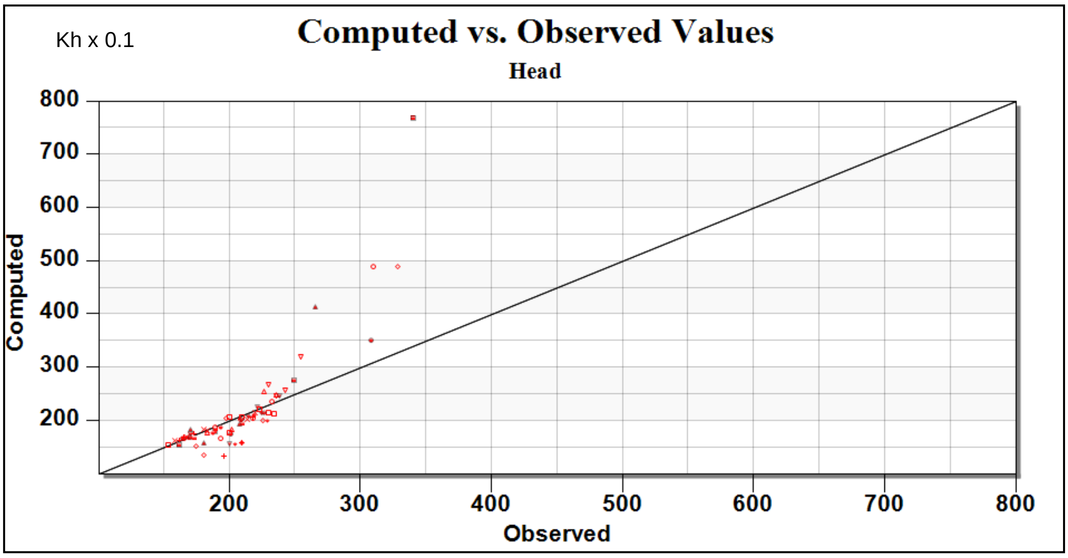
Sensitivity scenario	**Site**				
	Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
	Change in average flow (l/s)				
Original model	-188	-37	-1	-5	-50
Parameters x 0.1	-184	-49	-2	-6	-51
Parameters x 2	-151	-39	-1	-5	-19
	Change in mean 7-day annual low flow (MALF) (l/s)				
Original model	+15	+218	-1	-3	+7
Parameters x 0.1	+42	+189	-1	-4	-3
Parameters x 2	+18	+195	-1	-2	-1

From Table 34, the difference in the average flows due to the proposed Tranche 2 activities are relatively consistent between the different sensitivity scenarios. This is expected as the overall flow balance is maintained (substantial water is not numerically created or removed as a result of changing aquifer parameters with a numerically-stable model). Small differences are evident due to changes in groundwater flow directions that results from the different model parameters.

The effects of changes in the flow directions are more evident in the changes in low flows. Compared to the calibrated state, the effects of the proposed Tranche 2 activities under both the x0.1 scenario and the x2 scenario are similar to the calibrated model. Low-flow changes at the monitoring sites remain positive or (where negative) small, and the total change in low flows exiting the basin (the sum of the Waipawa and Tukituki sites) is approximately consistent with the original model.

Figure 30 demonstrates the level of 'uncalibration' for the two sensitivity scenarios. Given how different the modelled and measured groundwater levels are for the two sensitivity scenarios (particularly the x0.1 scenario), yet with relatively consistent results in predicted river flow changes (the combined low flow differences exiting the basin are still predicted to be positive), it can be concluded that the model and associated outputs are adequate for predicting the effects of the proposed Tranche 2 activities. The resulting changes between scenarios are relatively insensitive to model parameters (within the bounds of acceptable calibration).





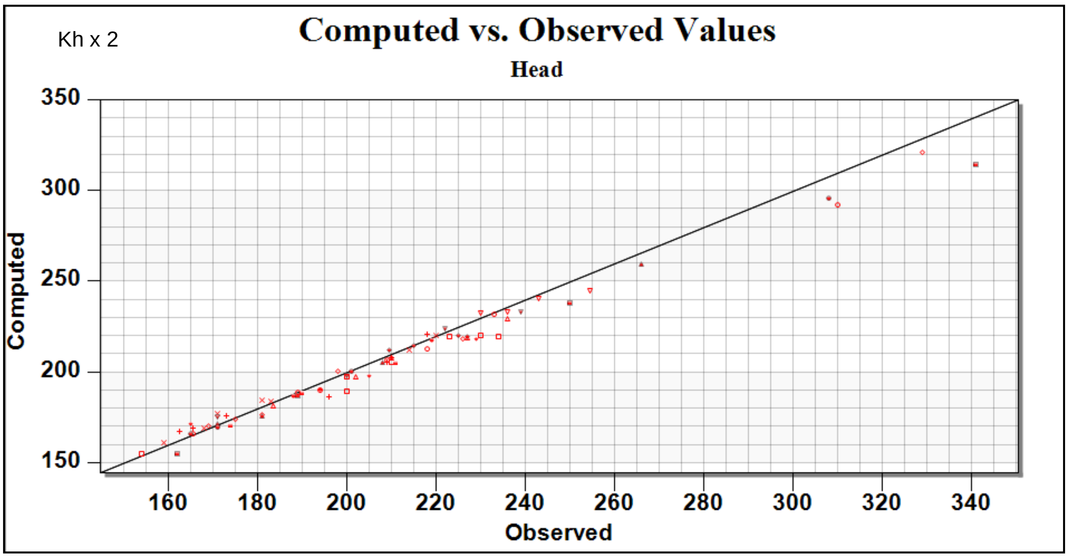


Figure 30: Measured versus modelled steady state (average) groundwater levels for the status quo scenario given different sensitivity parameters

3.17 Constrained Monte Carlo Assessment

To quantify the predictive uncertainty associated with modelled *changes* between scenarios, a Monte Carlo simulation has been completed on the transient model. This technique is conceptually similar to the manual sensitivity analyses, but tests a larger range of parameter combinations to quantify of the uncertainty associated with the predictions of change while constraining the parameters within acceptable calibration criteria. The analyses are constrained by only considering parameter sets that adequately meet calibration criteria.

The constrained Monte Carlo assessment involved the following key steps:

- Running the model many times with PEST to generate a range of parameter combinations. The parameters varied included aquifer hydraulic conductivity (both horizontal and vertical), storage (both shallow and deep), stream bed conductivity, general head conductances and groundwater pumping scaling (as discussed in Section 2.5).
- From these sets of parameter combinations, the top 10 were selected that resulted in adequate calibration to groundwater levels and river flows. The criterion for 'adequate' was defined whereby the objective function (discussed in Section 2.4) was no more than 10% higher than the equivalent in the calibrated model.
- For each of these 10 parameters sets, the transient model was run under both the status quo scenario and the augmentation scenario 4. Differences in low groundwater levels and 7-day MALFs were then calculated, resulting in 10 predictions for these differences.

Table 35 summarises the predicted variability in low groundwater levels from this assessment, and Table 36 presents the equivalent for low river flows (7-day MALFs). Generally, the 95% confidence interval for each predicted change encompassed a relatively narrow band around the best prediction of the original calibrated model. The predictions from the calibrated model are typically closer to the lower bound of the confidence interval which suggests the prediction is conservative.

Table 35: Results of the constrained Monte Carlo assessment on low groundwater levels

Bore	Groundwater level change as at 1 March 2011 (m)	
	Calibrated model (best prediction)	95% confidence interval
1376	-0.37	-0.38 – -0.28
1379	-0.62	-0.67 – -0.52
1426	-1.59	-2.06 – -1.24
1429	-3.82	-3.83 – -2.96
1430	-1.96	-2.55 – -1.53
1452	-4.25	-4.39 – -3.78
1458	-0.39	-0.40 – -0.33
1475	-1.05	-1.41 – -0.90
1485	-0.66	-1.44 – -0.59
1558	-0.03	-0.16 – -0.03
1662	-0.22	-1.04 – -0.14
1826	-0.80	-1.36 – -0.70
1861	-2.14	-2.86 – -1.94
1900	-0.57	-0.57 – -0.42
1944	-0.26	-1.27 – -0.19
2220	-0.89	-1.28 – -0.76
2749	-1.84	-2.16 – -1.51
2979	-1.44	-1.58 – -1.24
3076	-0.39	-0.66 – -0.33
3452	-3.84	-3.85 – -2.99
3702	-2.07	-2.66 – -1.61
4685	-1.60	-2.05 – -1.25
4693	-0.13	-0.17 – -0.13
4694	-0.13	-0.17 – -0.13
4695	-0.02	-0.03 – -0.02
4696	-0.02	-0.03 – -0.02
4697	-1.64	-1.97 – -1.25
4700	-0.72	-1.17 – -0.62
4701	-1.83	-1.92 – -1.59
4702	-0.94	-1.09 – -0.82
5335	-0.01	-0.05 – -0.01
5445	-3.79	-3.80 – -2.95
6719	-1.67	-1.72 – -1.19
10993	-0.25	-0.25 – -0.20
15014	-1.21	-1.39 – -1.05
15015	-1.26	-1.45 – -1.09
15021	-0.72	-1.17 – -0.62
15048	-1.48	-1.82 – -1.20
16094	-1.84	-2.25 – -1.30
16095	-1.84	-2.25 – -1.30
16247	-1.63	-1.97 – -1.24
16248	-0.68	-1.16 – -0.59
16249	-2.96	-3.15 – -2.51
16250	-0.34	-0.36 – -0.29
16251	-1.79	-2.34 – -1.36
16252	-1.98	-2.77 – -1.36
16253	-0.29	-0.33 – +0.37
16477	-0.68	-1.16 – -0.59
16478	-1.27	-1.29 – -0.14
16479	-0.13	-0.13 – +0.24
16484	-0.14	-0.86 – -0.13
16485	-0.34	-0.35 – -0.28
16486	-0.62	-0.71 – -0.54
16487	-0.61	-0.65 – -0.51
16488	-0.69	-1.20 – -0.60
16489	-3.75	-3.80 – -3.07
16490	-1.28	-1.45 – -1.05
16491	-0.48	-0.48 – -0.37
16492	-0.86	-0.92 – -0.75
16498	-0.69	-0.70 – -0.58
16499	-0.41	-0.43 – -0.35
16500	-0.14	-0.15 – -0.11
16501	-2.33	-2.38 – -1.94
16502	-0.09	-0.23 – -0.05
16503	-0.78	-0.79 – -0.43
16504	-0.35	-0.37 – -0.29
16507	-0.95	-1.06 – -0.82
16639	-1.60	-2.05 – -1.25
16879	-6.70	-6.78 – -5.35
16880	-1.49	-1.84 – -1.20
16881	-0.67	-1.15 – -0.59
16882	-0.67	-1.15 – -0.59
Dummy1	-0.17	-0.69 – -0.07
Dummy2	-0.17	-0.77 – -0.05
Dummy3	-0.23	-0.87 – -0.14
Dummy4	-0.11	-0.73 – -0.08
Dummy5	-0.16	-0.17 – -0.09
Dummy6	-0.14	-0.15 – -0.07
Dummy7	-0.14	-0.59 – -0.09

Table 36: Results of the constrained Monte Carlo assessments on low river flows

Property	River	Location	Change in 7-Day MALF (m^3/s)		Comment
			Calibrated model	95% confidence interval	
HBRC's low-flow restriction sites					
n/a	Waipawa	SH2	+15	+13 – +70	
n/a	Tukituki	Tapairu Rd	+218	+175 – +219	
n/a	Tukipo	SH50	-1	-1.4 – -0.2	
n/a	Tukipo	Ashcott Rd	-3	-3.2 – -1.3	
n/a	Mangaonuku	u/s Waipawa	+7	+4 – +14	
Locations near applicants properties (from Table 33)					
TAFT	Mangaonuku	u/s augmentation site	-1	-1.2 – -0.3	
	Mangaonuku	d/s property	+2	+1.5 – +3	
	Mangamate	u/s Mangaonuku	-1	-1.1 – -0.2	
	Mangamauku	u/s Mangaonuku	-1	-1.1 – 0	
Papawai	Waipawa	u/s augmentation site	-4	-5 – -2	
	Waipawa	d/s augmentation site	+14	+10 – +15	
Tuki Tuki Awa	Tukituki	u/s augmentation site	0	0	
	Tukituki	d/s augmentation site	+10	+6 – +10	
	Avoca	u/s Tukipo	0	0	Estimated from effect on Tukipo
PRD	Kahahakuri	u/s augmentation site	0	0	
	Kahahakuri	d/s property	+1	-5 – +2	
	Ongaonga	u/s Tukituki	-2	-2.5 – 0	
Springhill	Mangaoho	u/s Mangaonuku (u/s augmentation)	-10	-11 – -5	
	Mangaonuku	d/s Mangaoho (d/s augmentation)	+7	+4 – +11	
	Waipawa	u/s Papawai augmentation site	-4	-5 – -2	Same site as Papawai
I&P	Tukituki	u/s augmentation site	+20	+19 – +23	
	Tukituki	d/s augmentation site	+24	+23 – +30	
	Black Stream	d/s property	0	-0.1 – +0.1	Estimated from effect on Ongaonga
Buchanan	Ongaonga	u/s augmentation site	0	-0.1 – +0.1	
	Ongaonga	d/s augmentation site	0	-0.3 – 0	
	Kahahakuri	u/s PRD augmentation site	0	0	Same site as PRD
Purunui	Waipawa	u/s augmentation site	+11	+6 – +14	
	Waipawa	d/s augmentation site	+12	+8 – +16	
	Kahahakuri	d/s PRD property	+1	-5 – +2	Same site as PRD

3.18 Climate Change

Climate change predictions are highly uncertain. However, a high-level assessment has been made and applied to a new set of model scenarios to represent potential future climate. This assessment is largely based on information provided in MfE (2016) and Collins & Zammit (2016). These publications include predicted changes out to approximately 2050 (mid-century), which is of a similar (or longer) duration as the proposed Tranche 2 consents (20 years).

Global climate change projections utilise a number of different possible future scenarios. To ensure a conservative assessment, only projections from the scenario with the highest increase in global green-house gas emissions have been presented. This is RCP (Representative Concentration Pathways) 8.5, which is a 'do nothing' scenario. Other scenarios make assumptions about the timing and magnitude of reduction to greenhouse gas emissions. Therefore, scenario RCP8.5 presents a worst case prediction.

Climate change projections have been assessed for the following relevant model inputs:

- Rainfall;
- Temperature and potential evapotranspiration;
- Soil moisture and irrigation demand; and
- Stream flows.

These are each discussed below.

3.18.1 Rainfall

From Table 10 of MfE (2016), annual rainfall in the Hawke's Bay region under RCP8.5 is predicted to reduce by approximately 2%, with no change during the summer months. A small increase (2%) is predicted during autumn, and 5-6% reductions are predicted for spring and winter respectively. Applying these changes results in an average rainfall reduction of approximately 25 mm/year over the basin.

3.18.2 Temperature and Potential Evapotranspiration

Temperature in the Hawke's Bay area is projected to increase by 1.1ºC under the RCP8.5 scenario (Table 5 of MfE, 2016), and this is predicted relatively evenly over all seasons (1.0-1.1ºC change). Warmer temperatures will result in faster growing crops (particular in the shoulders of the irrigation season) and associated higher potential evapotranspiration and water demand. Changes in potential evaporation deficit (PED) (Figure 55 of MfE, 2016) are very approximate and broad-scale. However, for the Hawke's Bay area, PED is estimated to increase by 100-150 mm/year. This is a combined result of changes in rainfall, temperature, humidity and wind patterns. A value of 150 mm has been assumed.

Given an annual average rainfall reduction of approximately 25 mm per year, the remaining change in PED is attributed to an increase in PET, which is 125 mm. This equates to an increase of 15% (approximately) over and above existing PET, applied throughout the year.

3.18.3 Soil Moisture and Irrigation Demand

Given the above predicted changes in rainfall patterns and PET, irrigation will be relied upon more frequently to maintain soil moisture levels. To model this, these changed climate datasets have been run through IrriCalc to calculate the resulting change in irrigation demand and land surface recharge. Key outputs are:

- Irrigation increases by 18% (approximately); and

- LSR reduces by 9% (approximately).

These changes have been applied to the model climate change scenarios. Non-irrigation takes have been left unchanged.

3.18.4 Stream Flows

From figures 3-1 to 3-5 of Collins & Zammit (2016), projections indicate that climate change is unlikely to affect median river discharges, though the 7-day mean annual low flow (7-day MALF) is projected to reduce by 0-20% and mean annual floods are forecast to increase by 0-40%. Therefore, river inflows (from the greater catchment above the basin) have been modified as follows:

- No change in mean discharge;
- Low flows have been reduced by 10%; and
- High flows have been increased by 10% (a smaller increase than predicted has been adopted to be conservative).

3.18.5 Implications for the Tranche 2 Consents

It has been assumed that the proposed Tranche 2 takes will still be limited by seasonal volumes defined by past climate (i.e. the same seasonal volumes as applied). Therefore, if irrigation demand increases, then these limits, if reached, may be reached sooner in the season, and the full irrigation volume may be needed more frequently. Furthermore, river low-flows are predicted to reduce, and hence low flow triggers are expected to be reached more frequently. Therefore, the full augmentation volumes (also defined by past climate) are also likely to be needed more frequently. As HBRC limit the total volume of abstracted water, the subsequent effects on low flows are also limited. A warming climate will therefore likely pose most risk to the applicants (rather than the environment) and will require them to manage their water use as efficiently as possible.

The 'Status Quo' scenario has been re-run with the scaled LSR, pumping and river flows, and the output river flows examined to generate the difference in flow time series (compared to no climate change) at the five low-flow control sites. Flow differences between 'with' and 'without' climate change have then been added to the existing flow time series to generate a new (less reliable) series of flow restrictions. These have then been incorporated into the augmentation scenario 4 and the model run. River flow statistics have been calculated (as previously) and compared. Results are as presented in Table 37.

Table 37: Modelled changes in 7-Day MALF (over the period 1972-2012) between status quo and augmentation scenario 4 scenario under predicted future climate change

Site				
Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
Change in average flow (l/s)				
-220	-94	-6	-22	-83
Change in mean 7-day annual low flow (MALF) (l/s)				
+2	+267	-2	-4	+1

Compared to the results under existing climate (Table 31), the net effects on low flows still remains positive or (where negative) small under future climate. This is primarily because augmentation flows are triggered more frequently. Average flows are lower (as there is more groundwater pumping), but since augmentation is triggered more frequently, then the effects on low flows are also mitigated.

4 PRACTICAL IMPLICATIONS

To aid practical management, operation and compliance of the Tranche 2 activities, several protocols for the takes and augmentation are proposed. These proposals differ to the modelling assumptions. However, at a practical level, the differences are only marginal, and it is expected that the net effect on river flows and groundwater levels will be very similar to, or better than, those presented in the modelling above. The practical implications relate to:

- Staged development and transitional implementation;
- Automated monitoring of river flows; and
- Defining a 'Water Year' and associated start date of irrigation and augmentation.

These are each discussed below.

4.1 Staged Development and Transitional Implementation

The modelling scenarios presented above assume that every Tranche 2 take operates fully from day 1 (e.g. all bores are installed; irrigation systems are fully operational with mature pasture; augmentation is fully operational; etc.). This presents the extreme (or 'final') state that is eventually expected. However, this will not be the case initially. Some property owners have existing bores from which they can irrigate as soon as consents are granted; others have partial development; and others currently have no infrastructure and are awaiting for consents to be granted before commencing significant investment. This means that the full uptake of Tranche 2 water will not be instantaneous upon granting of the consents, but will progressively develop ('ramp up') over several years. Hence, implementation will be transitional.

The Tranche 2 applicants considered a range of options to practically manage the effects throughout the transition period. The most sensible solution arrived at proposes that each consent holder nominates (to HBRC) a maximum seasonal volume of water that they expect to need that season, proportional to the scale of property development. This then becomes the maximum allocation volume for that season (only) and the augmentation discharge rate is pro-rated on this same basis. This volume is then reassessed in subsequent years. For example, let's assume that a property has a 1-in-10 year maximum seasonal volume of 1,000,000 m^3/year and proposes to augment the adjacent river at 20 l/s when low-flow triggers are reached. If by the first irrigation season the property is 40% developed, then the maximum irrigation volume for that year will be 400,000 m^3 and the augmentation rate would be 8 l/s. If by the following year development has expanded to 60%, then the maximum irrigation volume for that year would be 600,000 m^3 and the augmentation rate would be 12 l/s. And so on up to 100% development.

This transitional implementation is founded on the principle that, while the effects of pumping propagate over a relatively large distance, the effects are largely seen in the vicinity of the abstraction location. Consequently, effects and subsequent augmentation to mitigate these effects (during low flows) are proportional to the scale of the take.

If a Tranche 2 consent holder is unsure of the level of development expected for an upcoming season, they will not want to under-predict their water needs. Hence, they would be more likely to nominate a higher percentage than a lower one. The nominated percentage of development then dictates (and locks in) the rate of augmentation for that year, regardless of whether or not the irrigation volume is used. Hence, it is more likely that the augmentation rate will be over compensated in these transitional years. This provides benefits to the rivers greater than modelled.

4.2 Automated Monitoring of River Flows

Of the five low-flow trigger sites modelled, HBRC currently monitor three of these automatically (Waipawa at SH2, Tukituki at Tapairu Rd, and Tukipo at SH50) with daily updates provided to consent holders. The other two sites are manually gauged, and updates are provided less frequently (such as weekly). Rivers and shallow groundwater downgradient of the augmentation discharge sites will respond rapidly to the discharge. Hence, daily controls are preferred to mitigate the low flows rapidly, but without significantly over compensating when river flows rise (e.g. if a fresh occurs between manual gaugings). Hence, the Tranche 2 applicants propose that their augmentation discharges are controlled daily based only on the existing three monitoring sites currently automatically monitored by HBRC. If automatic flow recorders are installed at the other two sites in the future, then these can be added to the daily control regime.

This triggering regime is expected to make little difference in the very dry years when augmentation is needed the most (all rivers experience naturally low flows). There may be some 'unders and overs' in the wetter years where the three continuously monitored sites do not fully represent the other two sites. In these cases, the augmentation may not be triggered when these other two sites are below the low flow trigger. However, it is expected that the targeted-overcompensation at other times provides a buffer that will partially mitigate effects on these streams at these times.

4.3 'Water Year' Definition and Associated Start Dates of Irrigation and Augmentation

HBRC currently define the allocation water year from 1 July to 30 June. On 1 July, monitoring of the annual volume is reset to 'zero' for the upcoming season. The Tranche 2 applicants have two volumetric limits: an irrigation volume and an augmentation volume, both defined by a 9-in-10 year season. If the water year commences 1 July (as currently defined by HBRC), it is possible that augmentation to rivers may be needed through winter at the start of the water year when there is no irrigation pumping. While this does acknowledge the fact that the effects of irrigation continue on beyond when pumping stops (as it takes time for the aquifer system to recover), there is a small possibility that augmentation water will be used in the cooler, wetter months (if minimum flows are triggered) resulting in insufficient augmentation water later in the warmer, drier parts of the season when the augmentation is needed most.

Because of this, the Tranche 2 applicants propose to define the water year commencing at the start of the irrigation season, nominally 1 October. Then, given that effects from the deep pumping take time to propagate to the surface, it is proposed that the augmentation year starts 1 month after this (i.e. 1 November). This has multiple consequences:

- Augmentation water is 'saved' for the driest times of the year when it is needed most, usually well beyond the start of the irrigation season.
- Delaying the start of augmentation will mean that, in most years, the augmentation volume will not be fully used before winter; this unused water can then be discharged throughout winter if low flows are triggered.
- Continuing to augment during winter results in the equivalent of full-year augmentation for most years (9 in 10), but provides the added assurance that there will be augmentation water available in the driest parts of driest seasons when it is needed most, rather than potentially running out just before it is needed.
- There may be the occasional time when low flows are reached during winter, but the augmentation volume is fully used and augmentation cannot continue. Based on historical records, this would occur infrequently (1 year in 10).

This proposal to define the water year as noted above will reduce the likelihood of augmentation water being used up before the irrigation water limit is reached.

5 SUMMARY AND RECOMMENDATIONS

The following key findings have been derived from the modelled scenarios:

- The effects on river flows from the proposed additional Tranche 2 takes are spread over both space and time throughout the basin.
- If augmentation occurs when both existing minimum flows are reached and when irrigation would be operating, it is insufficient to fully mitigate depletion of 7-day MALFs due to additional Tranche 2 takes.
- If augmentation is applied when minimum flows are reached, regardless of whether or not irrigation is operating, augmentation is more beneficial and results in an overall improvement in low flows exiting the basin in both the Tukituki and Waipawa rivers.
- For the Tranche 2 applicants, the adoption of higher minimum flow triggers (and therefore more frequent augmentation) provides greater benefit to 7-day MALFs. It also better protects the reliability for existing abstraction consent holders.
- Targeted over-compensation (i.e. the positive changes in MALFs) exiting the basin accommodates prediction uncertainty, enhances environmental low-flows, and accommodates across-catchment effects.
- Under augmentation scenario 4, adverse effects on surface water low flows as a result of the Tranche 2 activities are either avoided (positive effects occur as evidenced by the increased flows at the Waipawa, Tukituki and Mangaonuku flow sites), or are so minor that they fall within the margin of modelling and measurement uncertainty (i.e. for the Tukipo SH50 and Ashcott flow sites).
- Groundwater will not be mined. While groundwater levels will lower further with the additional Tranche 2 takes (made available under PC6), they will not continue to lower; they will simply reach a new (lower) dynamic equilibrium. Shallow groundwater levels are predicted to lower a maximum of 0.7 m in the vicinity of the Tranche 2 take locations, and less than 0.2 m further afield.
- The time for the new groundwater level equilibrium to be reached varies depending on location and depth. The full effects of the proposed Tranche 2 activities are predicted to take between zero and 40+ years to be fully realised. On average, the full effects are predicted to be reached within approximately 10 years and 90% within approximately 7 years.
- The reported irrigation and augmentation volumes are based on a 90-percentile year. Therefore, is it is possible that in extreme dry years (e.g. 1 year in 10), low flows could still be triggered after irrigation and augmentation volumes have been exhausted.
- Considering future climate predictions, the effects of the proposed Tranche 2 activities on low river flows at key monitoring sites are predicted to be positive or (where negative) small. Groundwater abstraction is expected to increase in the future, but so too is the frequency of augmentation, which mitigates the effects on low flows.

From the optimised scenario (augmentation scenario 4), the optimum area of irrigated pasture, augmentation rates and corresponding volumes are summarised in Table 38.

Table 38: Optimised augmentation rates, irrigated pasture areas and associated seasonal volumes

Applicant	Modelled augmentation rate (l/s, daily average)	Approx. area irrigated from Tranche 2 GW (ha) [1]	Modelled 90 percentile annual volumes (m^3/year) (1972-2012)			Tranche 2 GW volume applied (m^3/year)
			For irrigation	For augmentation (% of total)	Total	
TAFT	182	490	2,842,000	2,065,900 (42%)	4,907,900	4,914,920
Papawai	41	181	1,013,500	459,400 (31%)	1,472,900	1,475,517
Tuki Tuki Awa	30	135	607,500	342,600 (36%)	950,100	952,400
Plantation Rd Dairies	117	403	2,418,000	1,328,000 (35%)	3,746,000	3,751,225
Springhill Dairies	37	123	588,500	415,400 (41%)	1,003,900	1,005,213
I&P Farming	25	166	913,000	286,600 (24%)	1,199,600	1,200,010
Buchanan	31	131	786,000	355,400 (31%)	1,141,400	1,145,794
Purunui	16	62	372,000	181,400 (33%)	553,400	554,921
		Total	**9,540,500**	**5,434,700 (36%)**	**14,975,200**	**15,000,000**

[1] These areas are based on the assumption that pasture is irrigated. However, larger areas of less intensive crops or horticulture can be irrigated within the same yearly volumes used by pasture, with little-to-no difference in the hydraulic effect.

Proposed minimum flow triggers and net changes in 7-day MALF for key river flow monitoring sites under the optimised scenario are summarised in Table 39.

Table 39: Modelled changes in 7-day MALF (over the period 1972-2012) compared to status quo due to all applicants' irrigation takes with optimised augmentation (scenario 4)

Site				
Waipawa at SH2	**Tukituki at Tapairu Rd**	**Tukipo at SH50**	**Tukipo at Ashcott Rd**	**Mangaonuku u/s Waipawa**
Assumed low-flow restriction applied (l/s) [1]				
2,730	2,425	155	1,065	1,315
Change in mean 7-day annual low flow (MALF) (l/s) [2]				
+15	+218	-1	-3	+7
Change in 7-day MALF as a percentage of new low-flow limit				
+0.5%	+9.0%	-0.5%	-0.3%	+0.5%

[1] Discussed in Section 3.11.5. These are higher than current RRMP Table 5.9.3 limits to provide greater environmental benefit during low flows and to protect reliability of existing users.

[2] Reproduced from Table 31.

Several management, operational and compliance protocols are recommended to aid practical implementations of the Tranche 2 takes and augmentation.

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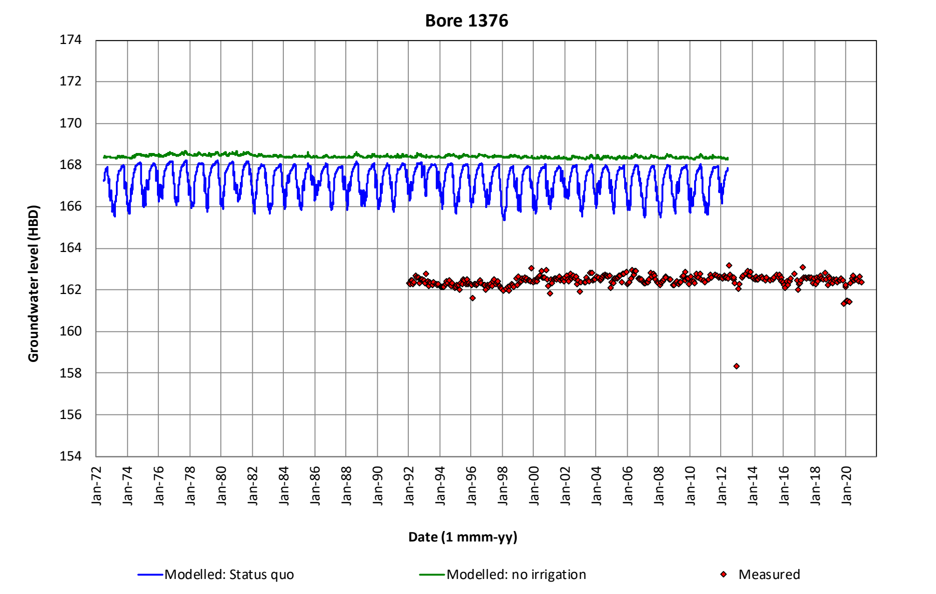
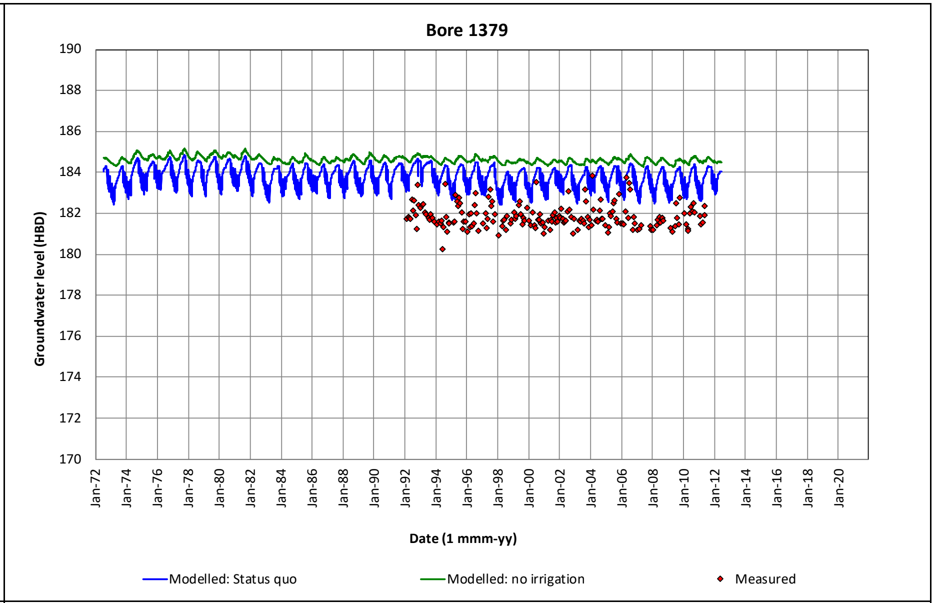
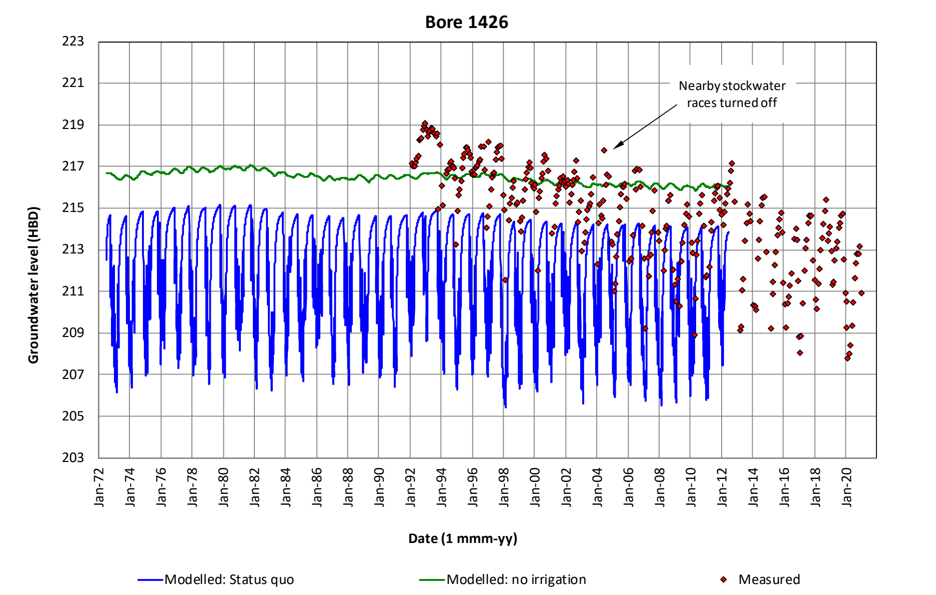
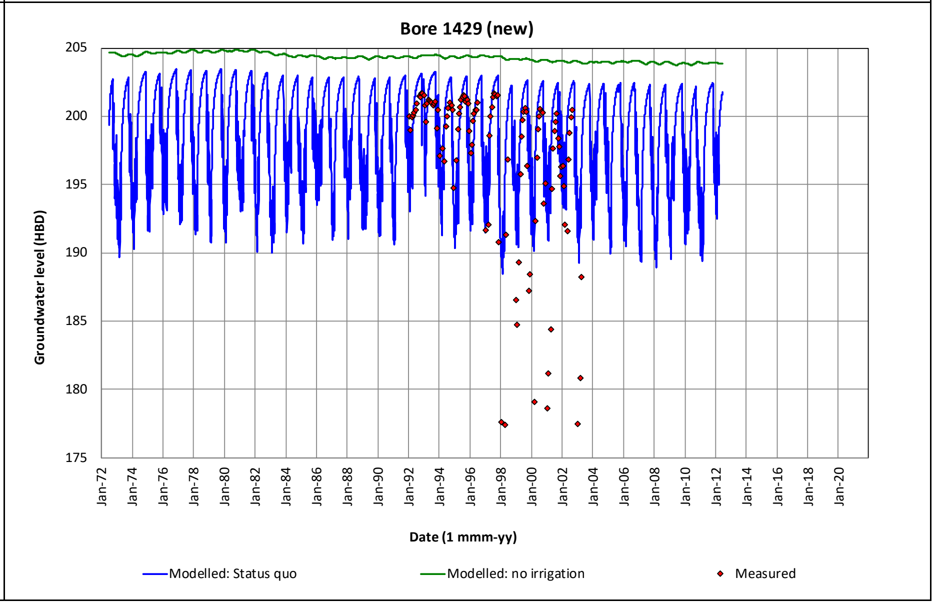
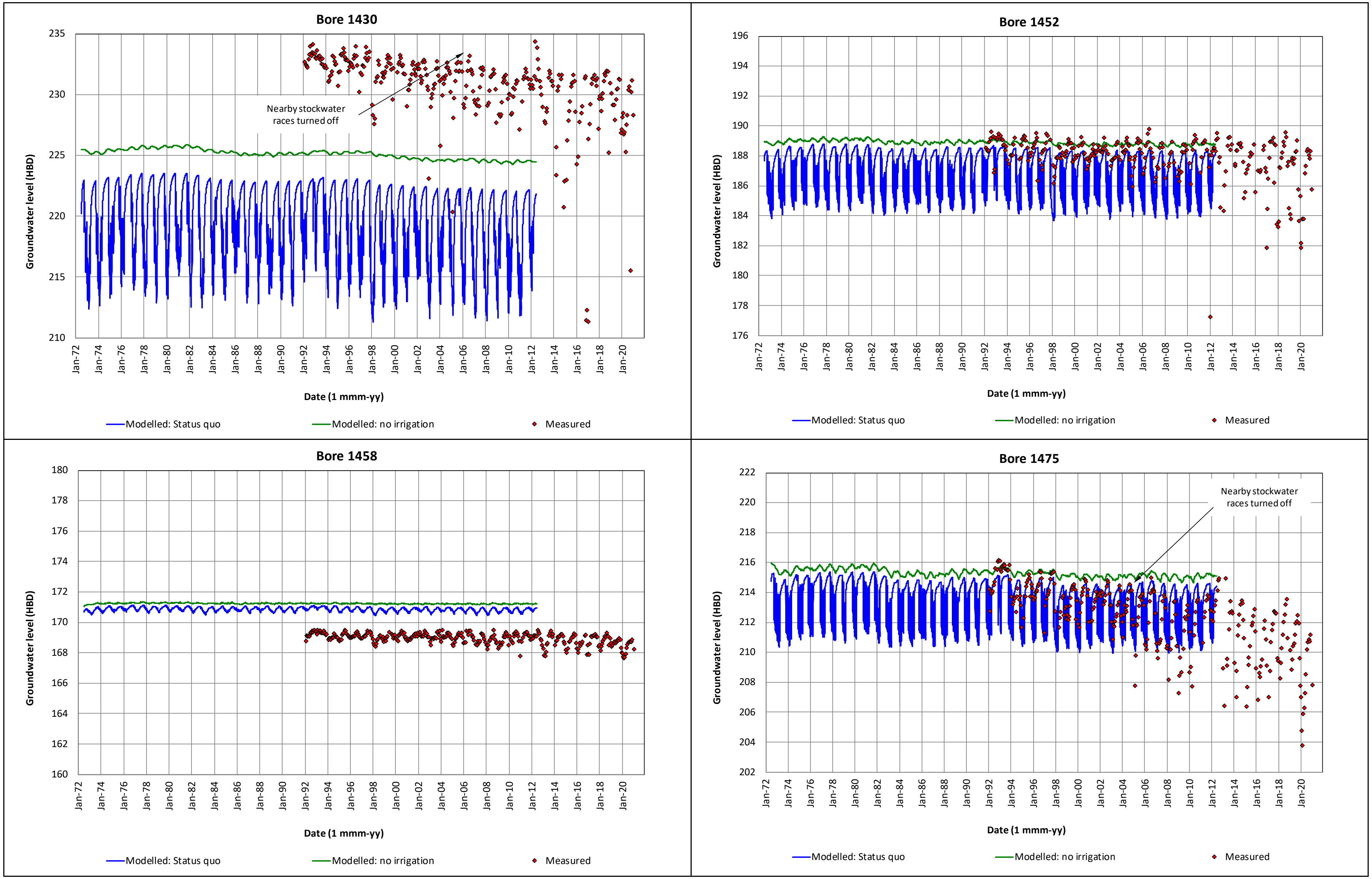
Appendix A: Groundwater level calibration plots

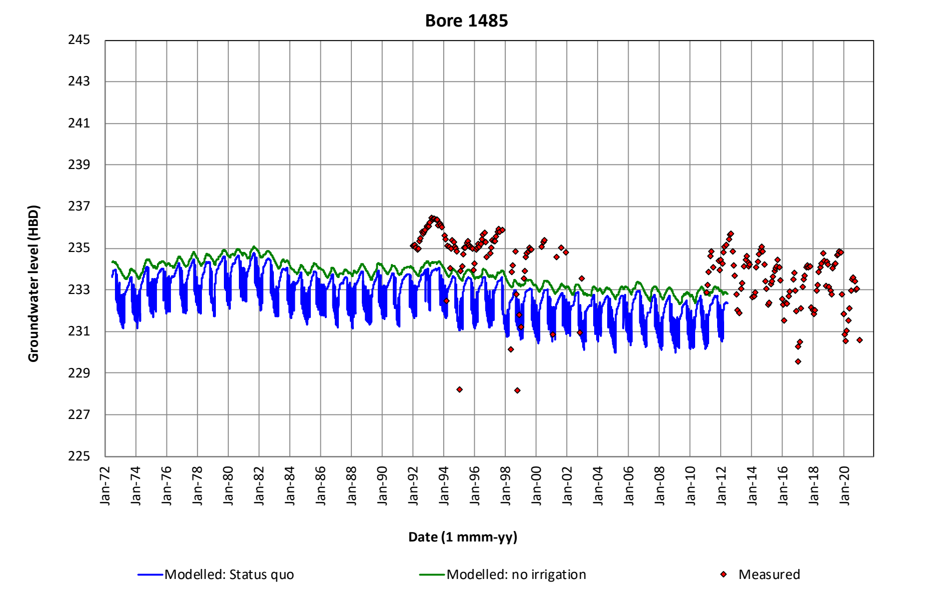

Bore 1376
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

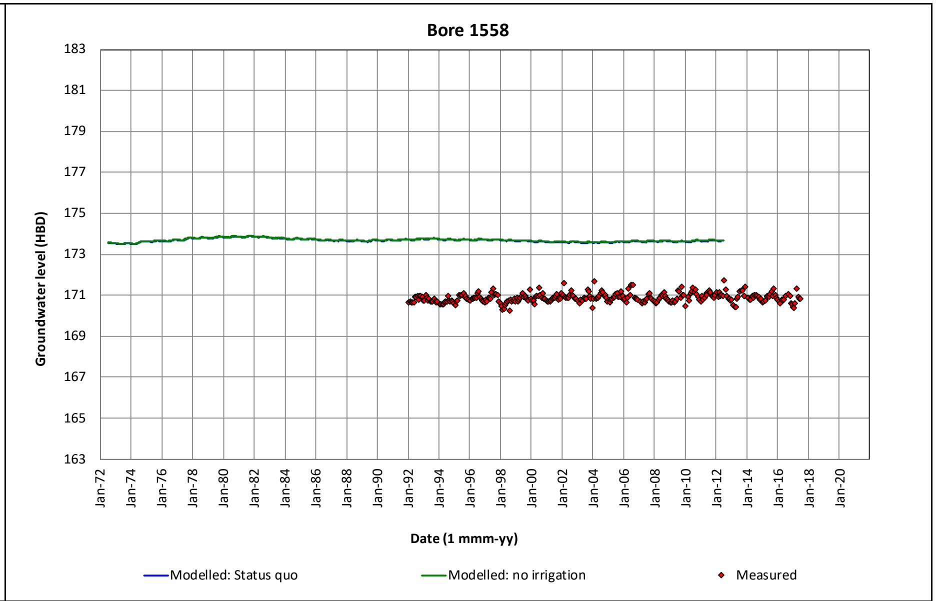

Bore 1379
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

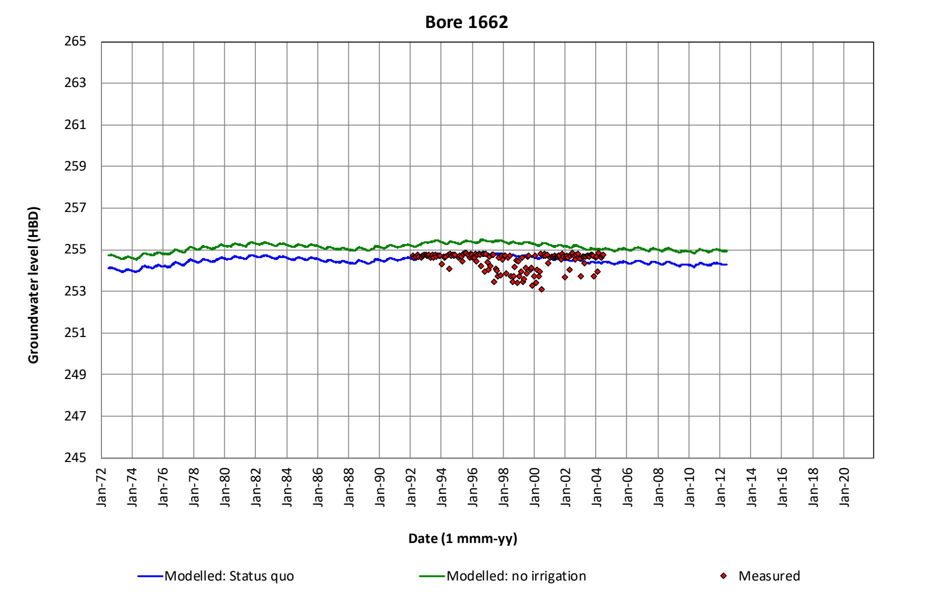

Bore 1426
Nearby stockwater races turned off
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

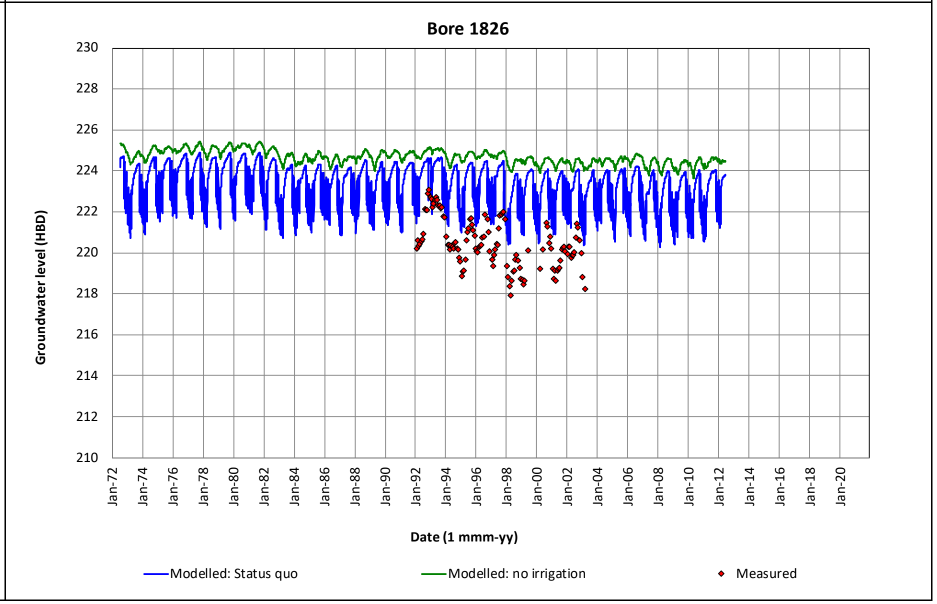

Bore 1429 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

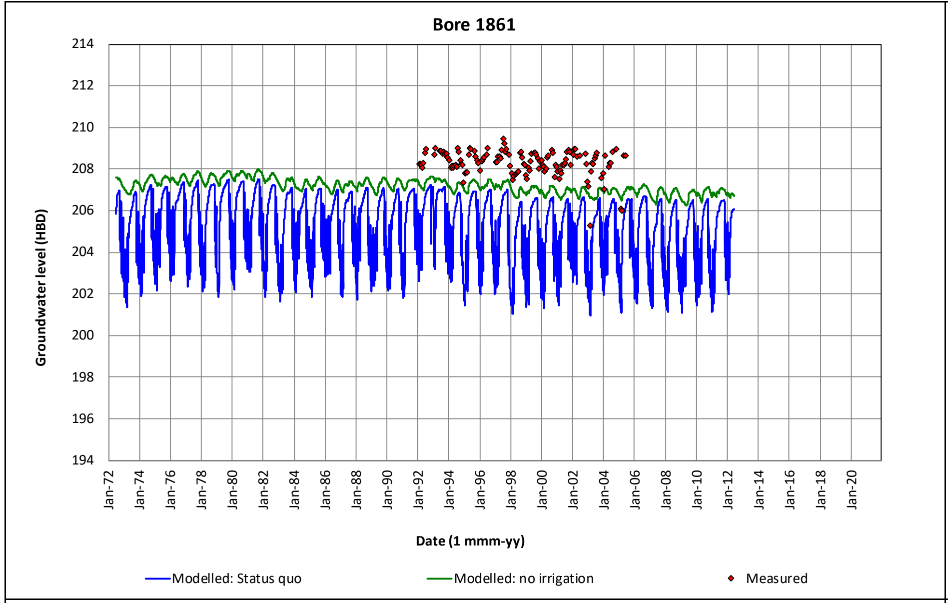

Bore 1430
Nearby stockwater races turned off
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured
Bore 1452
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured
Bore 1458
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured
Bore 1475
Nearby stockwater races turned off
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

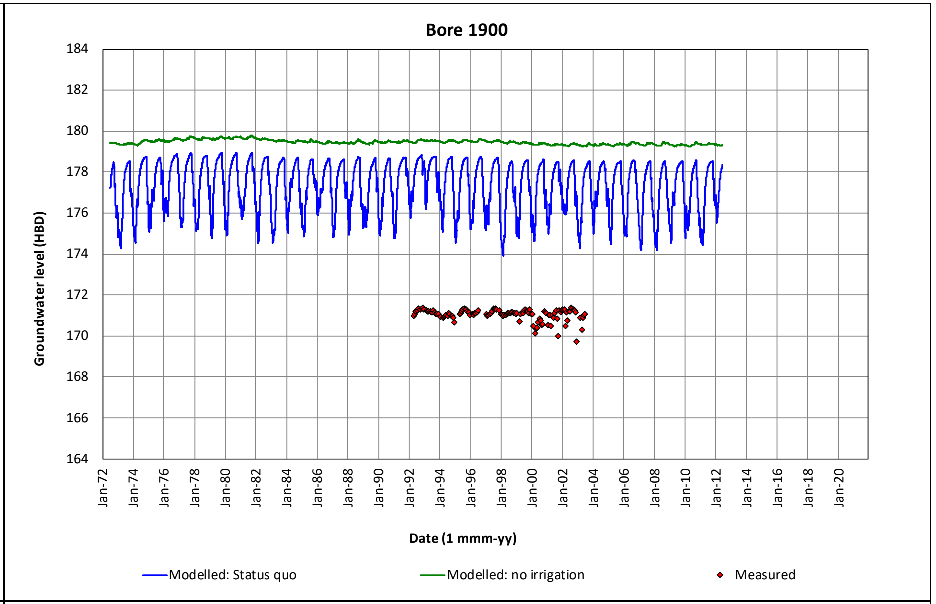

Bore 1485
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

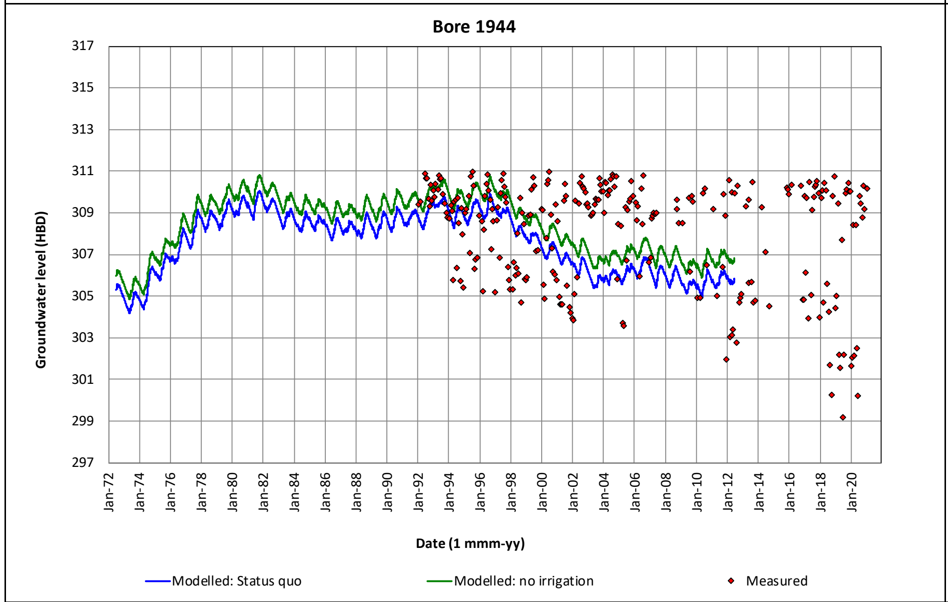

Bore 1558
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

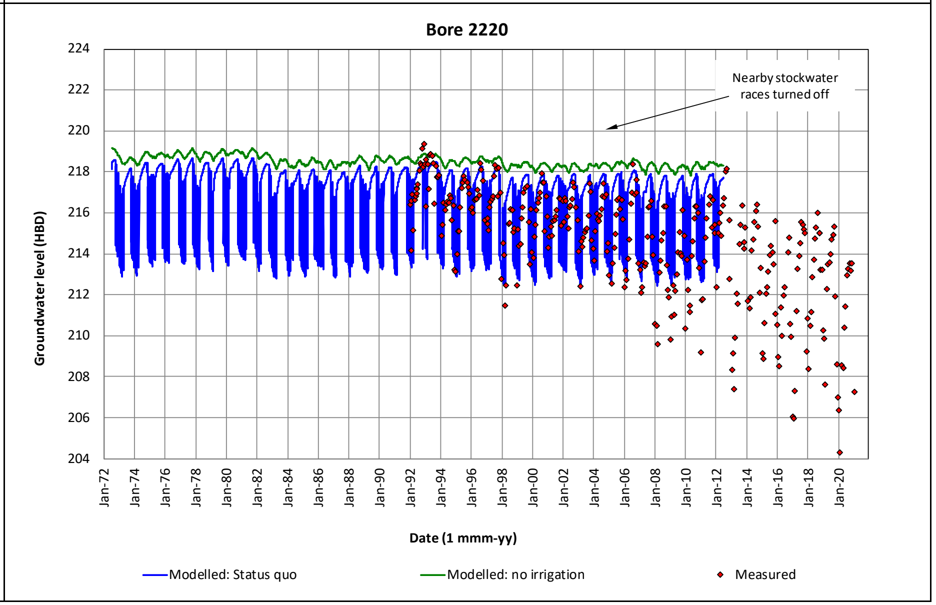

Bore 1662
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

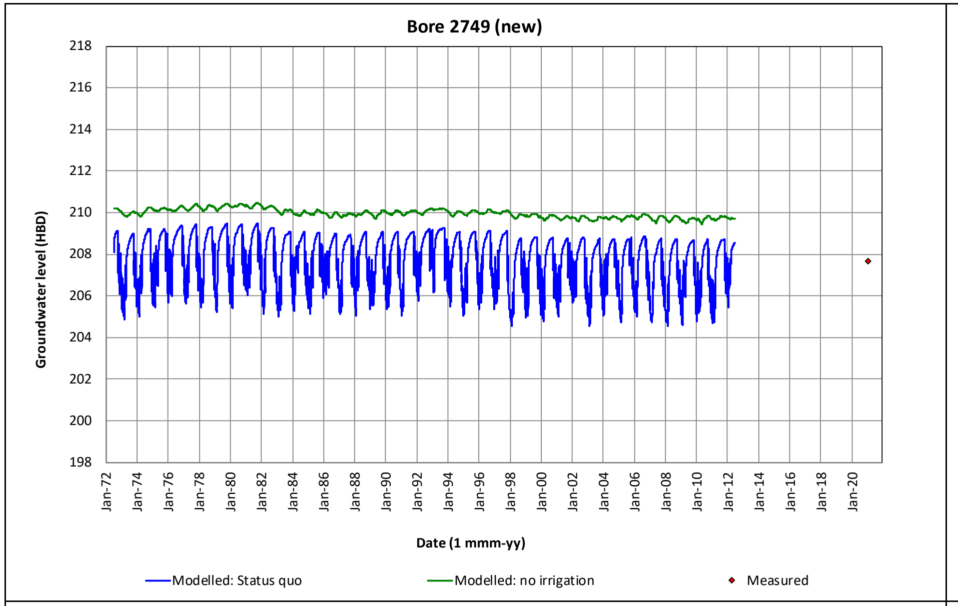

Bore 1826
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

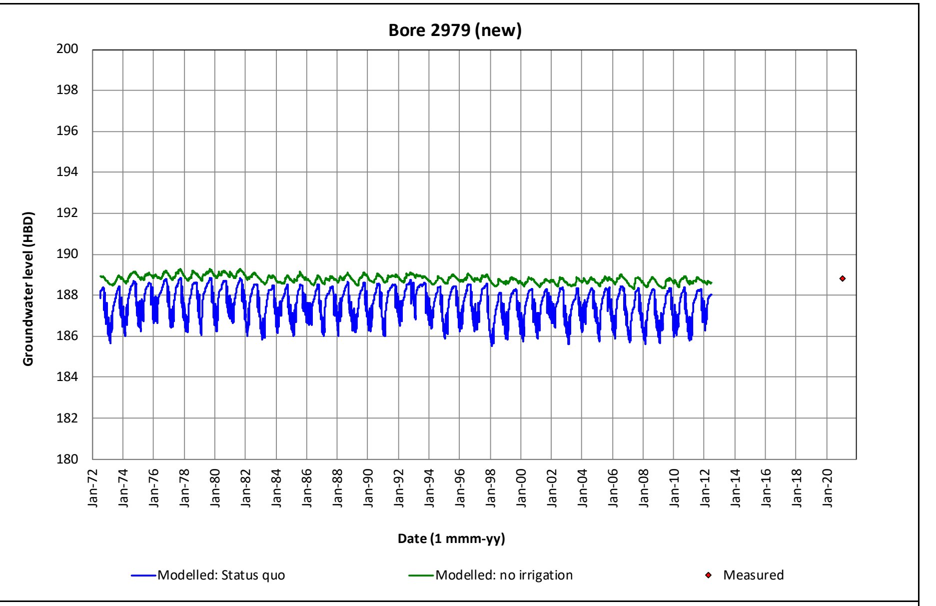

Bore 1861
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

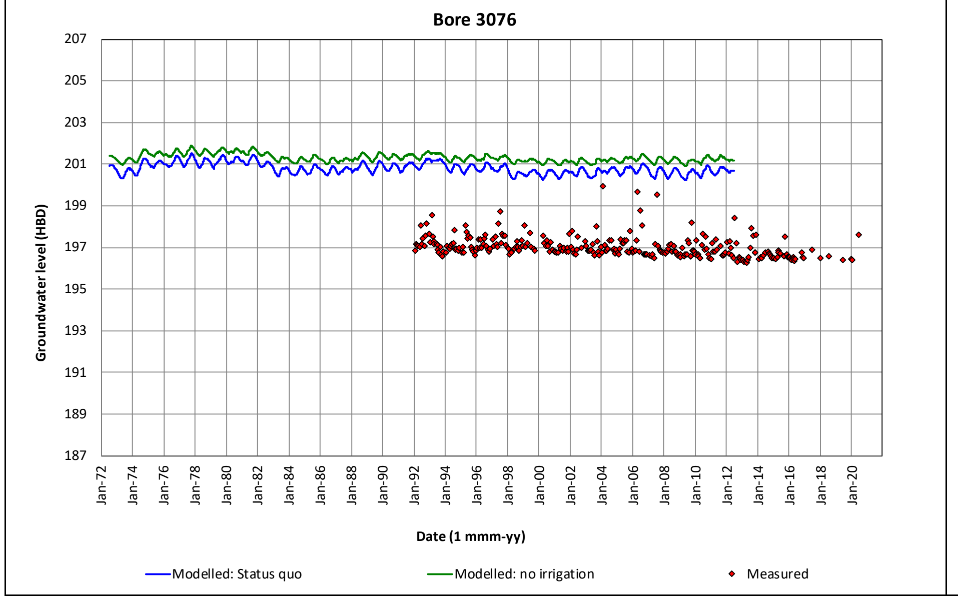

Bore 1900
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

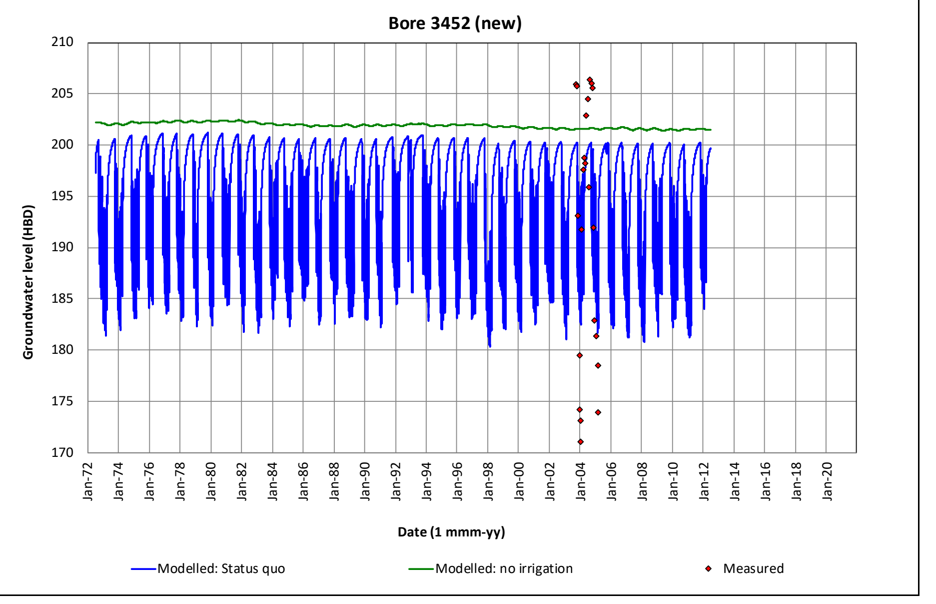

Bore 1944
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

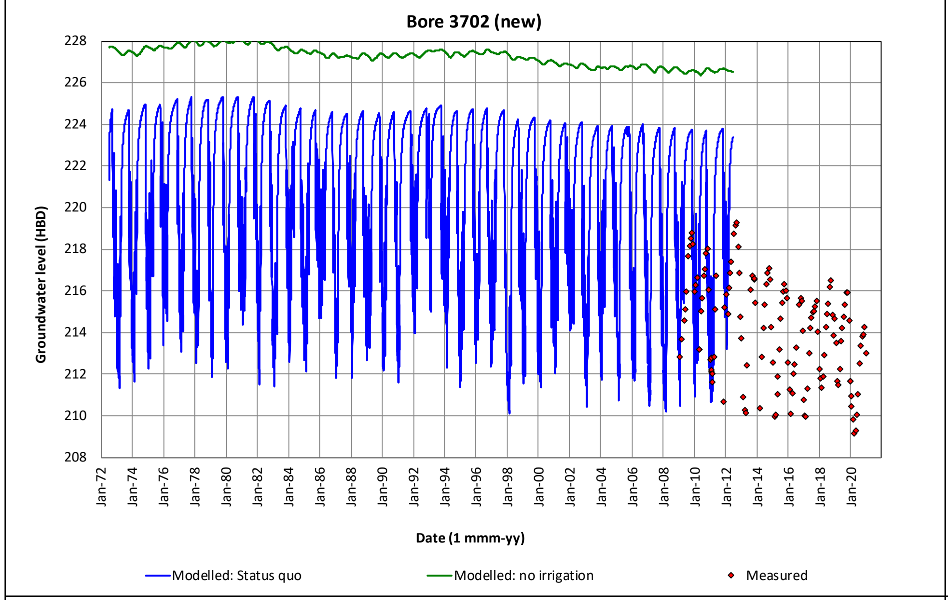

Bore 2220
Groundwater level (HBD)
Date (1 mmm-yy)
Nearby stockwater races turned off
Modelled: Status quo
Modelled: no irrigation
Measured

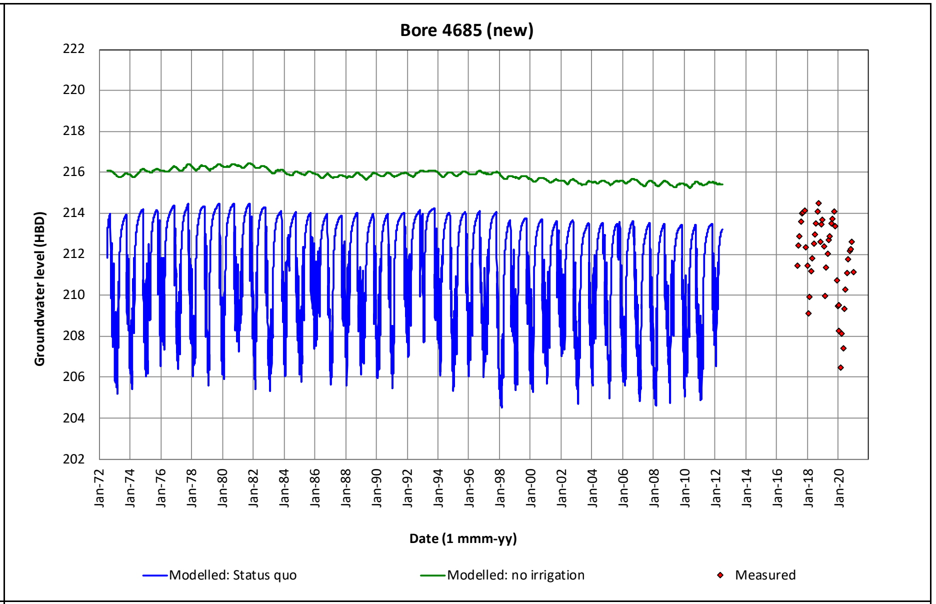

Bore 2749 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

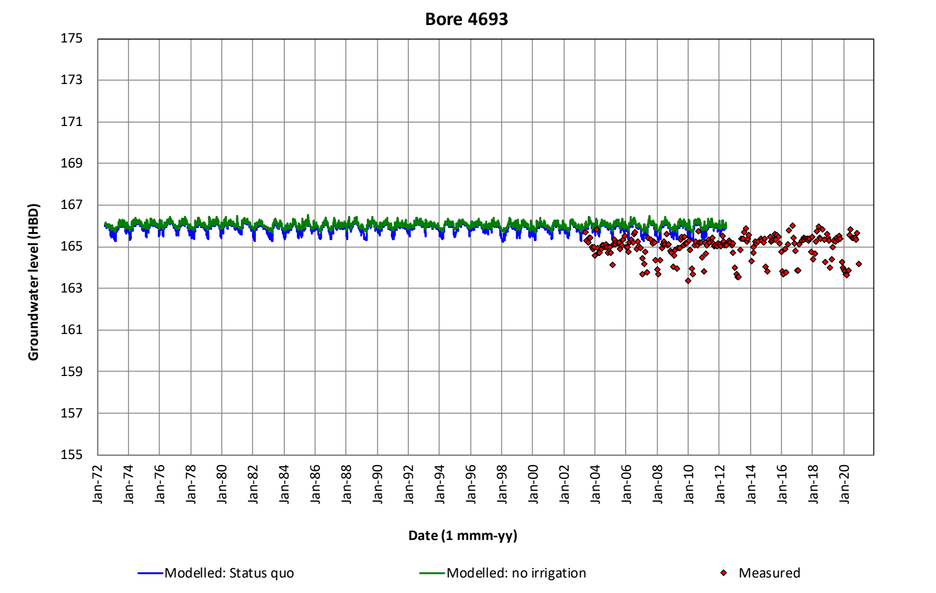

Bore 2979 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

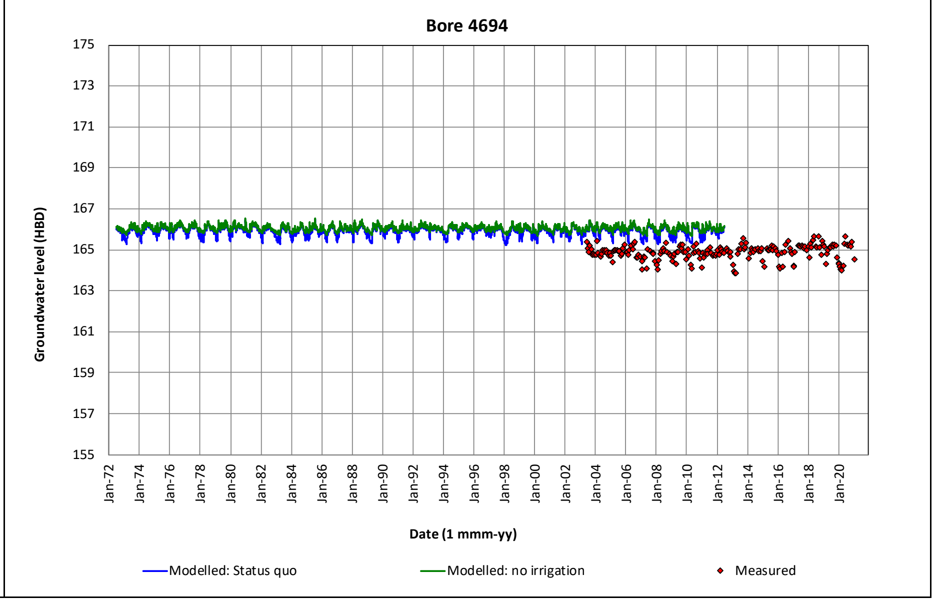

Bore 3076
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

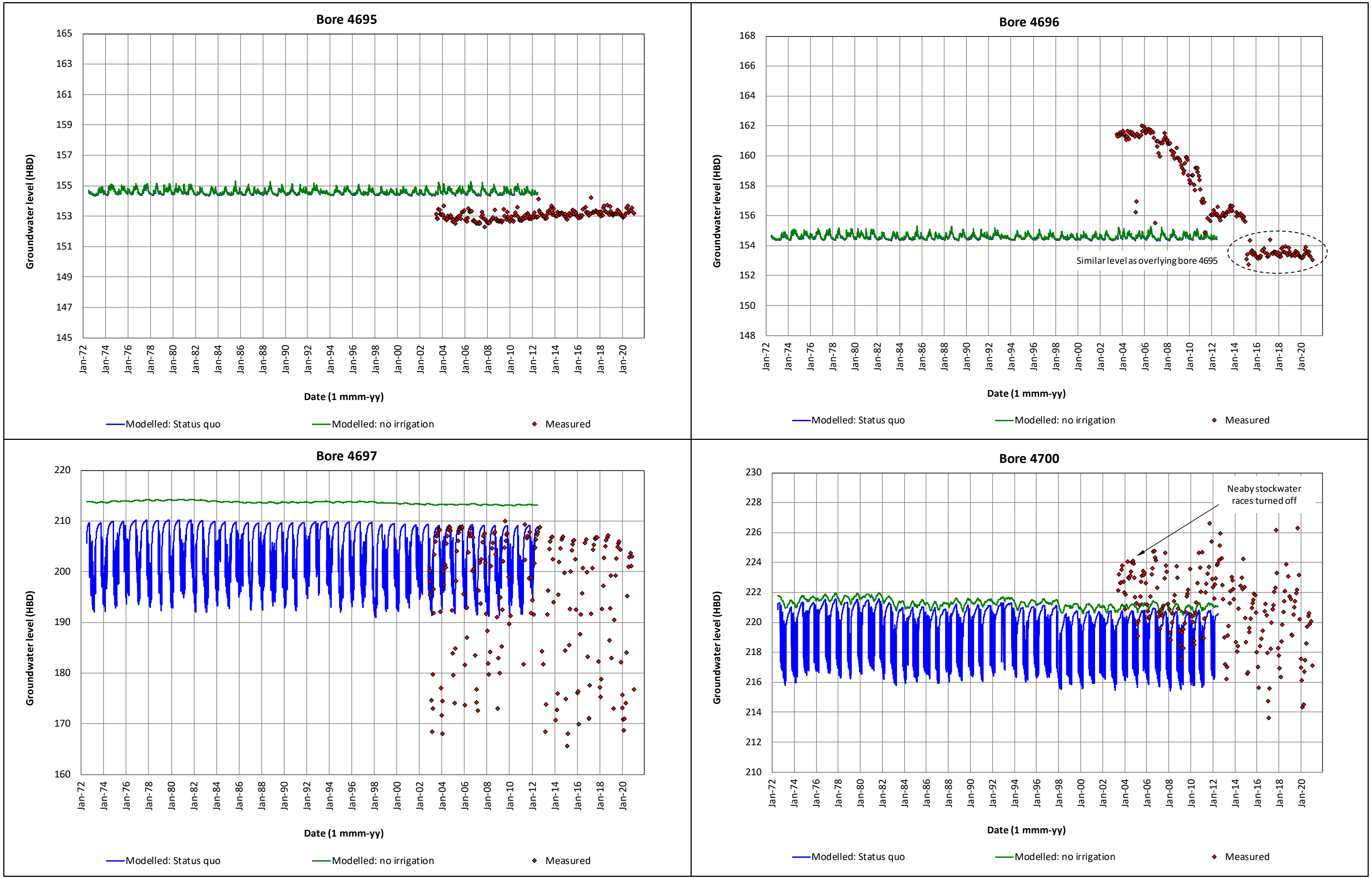

Bore 3452 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured


Bore 3702 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

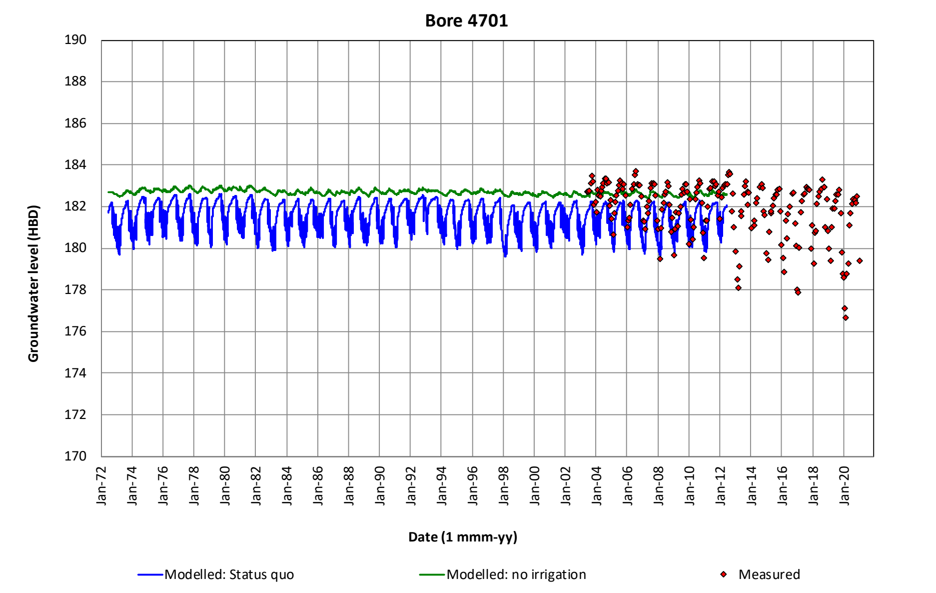

Bore 4685 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

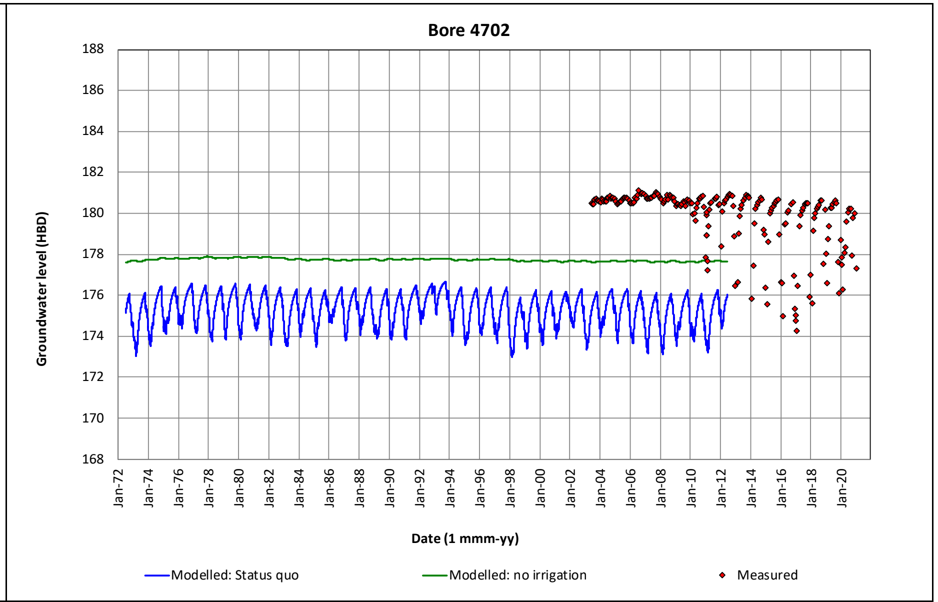

Bore 4693
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

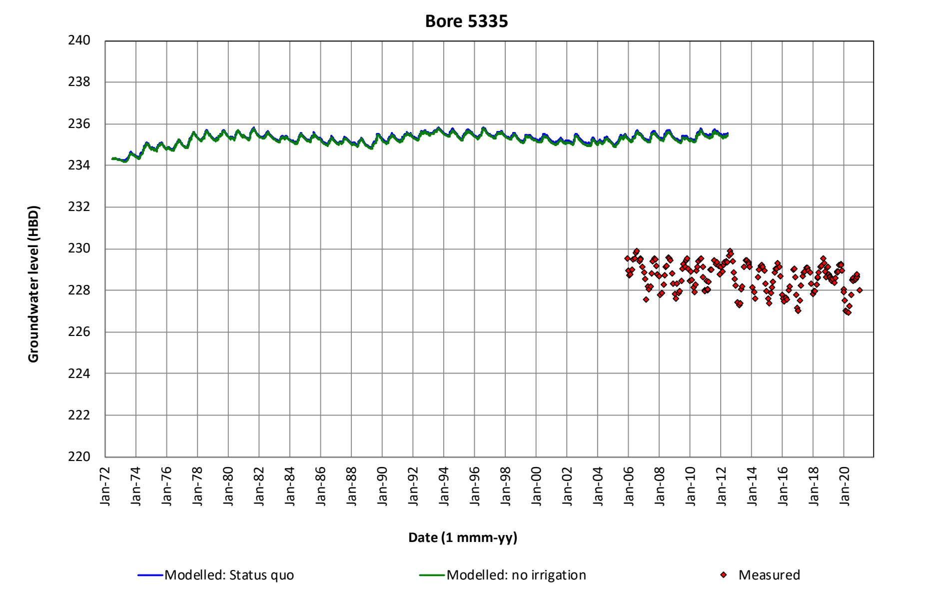

Bore 4694
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

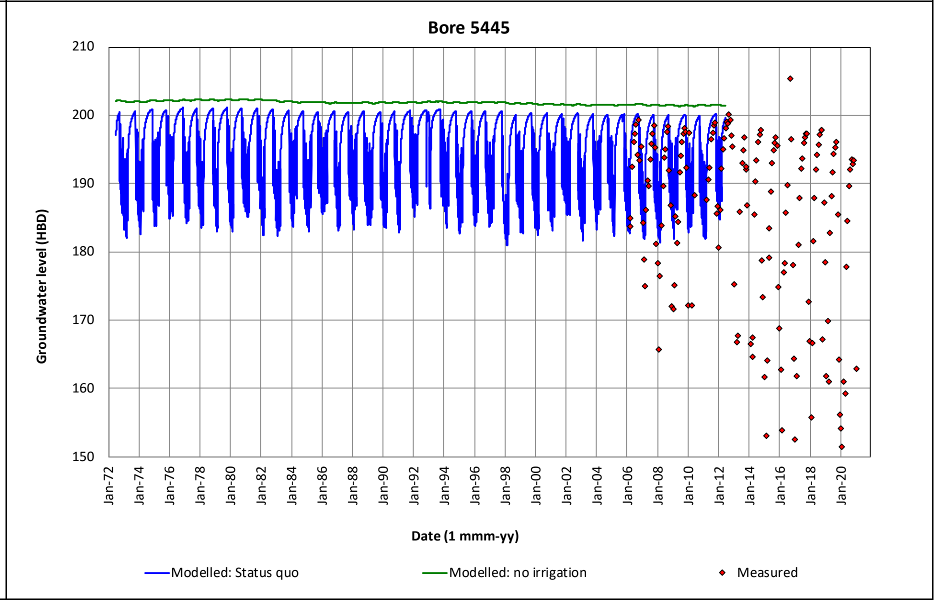


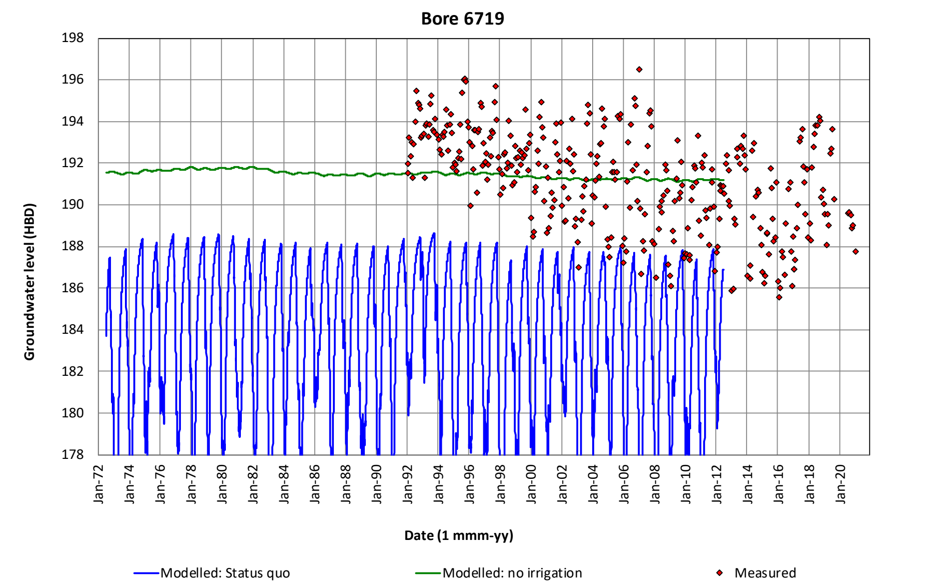
Bore 4695
Bore 4696
Similar level as overlying bore 4695
Bore 4697
Bore 4700
Neaby stockwater races turned off
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

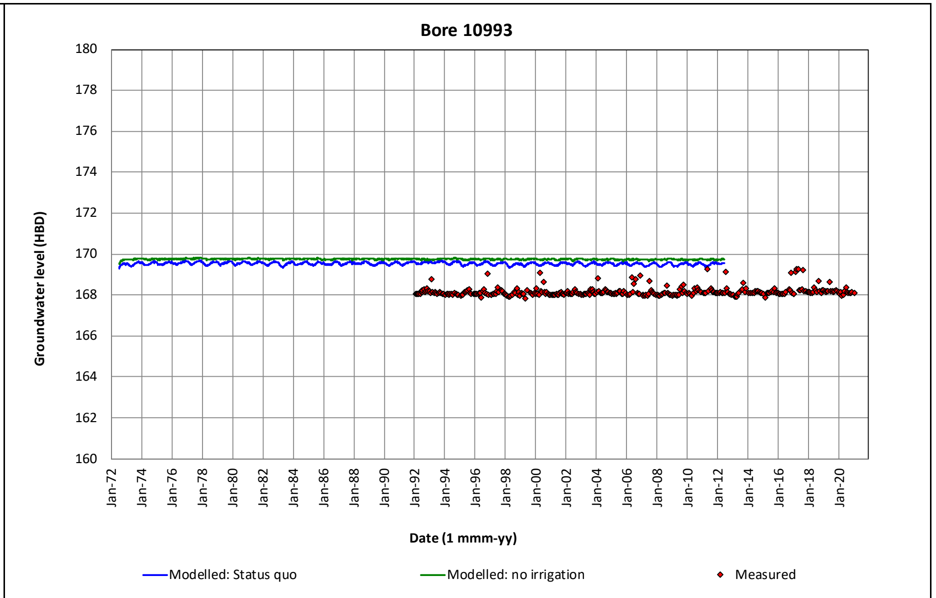

Bore 4701
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

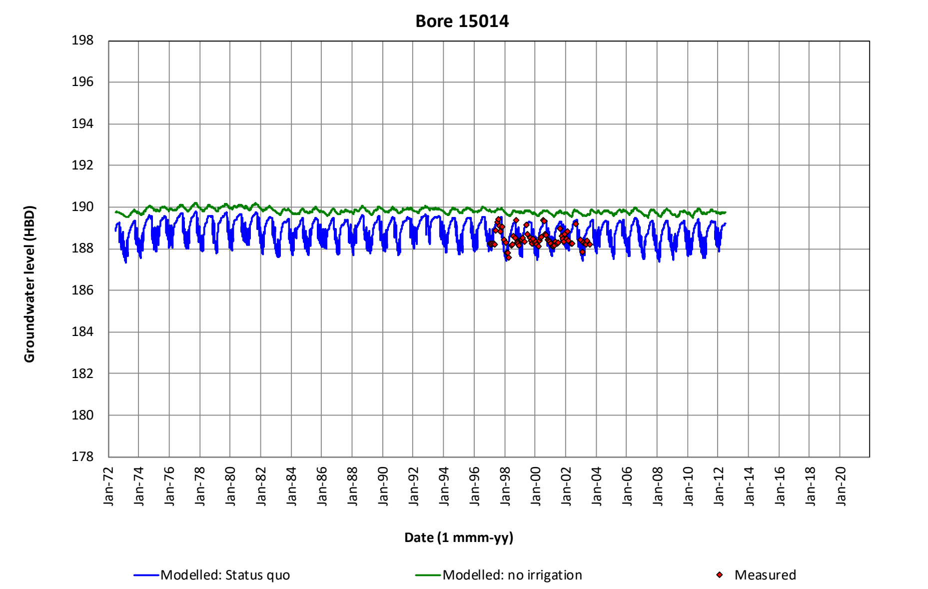

Bore 4702
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

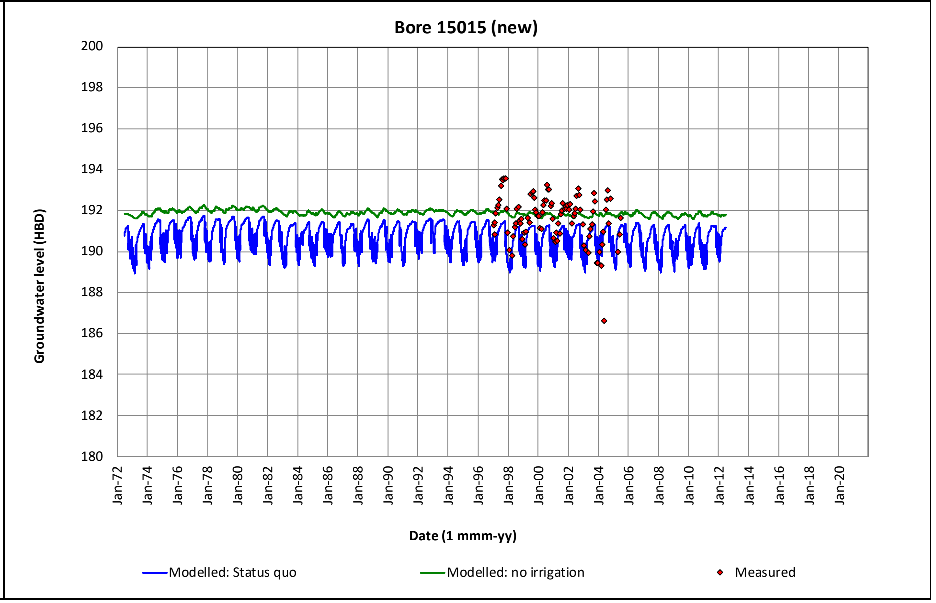

Bore 5335
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

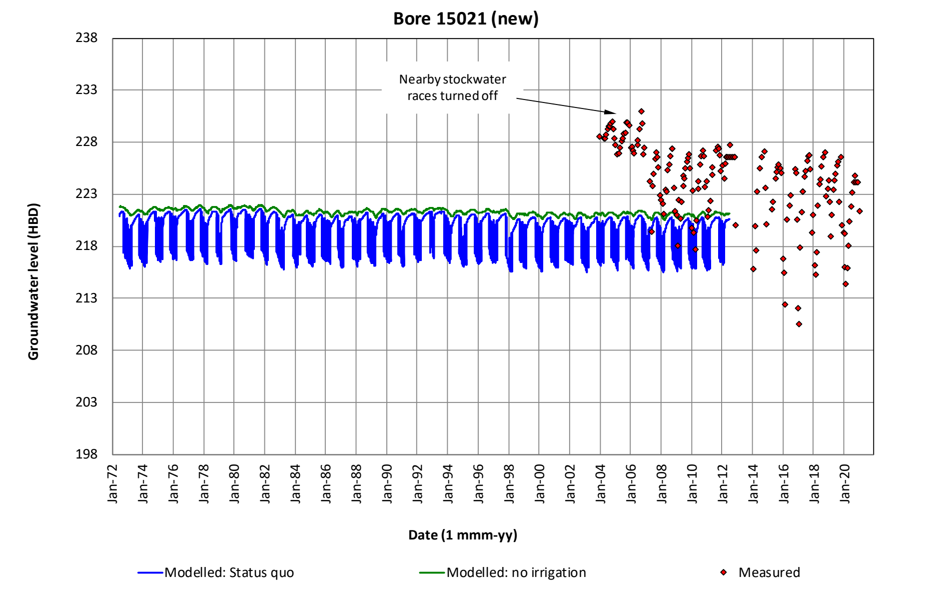

Bore 5445
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

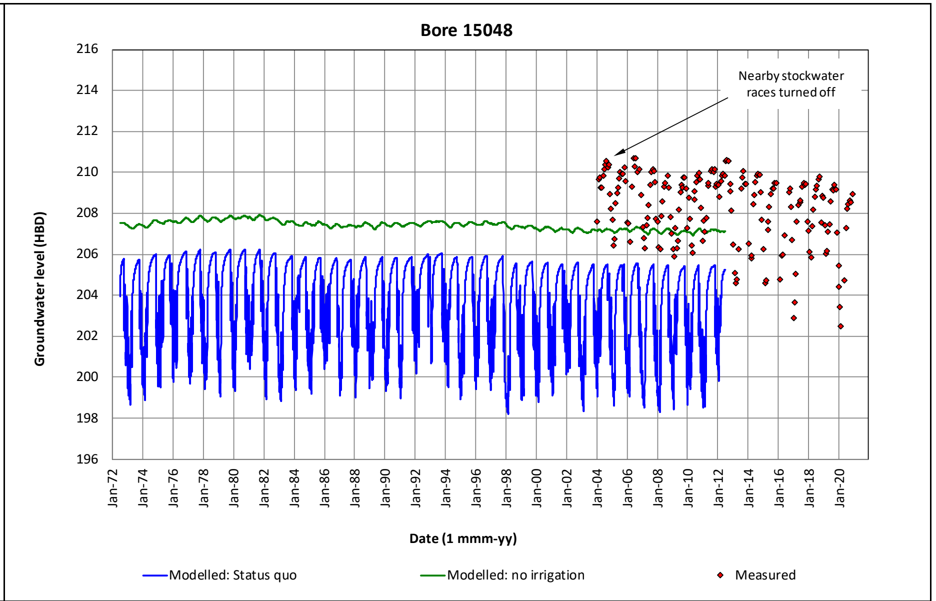

Bore 6719
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

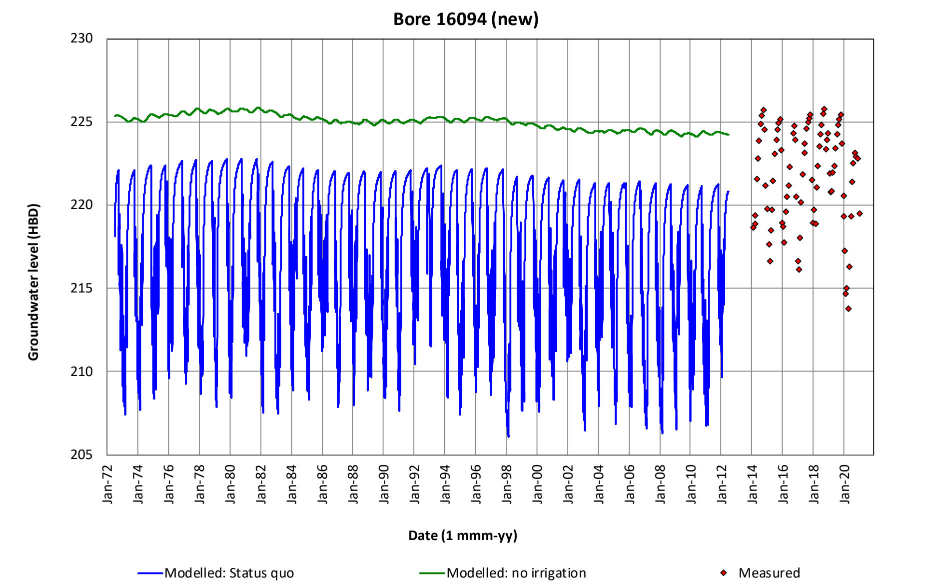

Bore 10993
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

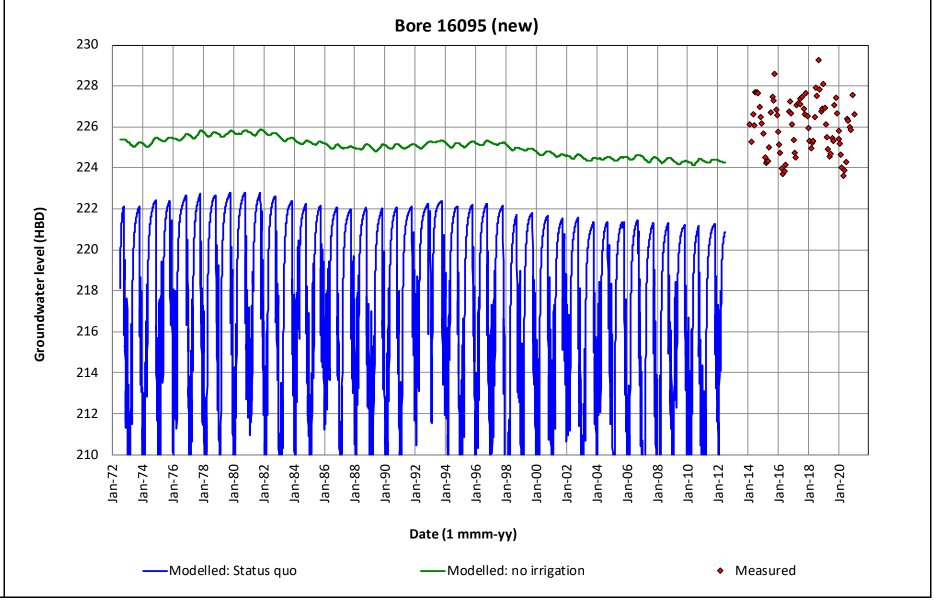

Bore 15014
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

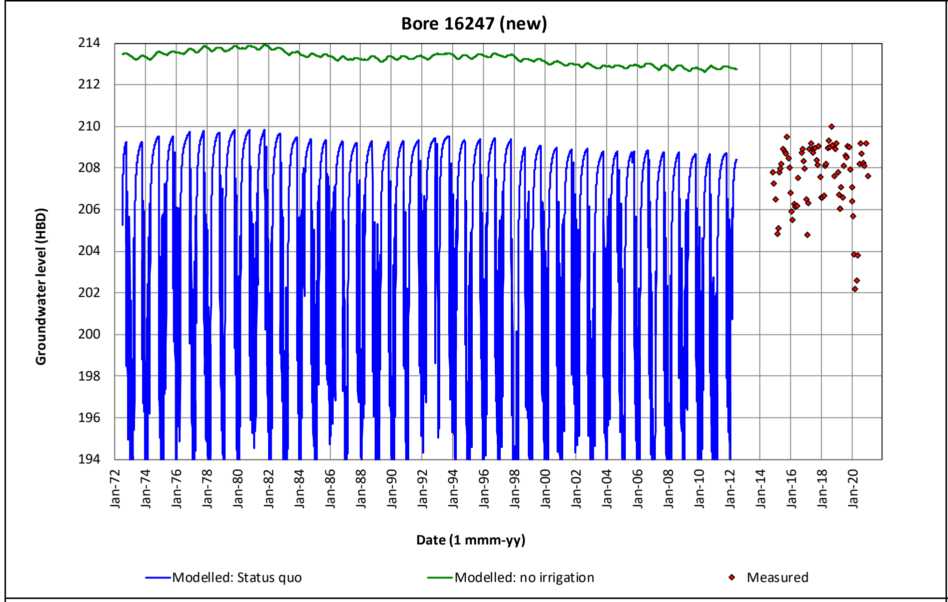

Bore 15015 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

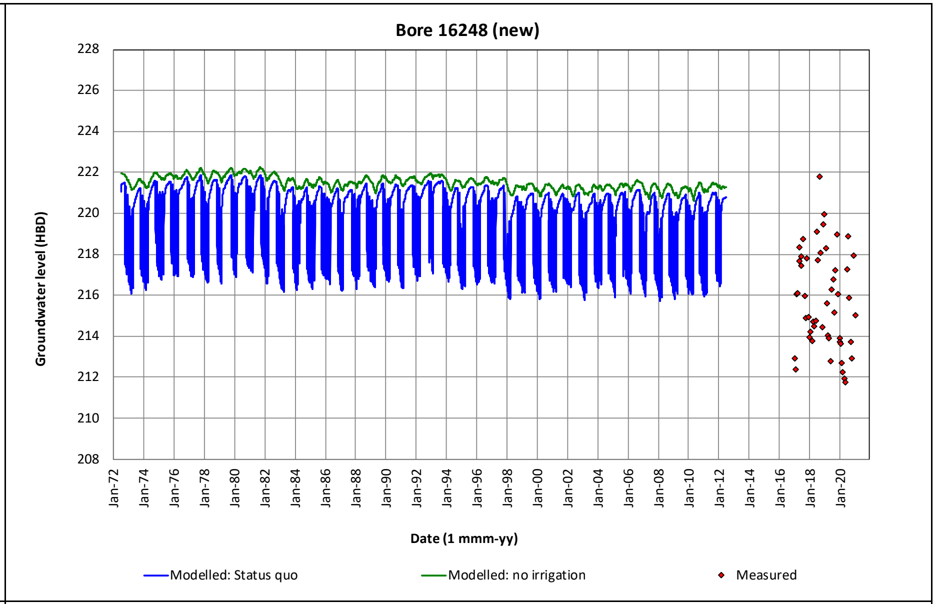

Bore 15021 (new)
Nearby stockwater races turned off
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

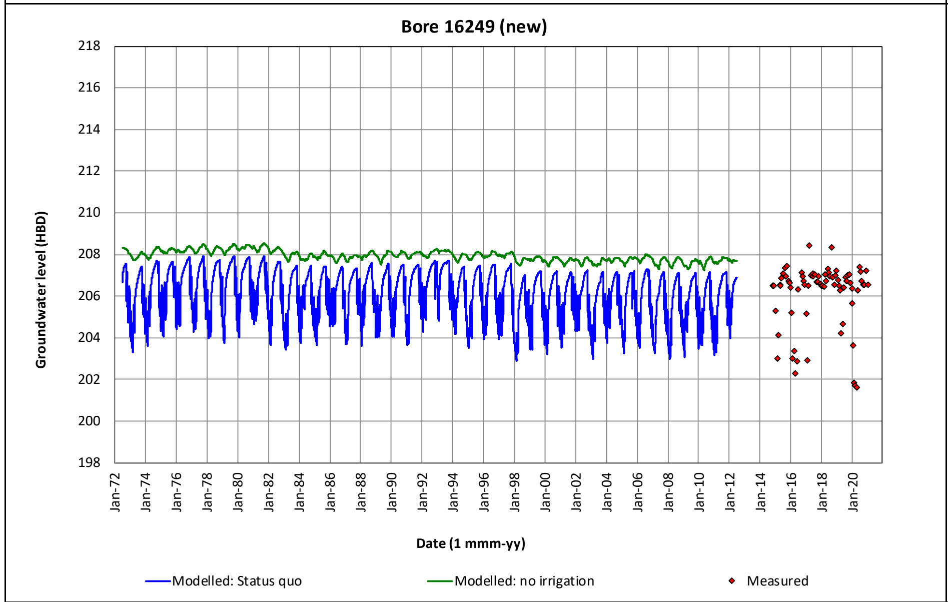

Bore 15048
Nearby stockwater races turned off
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

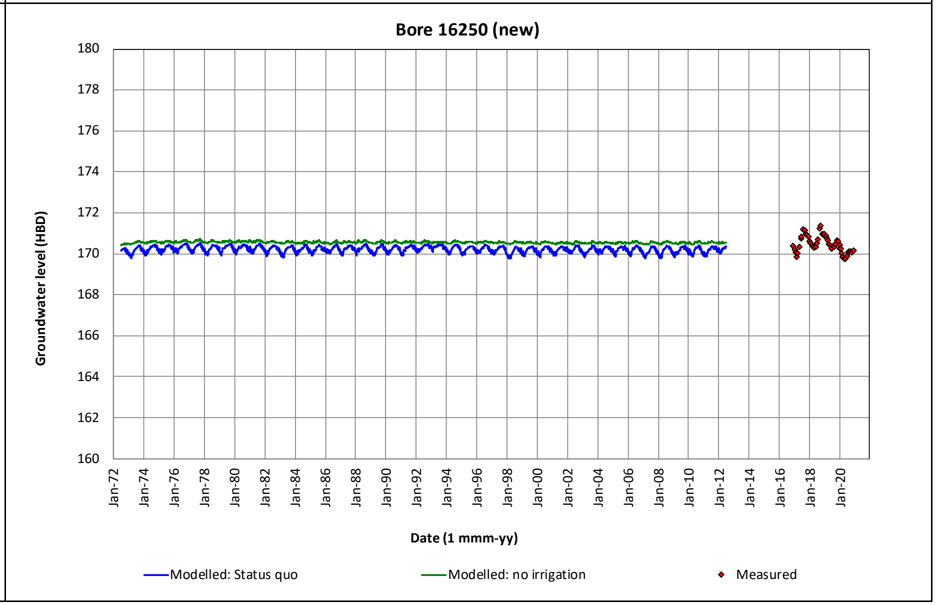

Bore 16094 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

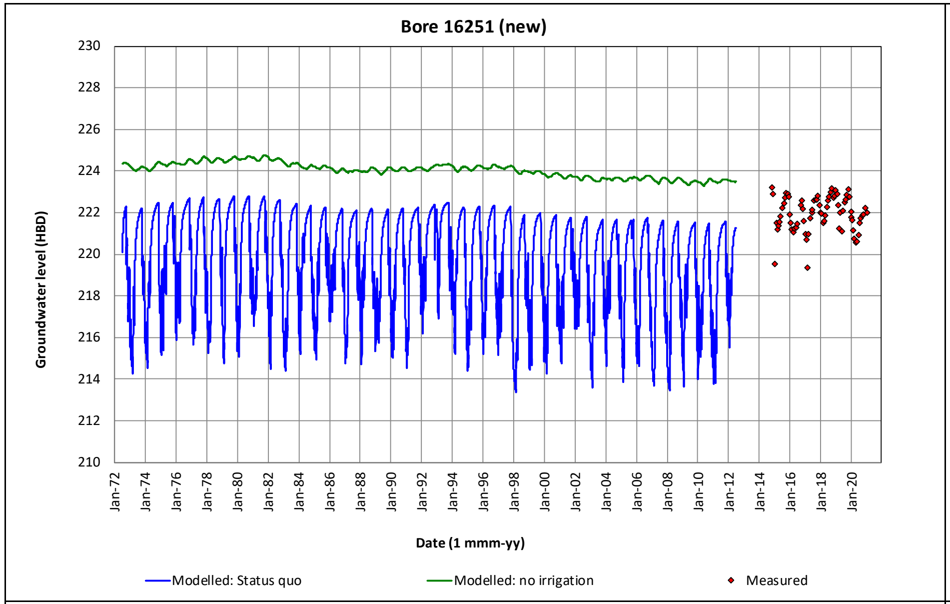

Bore 16095 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

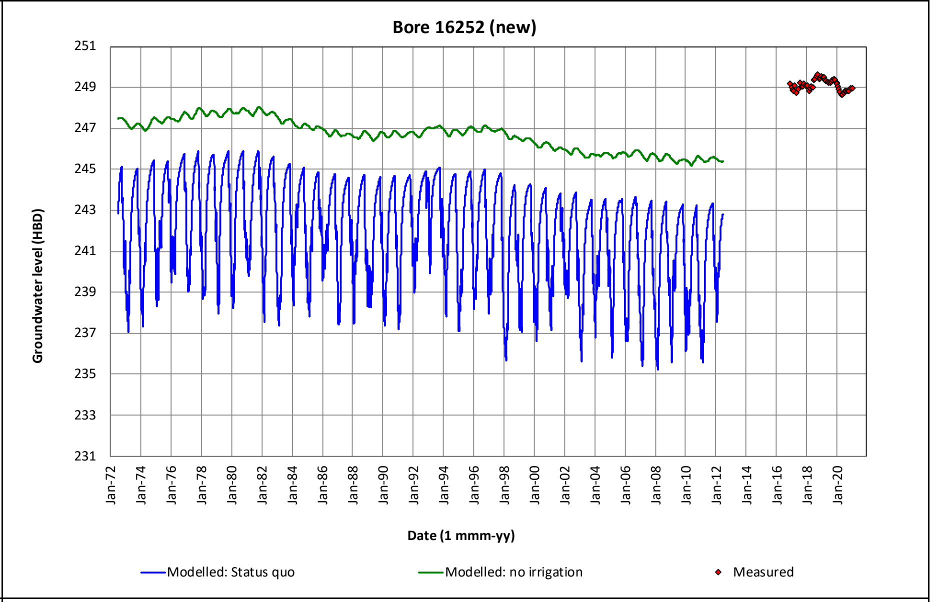

Bore 16247 (new)
Groundwater level (HBD)
214
212
210
208
206
204
202
200
198
196
194
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12 Jan-14 Jan-16 Jan-18 Jan-20
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

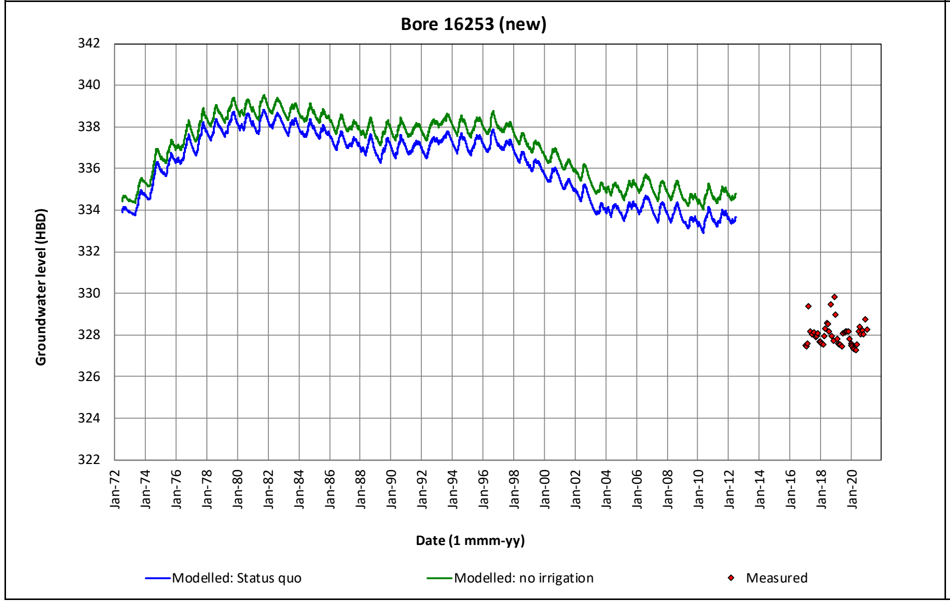

Bore 16248 (new)
Groundwater level (HBD)
228
226
224
222
220
218
216
214
212
210
208
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12 Jan-14 Jan-16 Jan-18 Jan-20
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

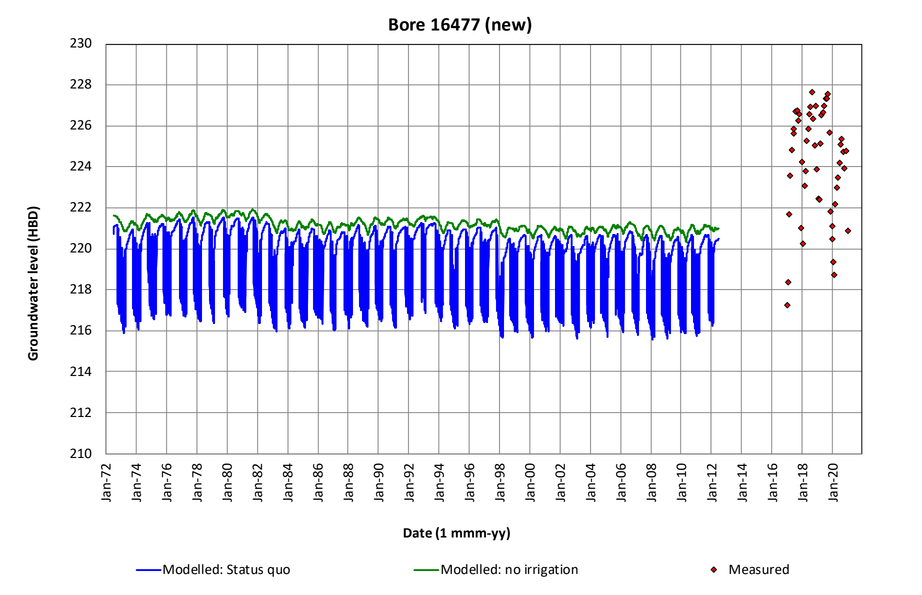

Bore 16249 (new)
Groundwater level (HBD)
218
216
214
212
210
208
206
204
202
200
198
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12 Jan-14 Jan-16 Jan-18 Jan-20
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

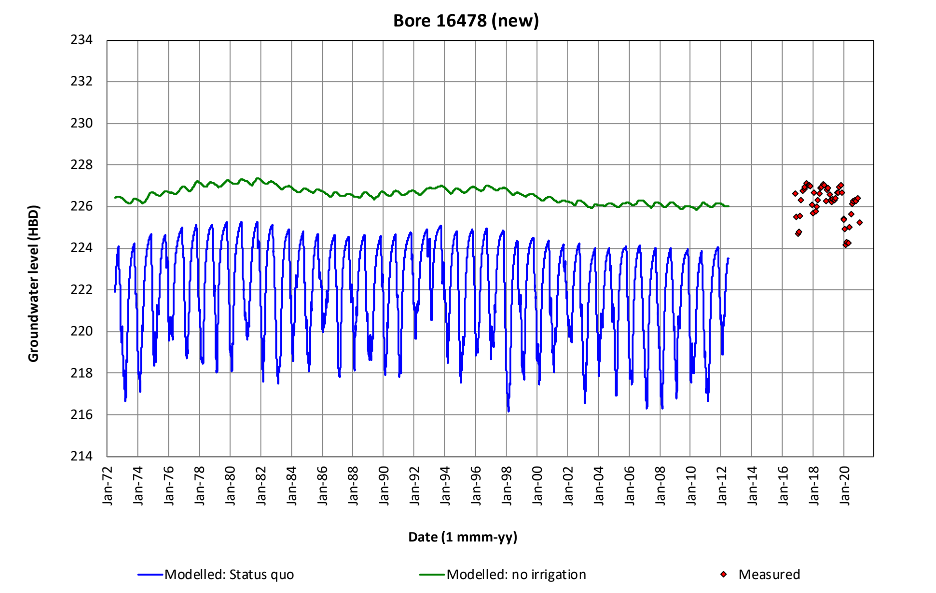

Bore 16250 (new)
Groundwater level (HBD)
180
178
176
174
172
170
168
166
164
162
160
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12 Jan-14 Jan-16 Jan-18 Jan-20
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

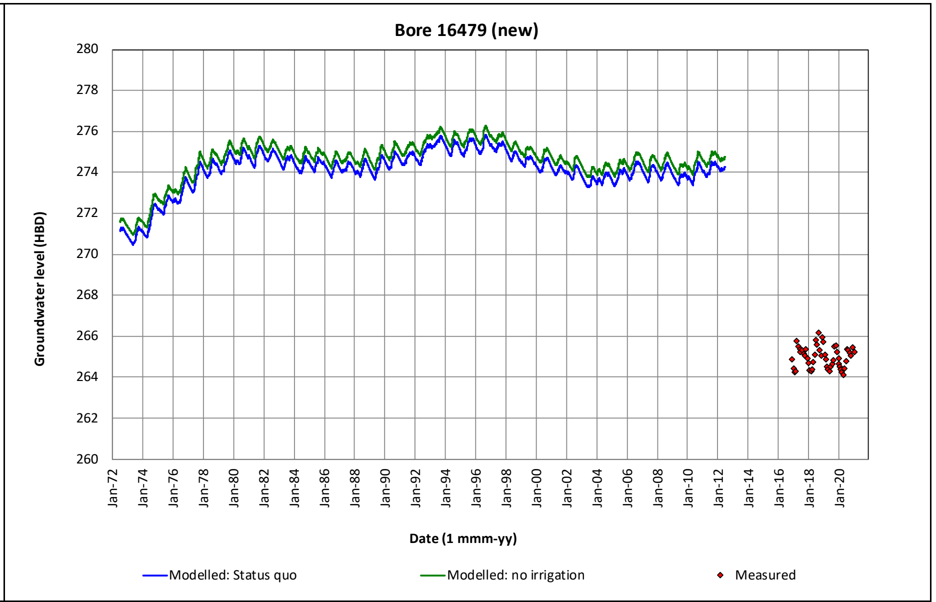

Bore 16251 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

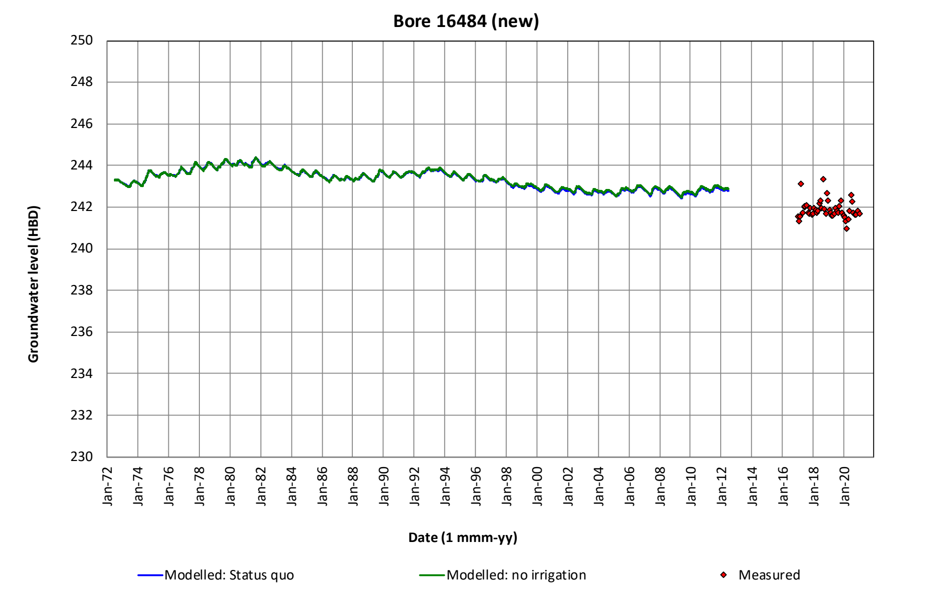

Bore 16252 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

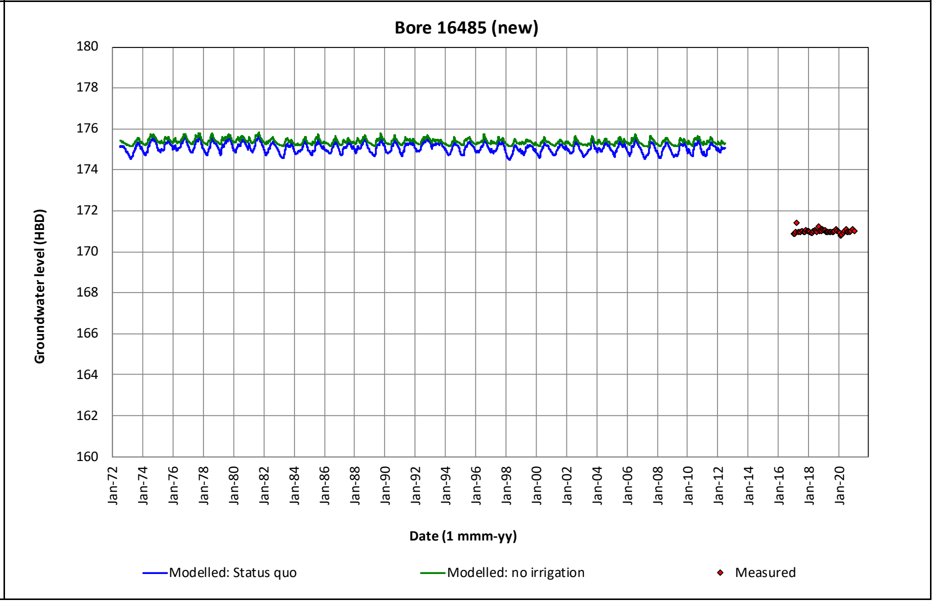

Bore 16253 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

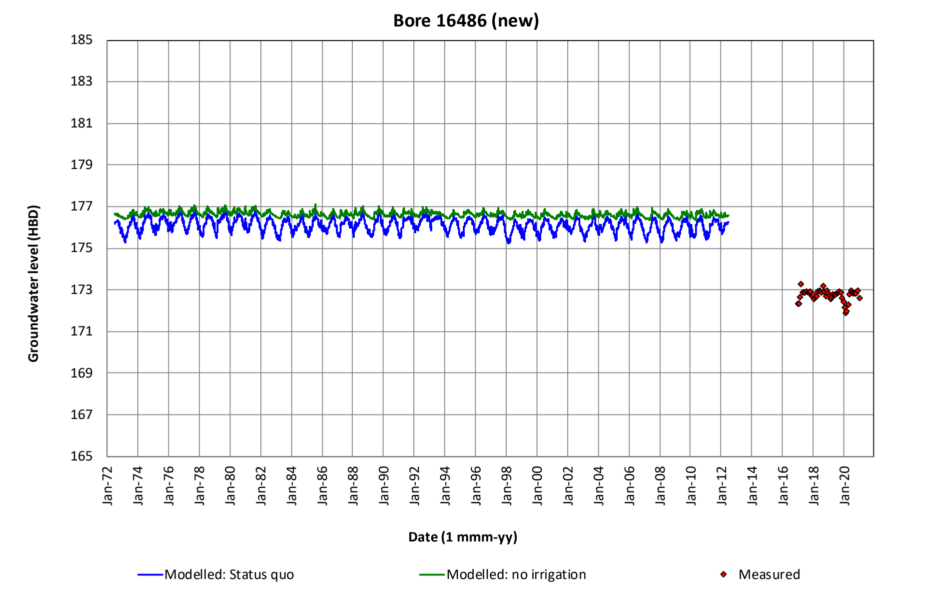

Bore 16477 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

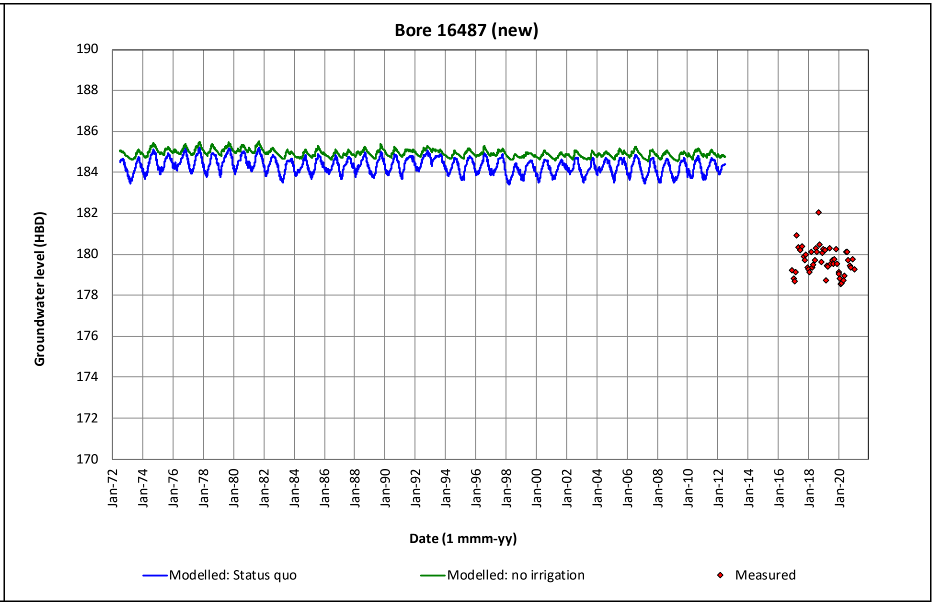

Bore 16478 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

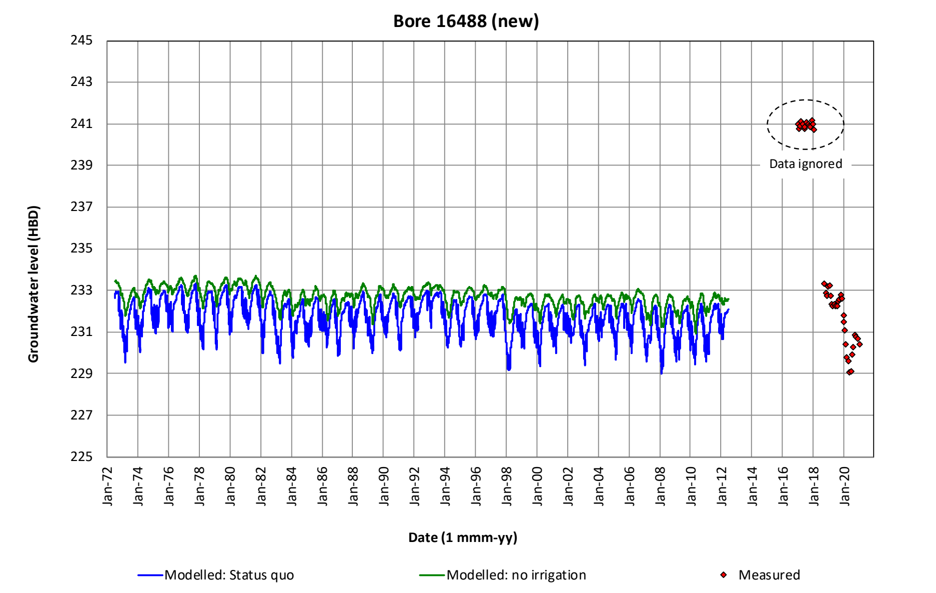

Bore 16479 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

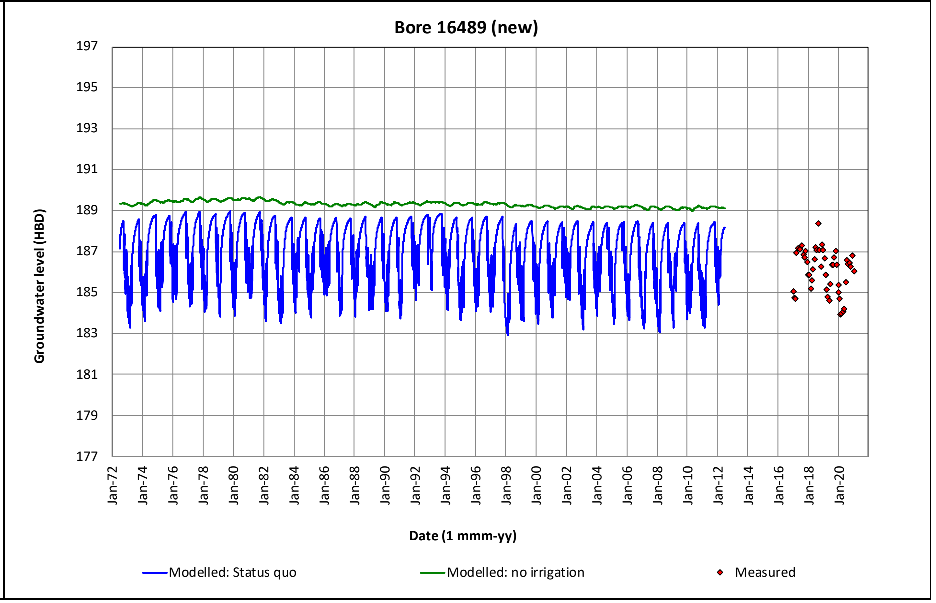

Bore 16484 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

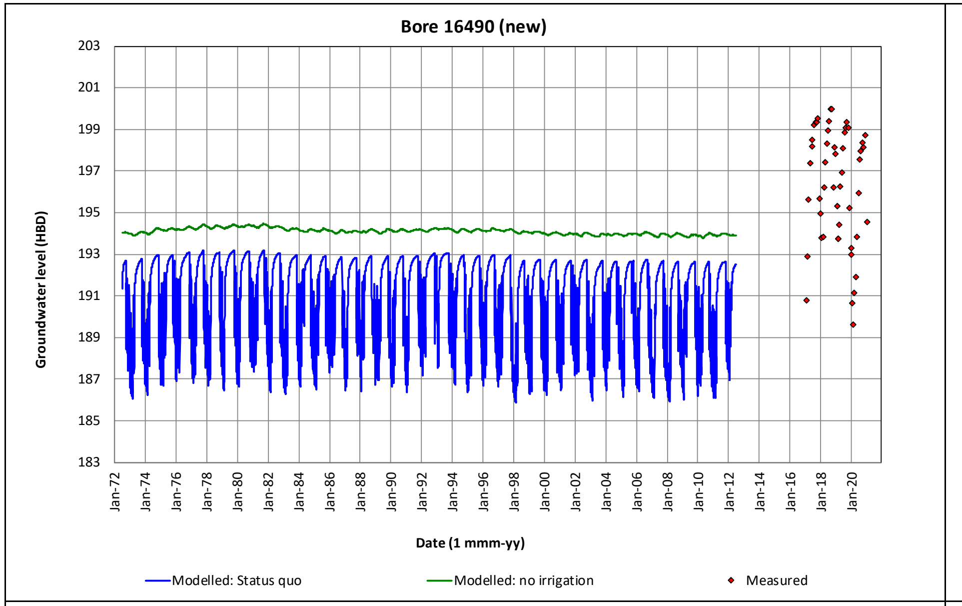

Bore 16485 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured


Bore 16486 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

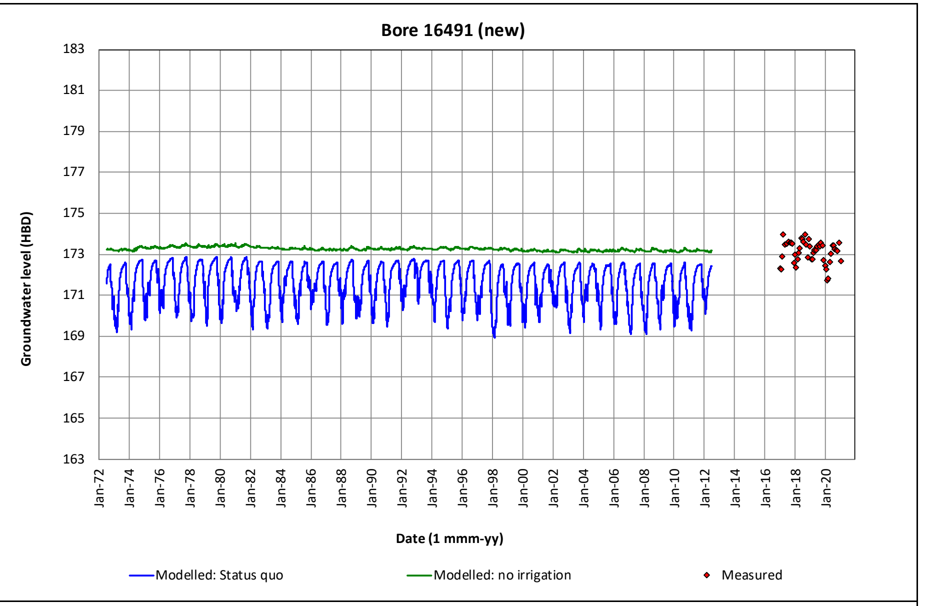

Bore 16487 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured


Bore 16488 (new)
Data ignored
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

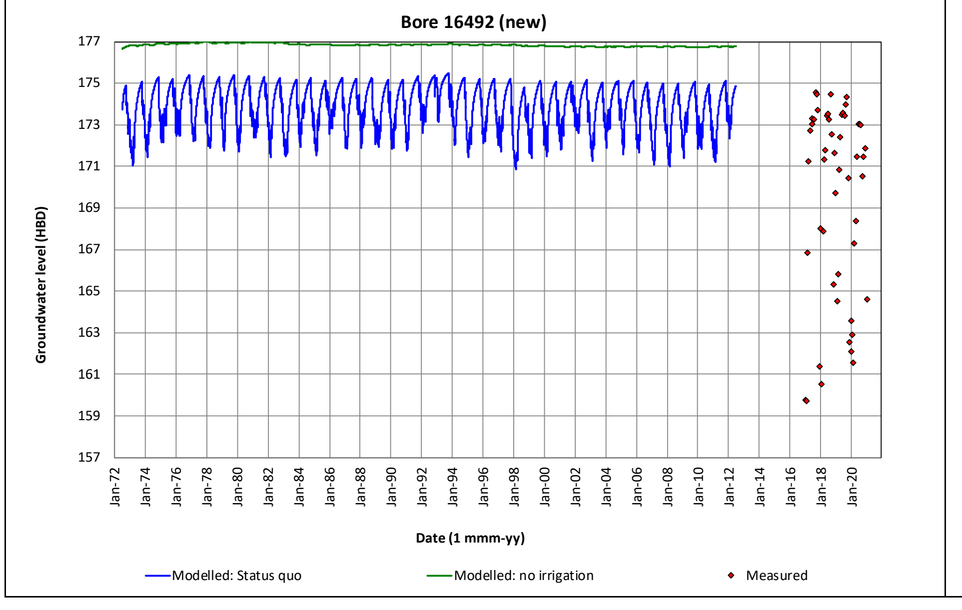

Bore 16489 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured



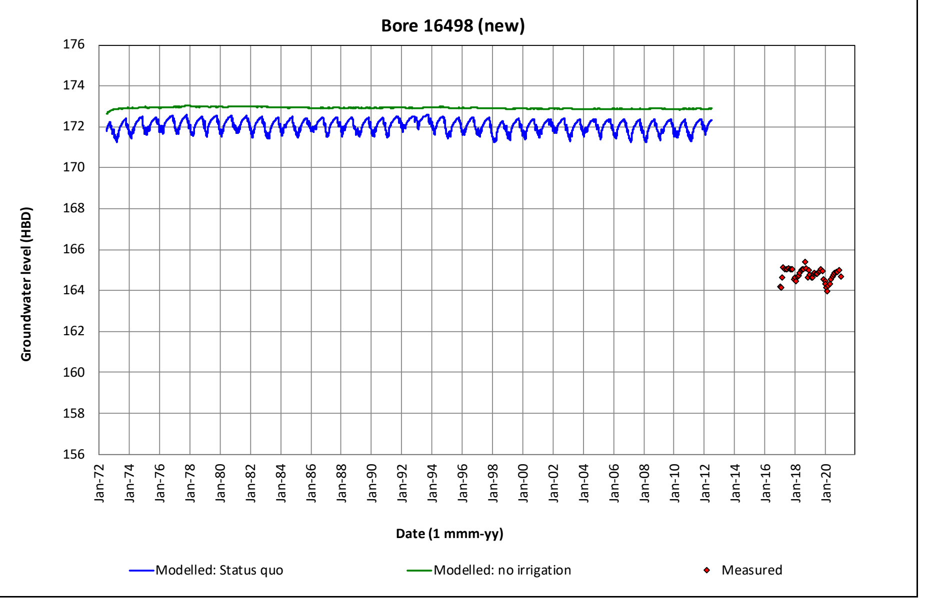
Bore 16490 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured



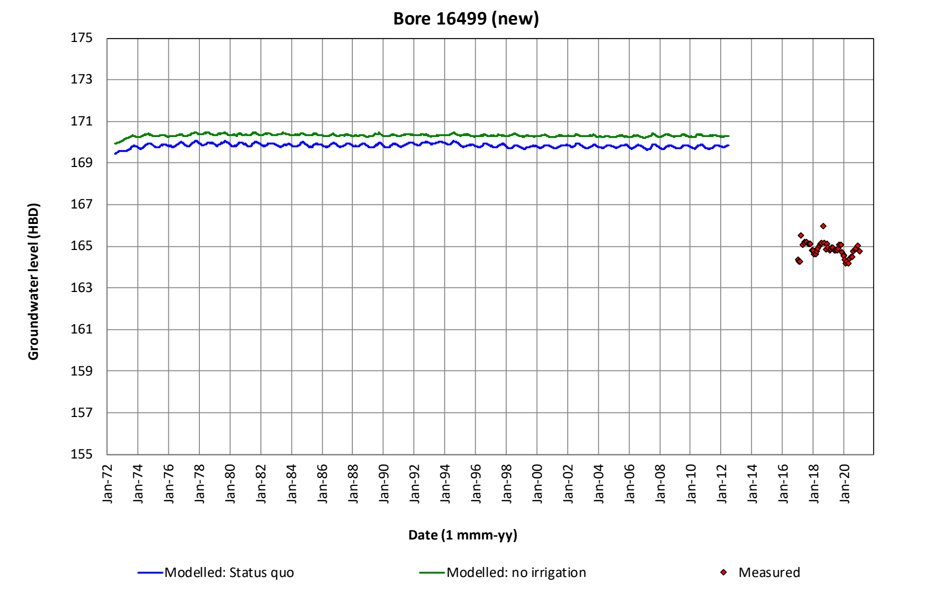
Bore 16491 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured



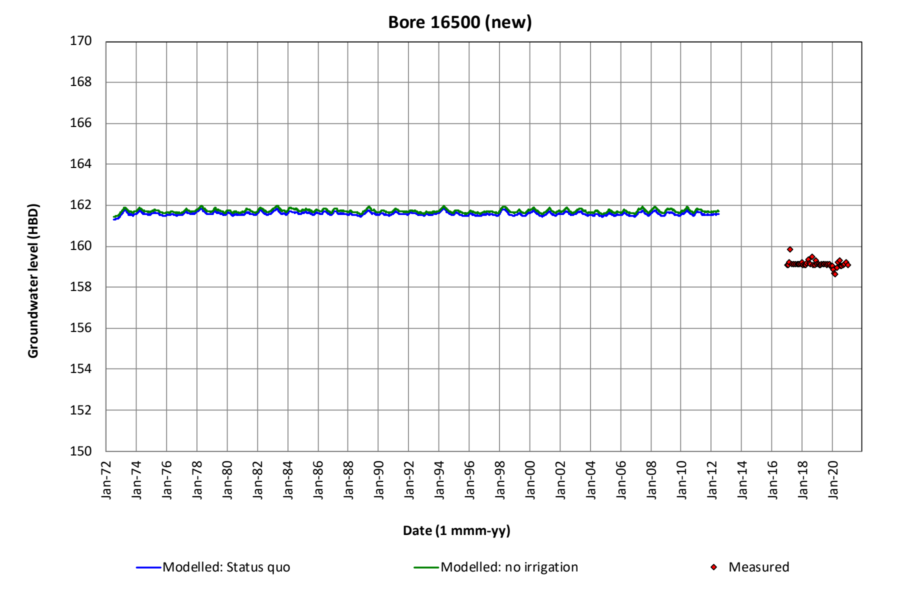
Bore 16492 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured



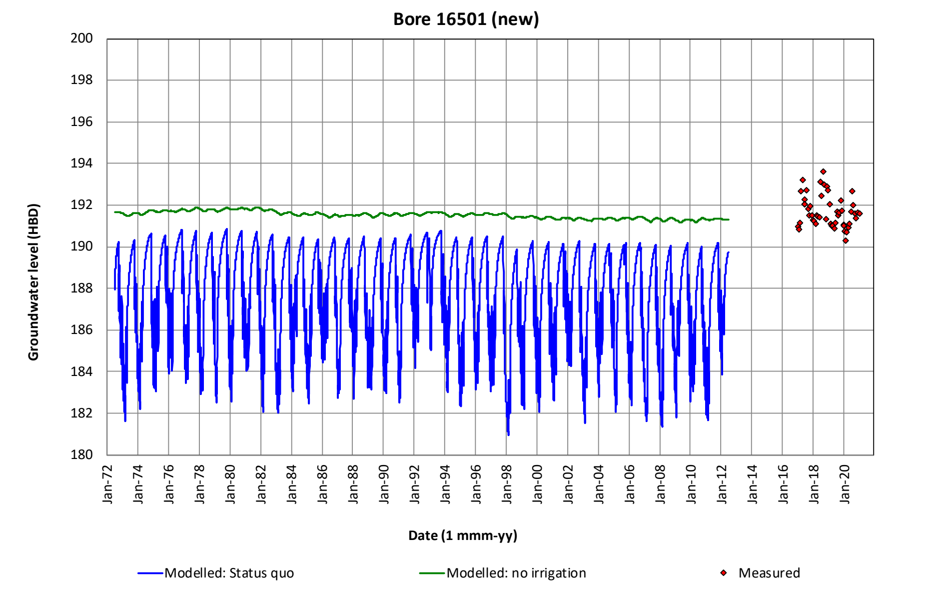
Bore 16498 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured



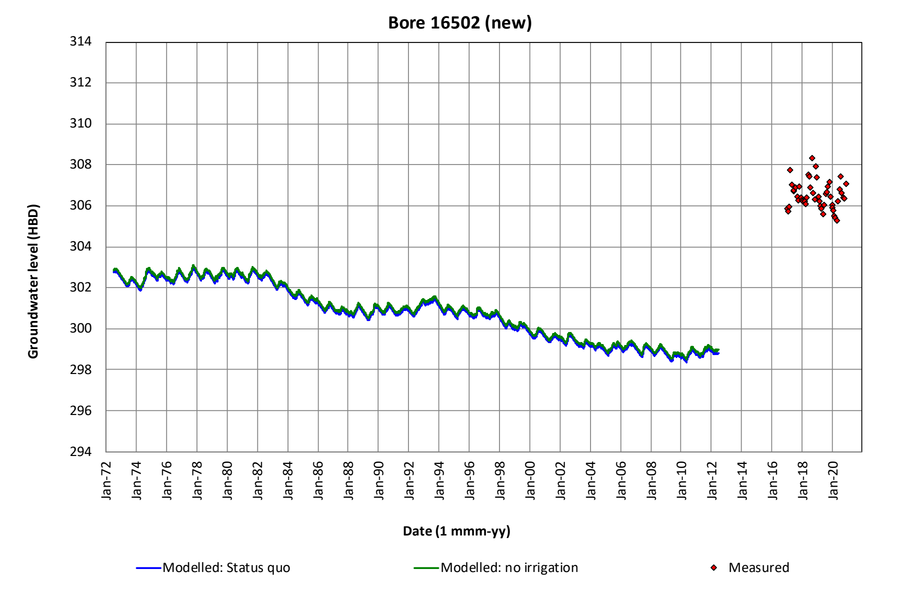
Bore 16499 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured



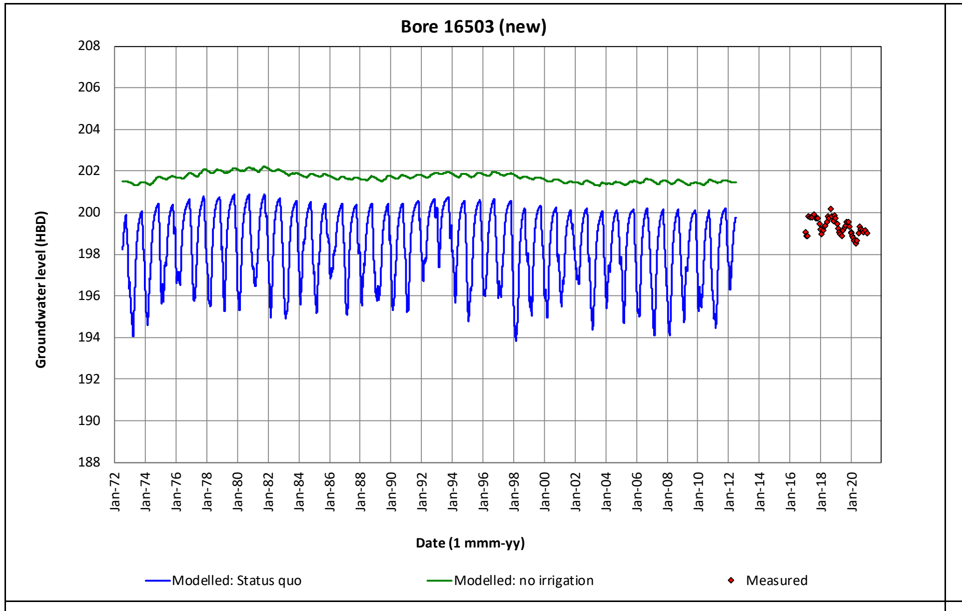
Bore 16500 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

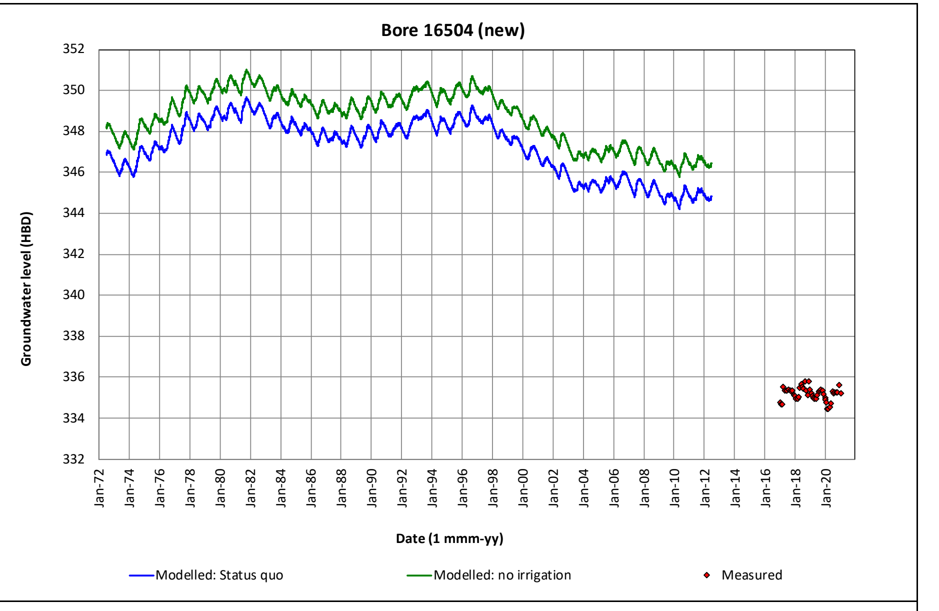


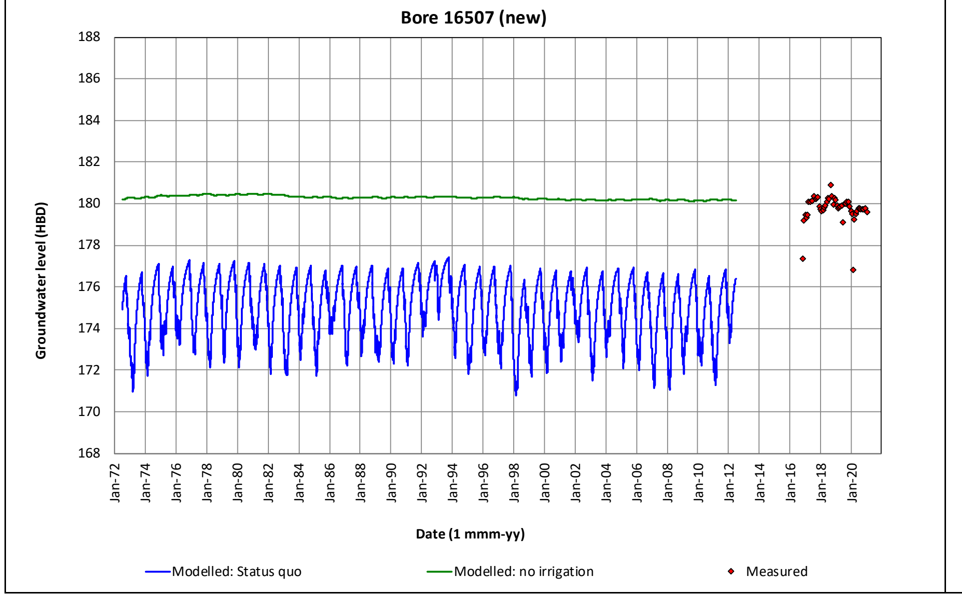
Bore 16501 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

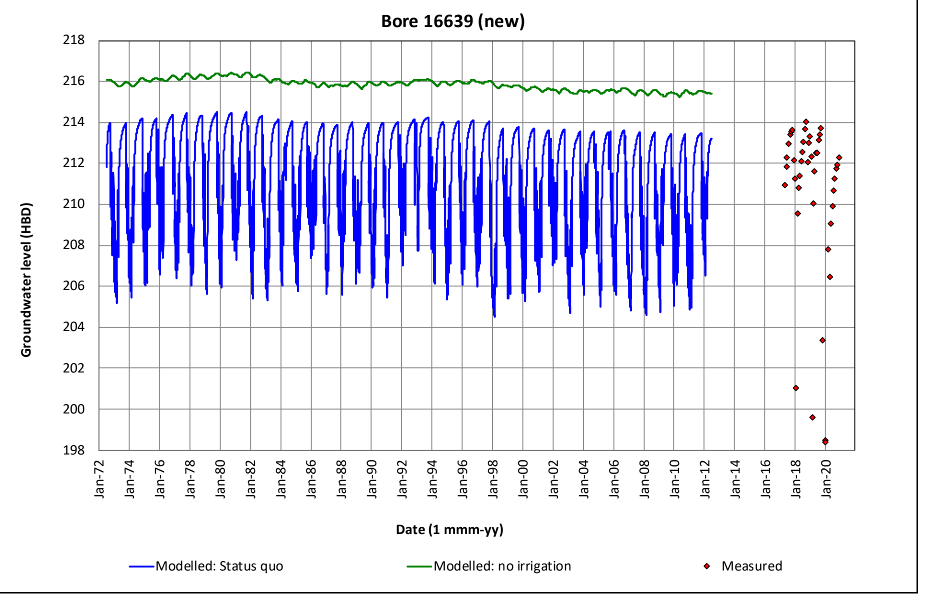


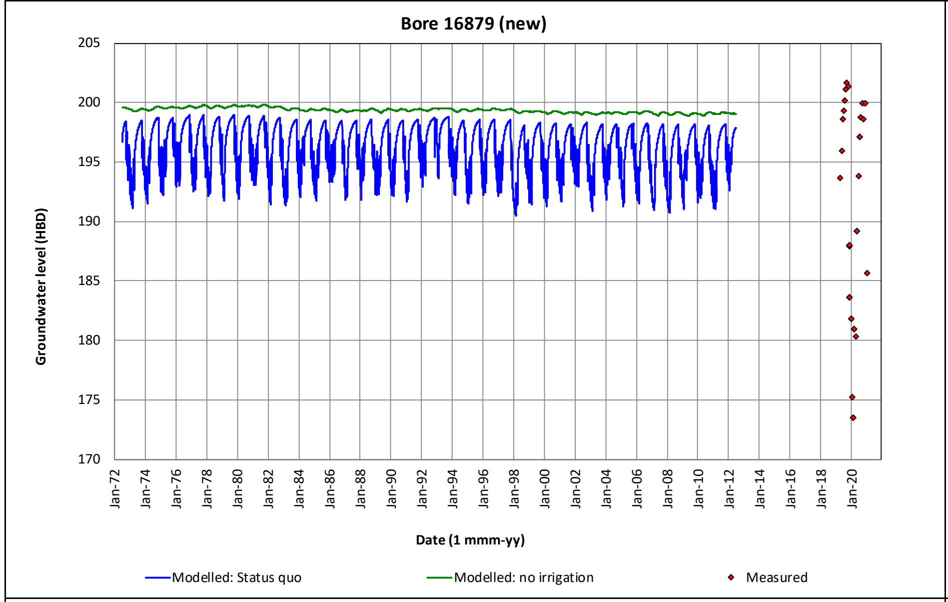
Bore 16502 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured


Bore 16503 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

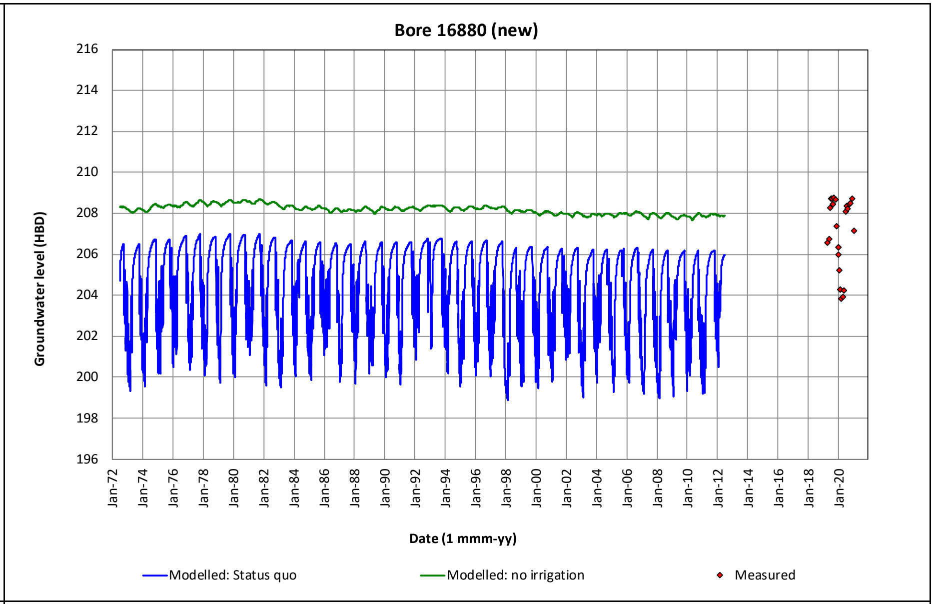

Bore 16504 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured


Bore 16507 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

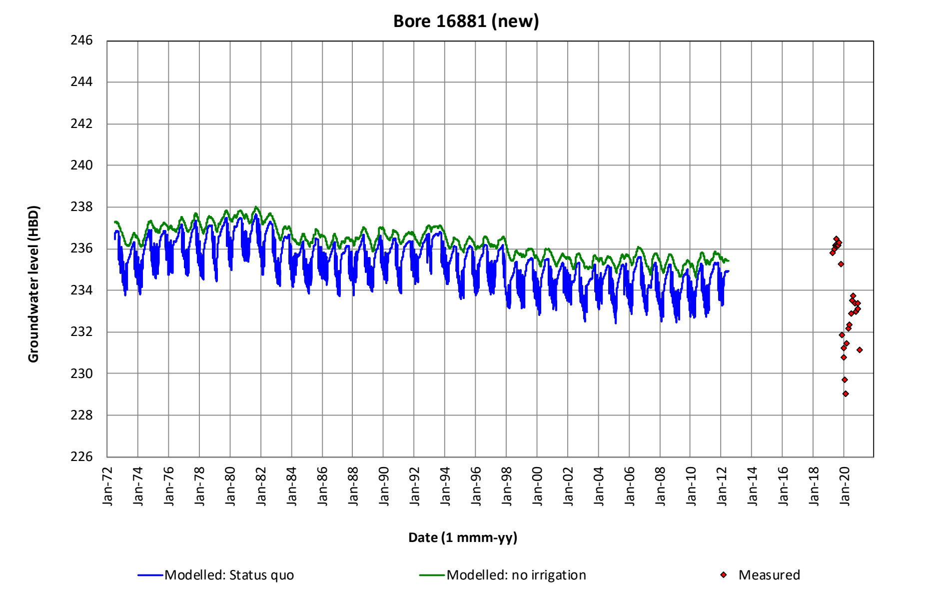

Bore 16639 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured



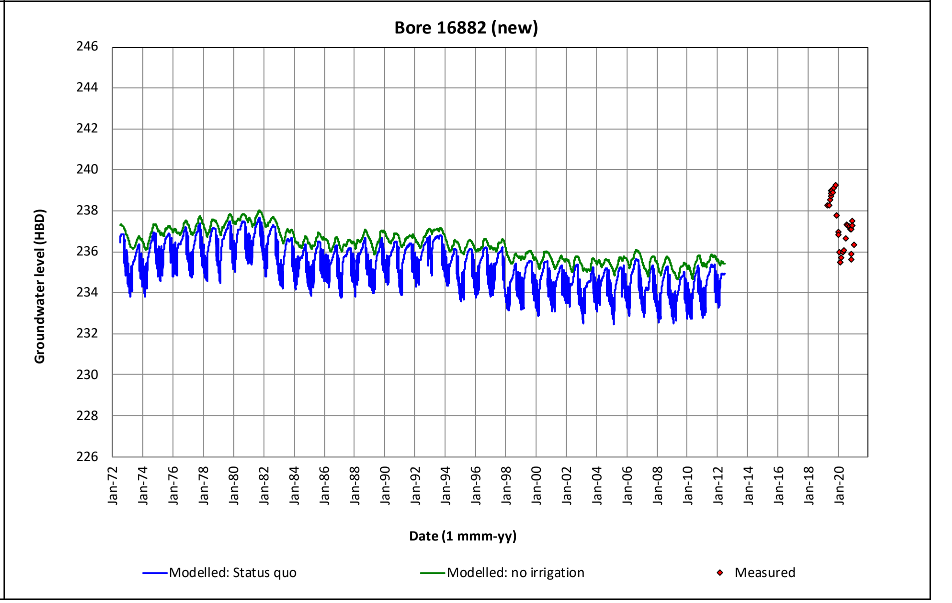
Bore 16879 (new)
Groundwater level (HBD)
205
200
195
190
185
180
175
170
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Jan-10
Jan-12
Jan-14
Jan-16
Jan-18
Jan-20
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured



Bore 16880 (new)
Groundwater level (HBD)
216
214
212
210
208
206
204
202
200
198
196
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Jan-10
Jan-12
Jan-14
Jan-16
Jan-18
Jan-20
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

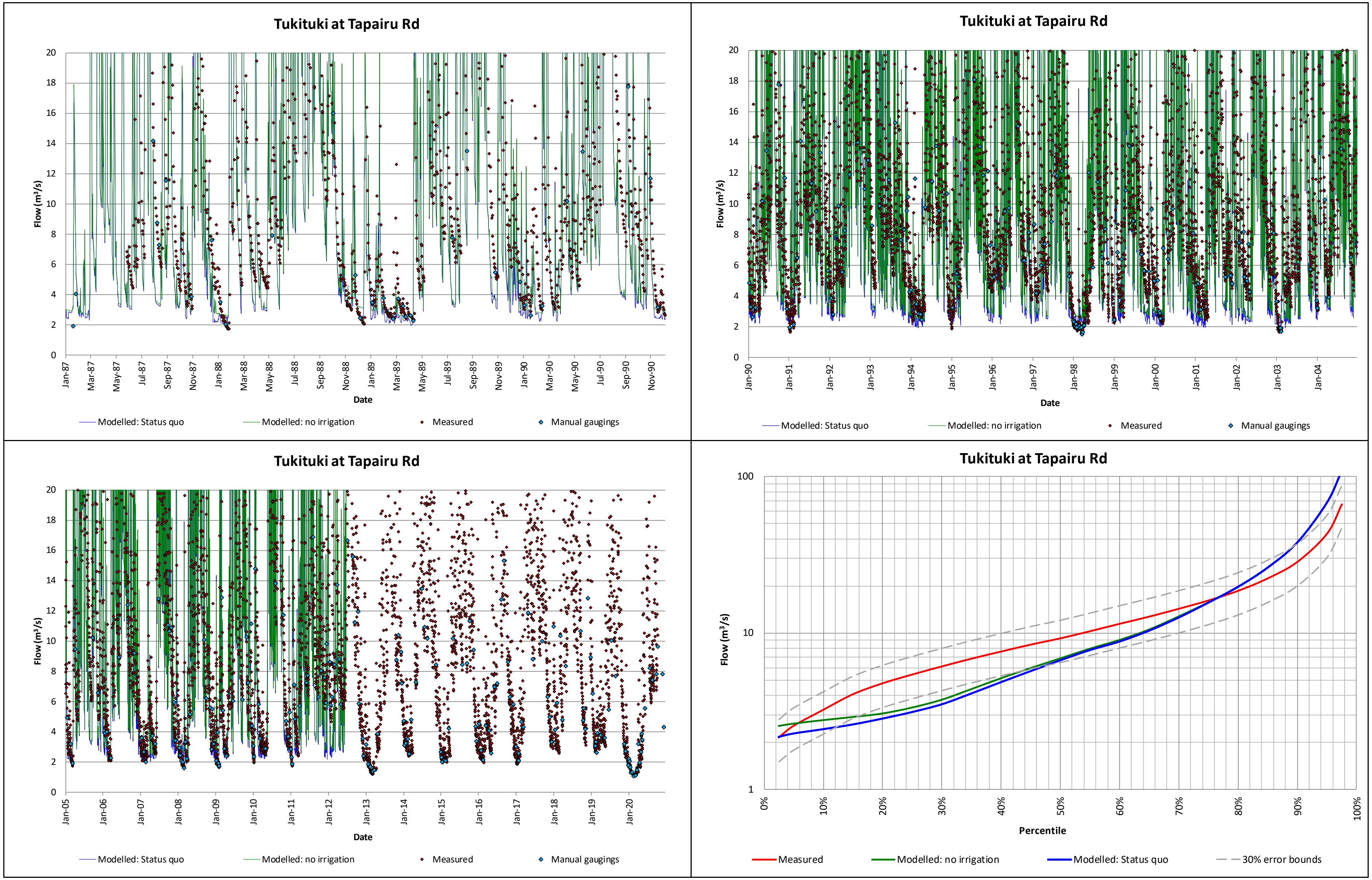


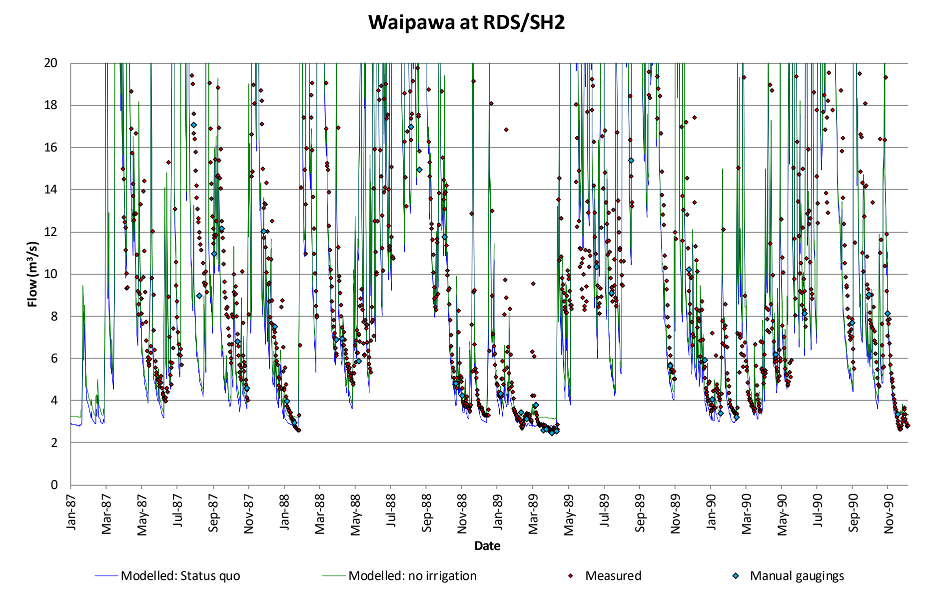
Bore 16881 (new)
Groundwater level (HBD)
246
244
242
240
238
236
234
232
230
228
226
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Jan-10
Jan-12
Jan-14
Jan-16
Jan-18
Jan-20
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

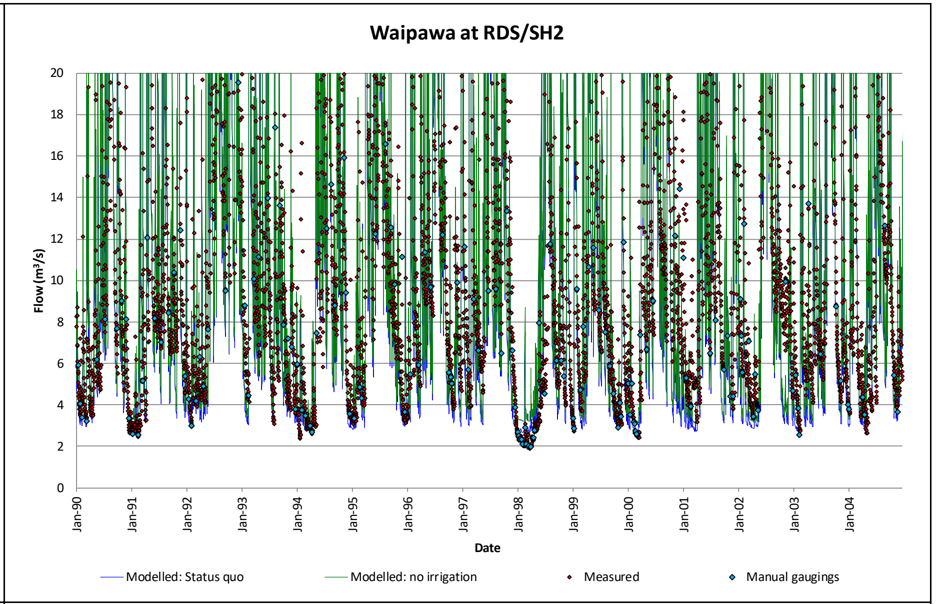


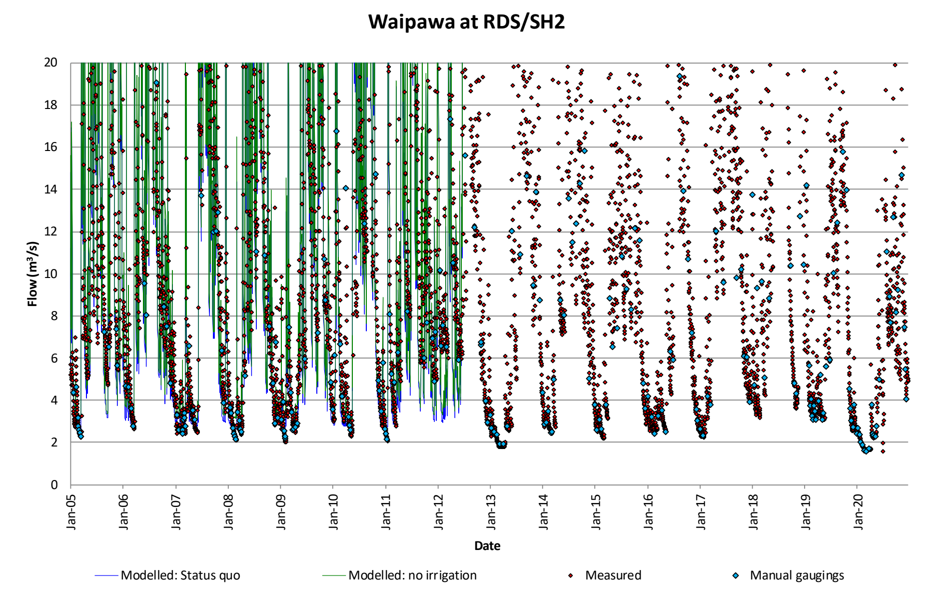
Bore 16882 (new)
Groundwater level (HBD)
246
244
242
240
238
236
234
232
230
228
226
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Jan-10
Jan-12
Jan-14
Jan-16
Jan-18
Jan-20
Date (1 mmm-yy)
Modelled: Status quo
Modelled: no irrigation
Measured

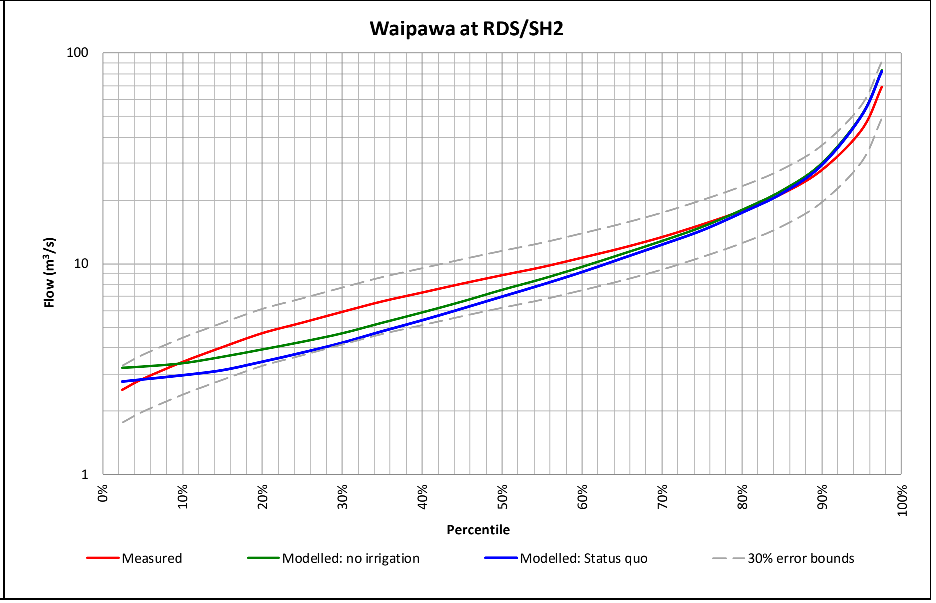
Appendix B: River flow calibration plots

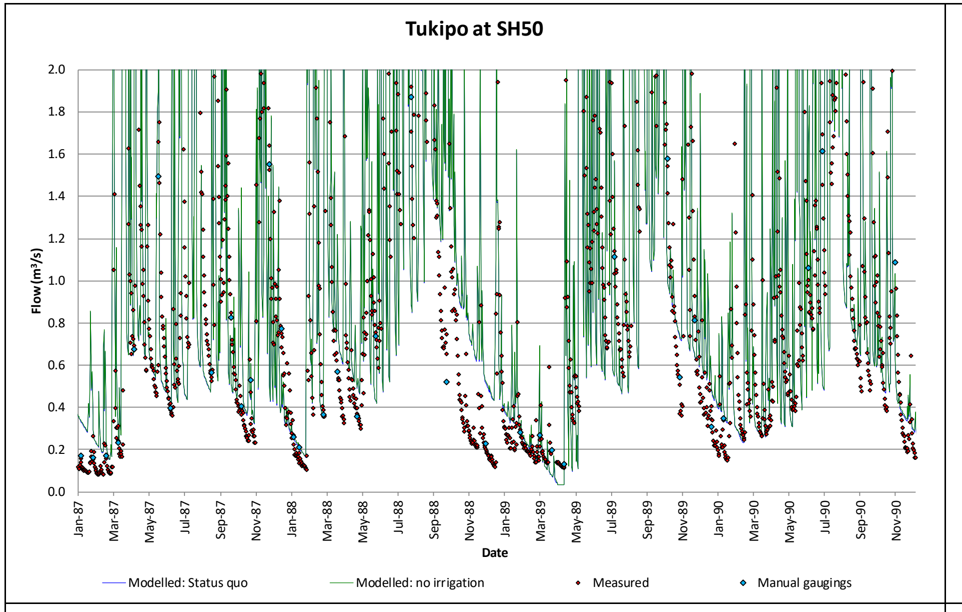

Tukituki at Tapairu Rd
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured
Manual gaugings
Tukituki at Tapairu Rd
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured
Manual gaugings
Tukituki at Tapairu Rd
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured
Manual gaugings
Tukituki at Tapairu Rd
Flow (m³/s)
Percentile
Measured
Modelled: no irrigation
Modelled: Status quo
30% error bounds

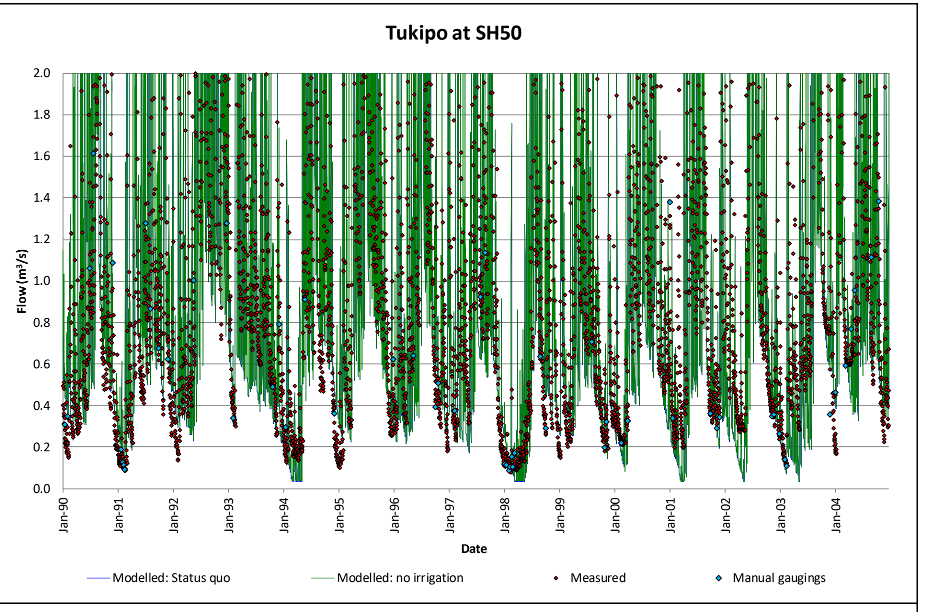

Waipawa at RDS/SH2
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured
Manual gaugings

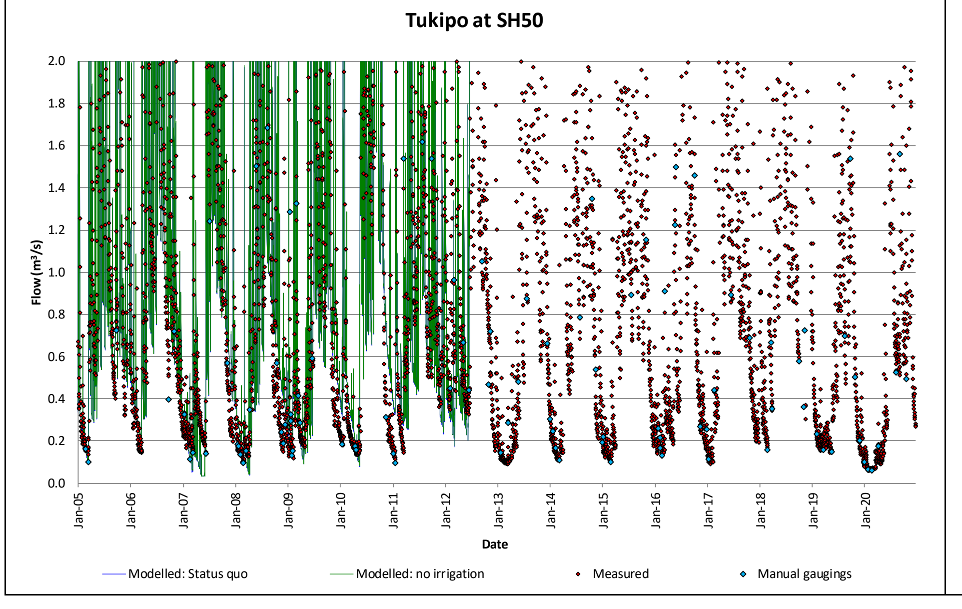

Waipawa at RDS/SH2
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured
Manual gaugings

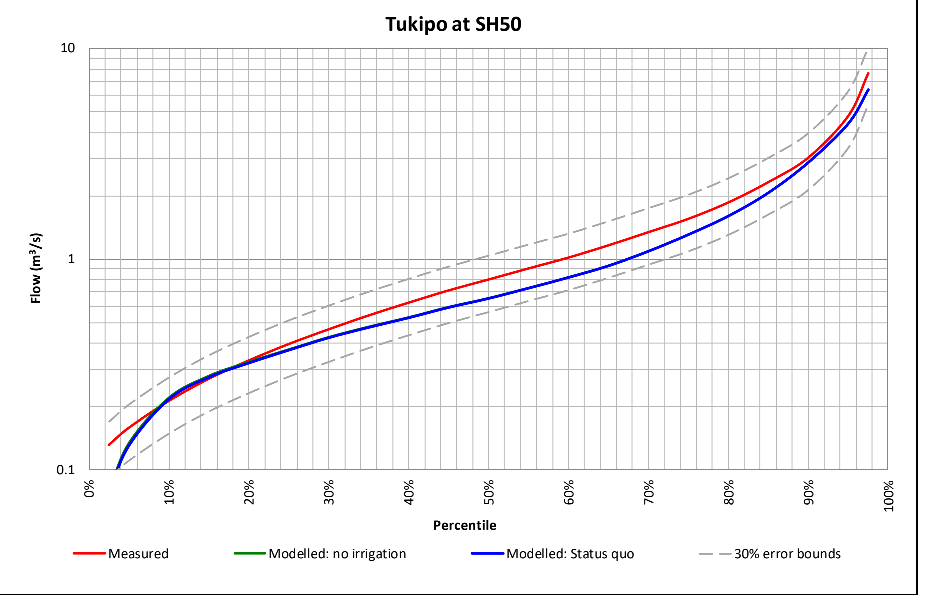

Waipawa at RDS/SH2
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured
Manual gaugings

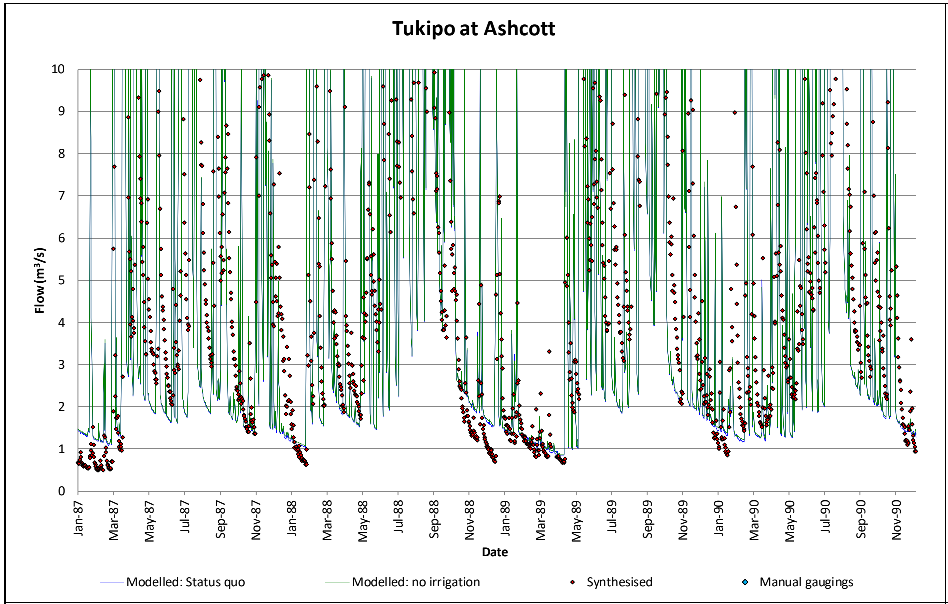

Waipawa at RDS/SH2
Flow (m³/s)
Percentile
Measured
Modelled: no irrigation
Modelled: Status quo
30% error bounds

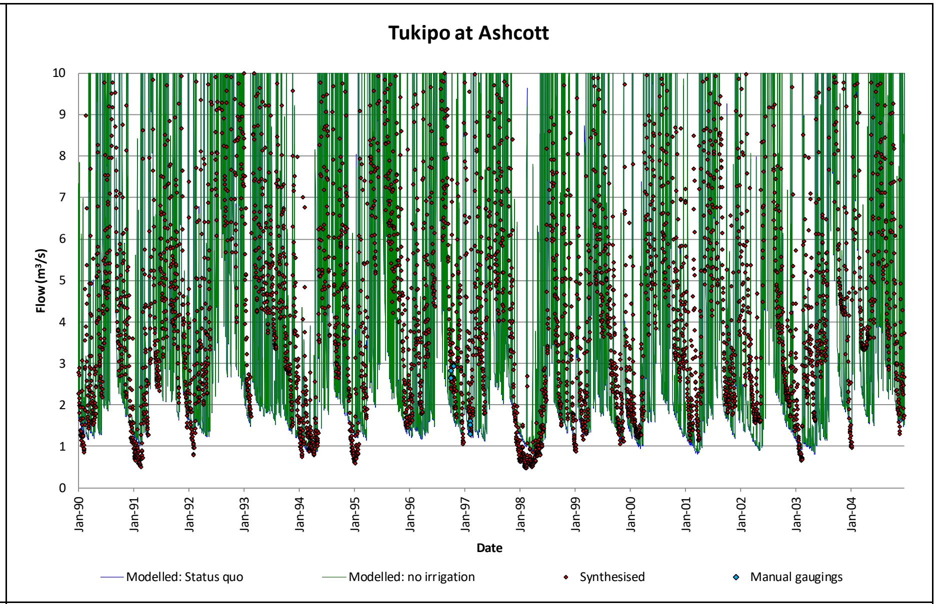

Tukipo at SH50
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured
Manual gaugings

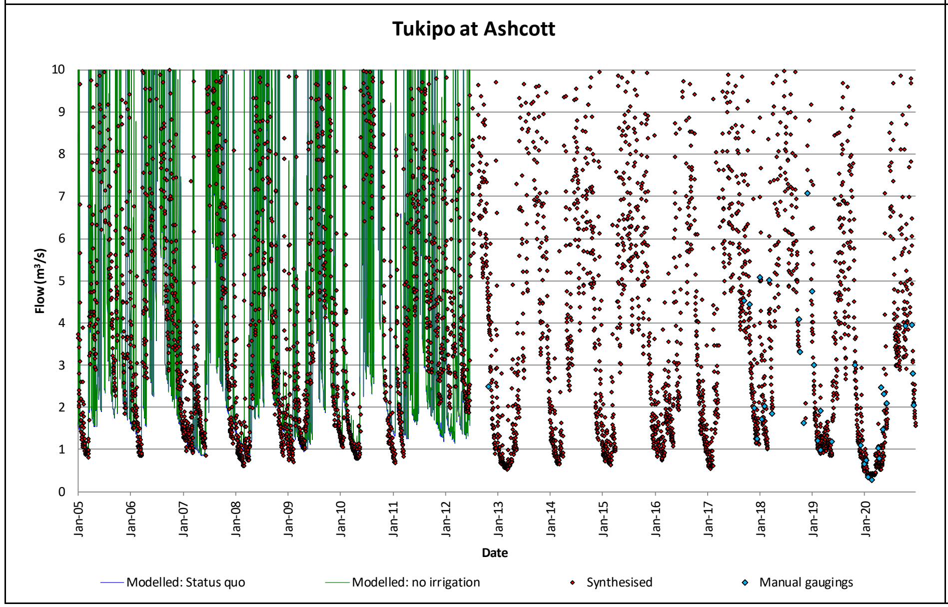

Tukipo at SH50
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured
Manual gaugings

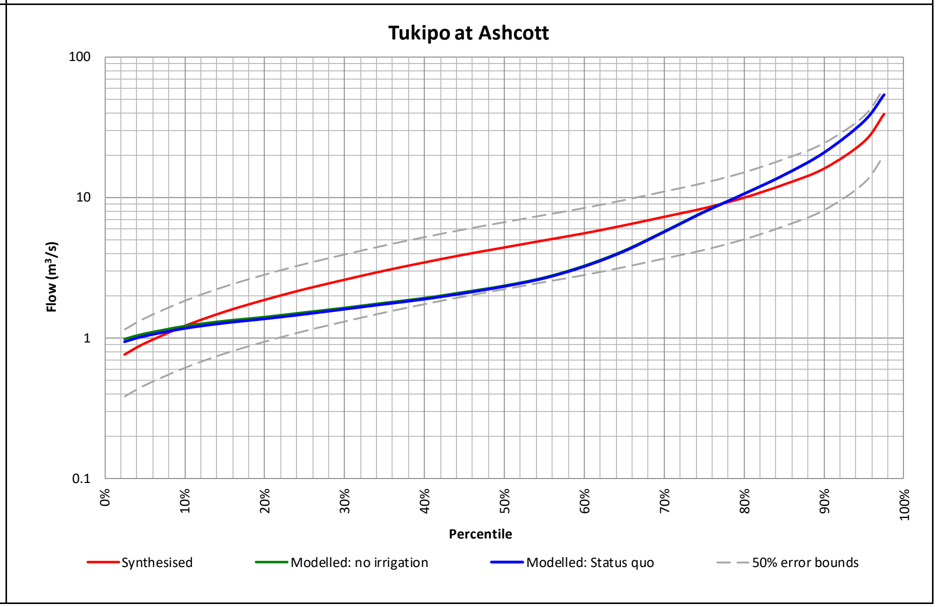

Tukipo at SH50
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured
Manual gaugings

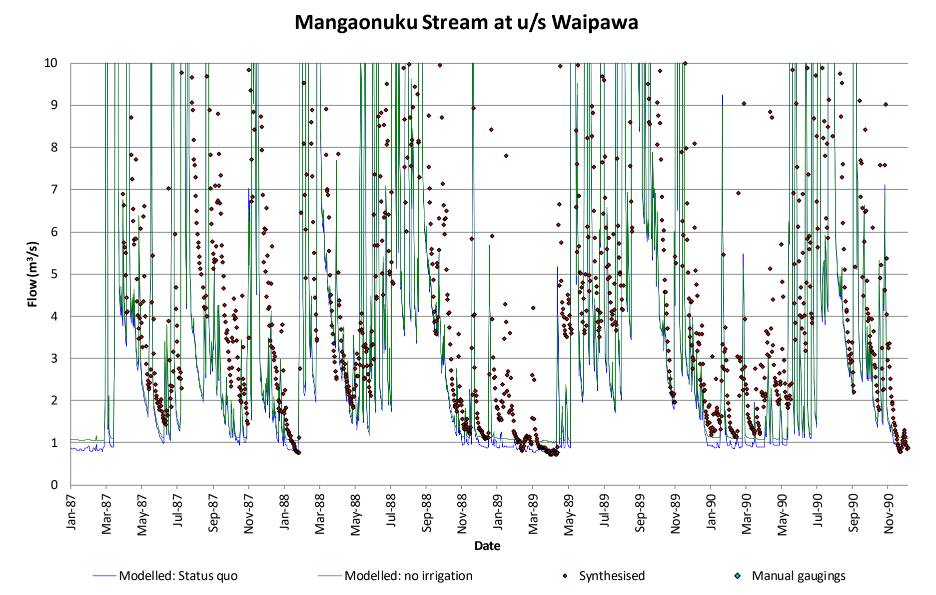

Tukipo at SH50
Flow (m³/s)
Percentile
Measured
Modelled: no irrigation
Modelled: Status quo
30% error bounds

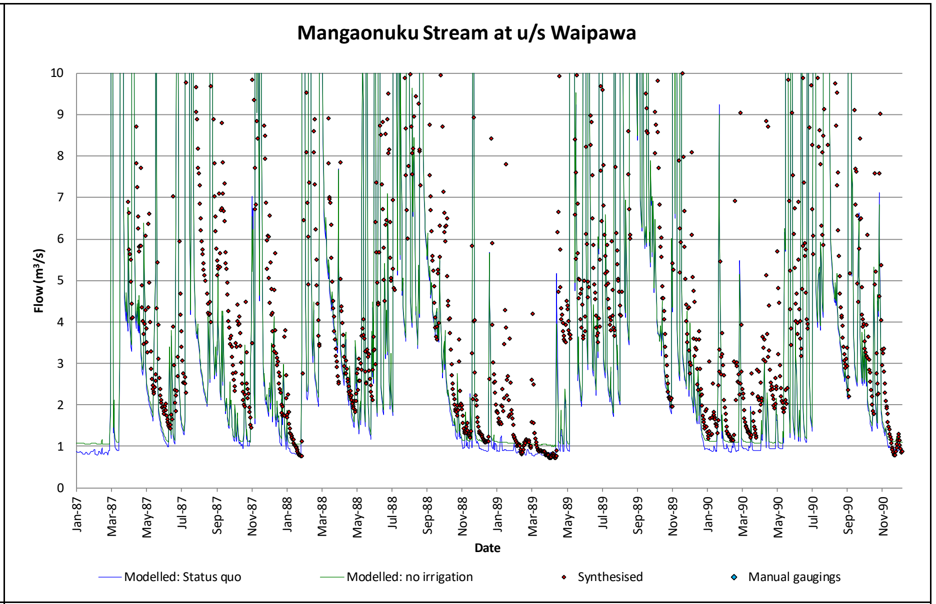

Tukipo at Ashcott
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Synthesised
Manual gaugings

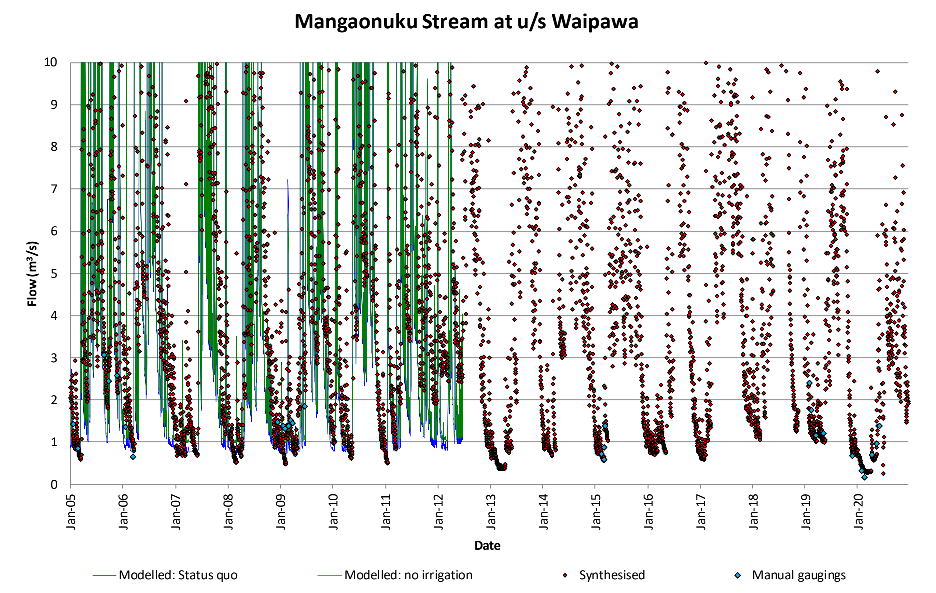

Tukipo at Ashcott
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Synthesised
Manual gaugings

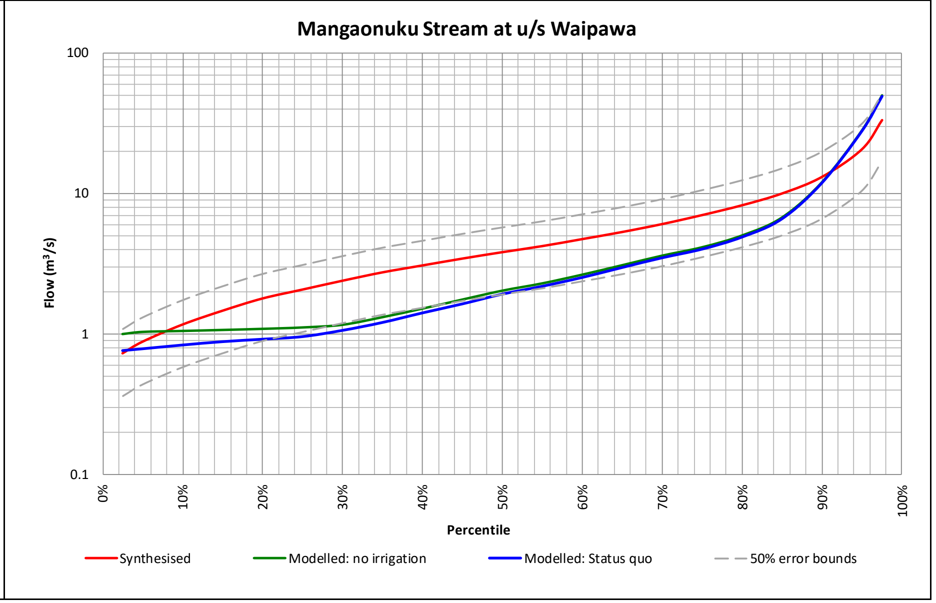

Tukipo at Ashcott
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Synthesised
Manual gaugings


Tukipo at Ashcott
Flow (m³/s)
Percentile
Synthesised
Modelled: no irrigation
Modelled: Status quo
50% error bounds

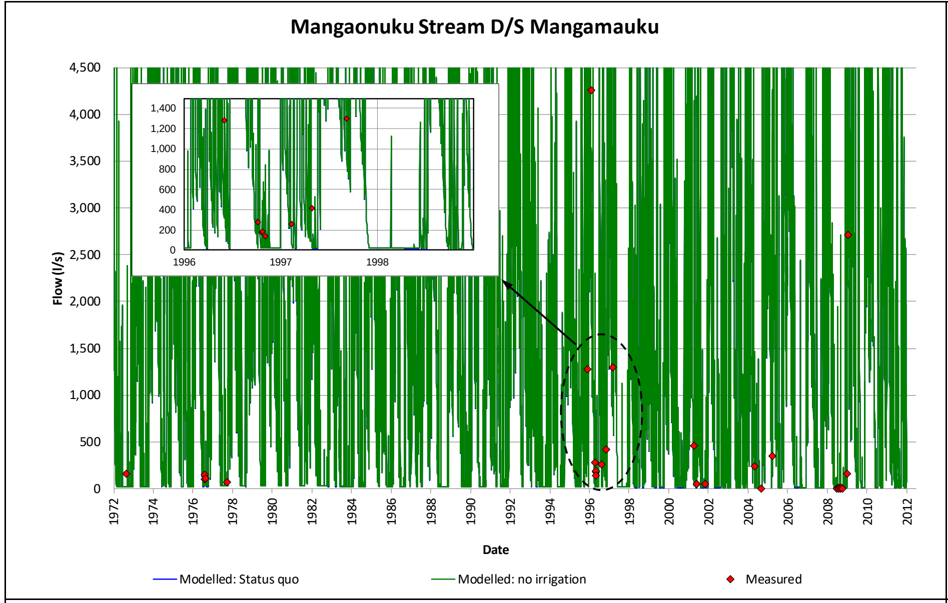

Mangaonuku Stream at u/s Waipawa
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Synthesised
Manual gaugings

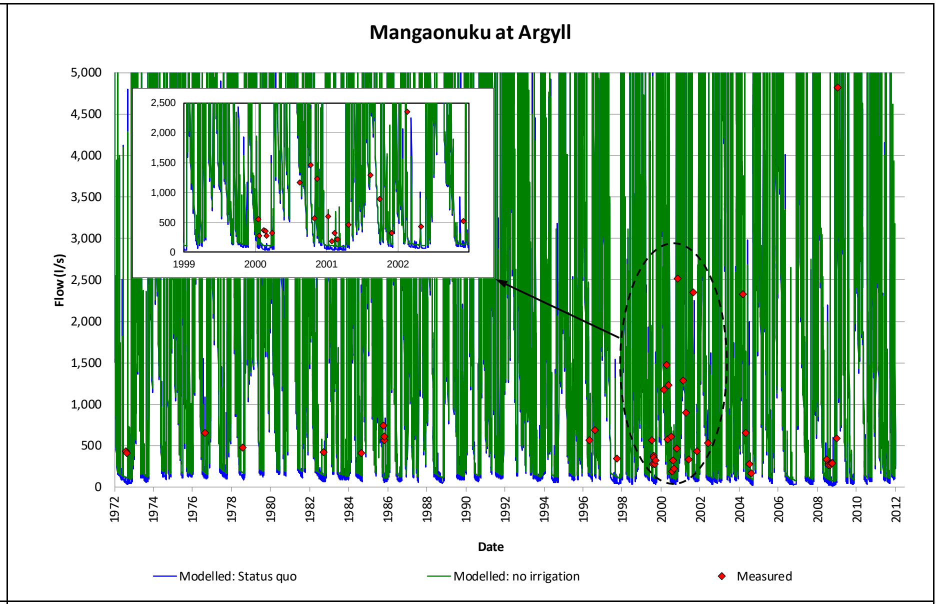

Mangaonuku Stream at u/s Waipawa
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Synthesised
Manual gaugings

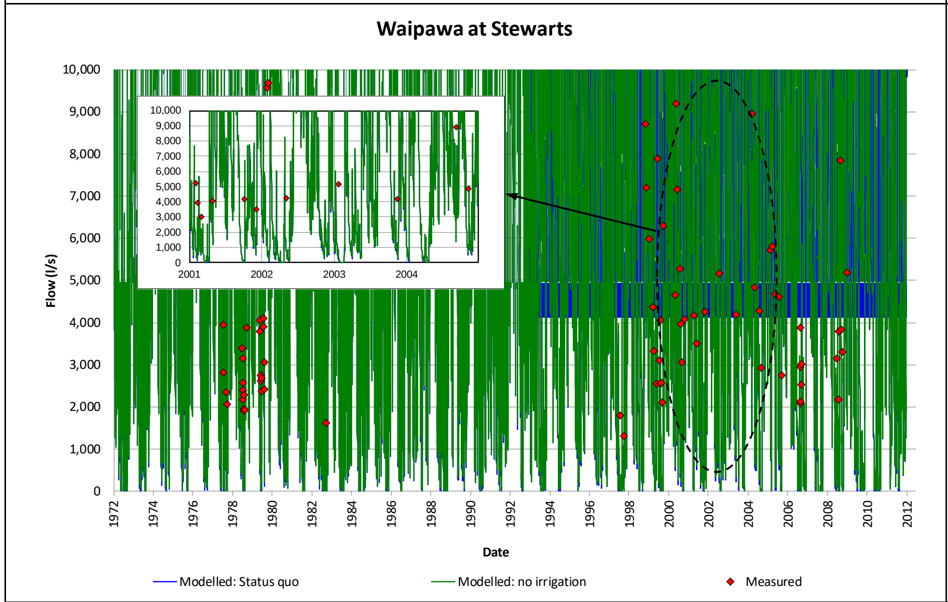

Mangaonuku Stream at u/s Waipawa
Flow (m³/s)
Date
Modelled: Status quo
Modelled: no irrigation
Synthesised
Manual gaugings

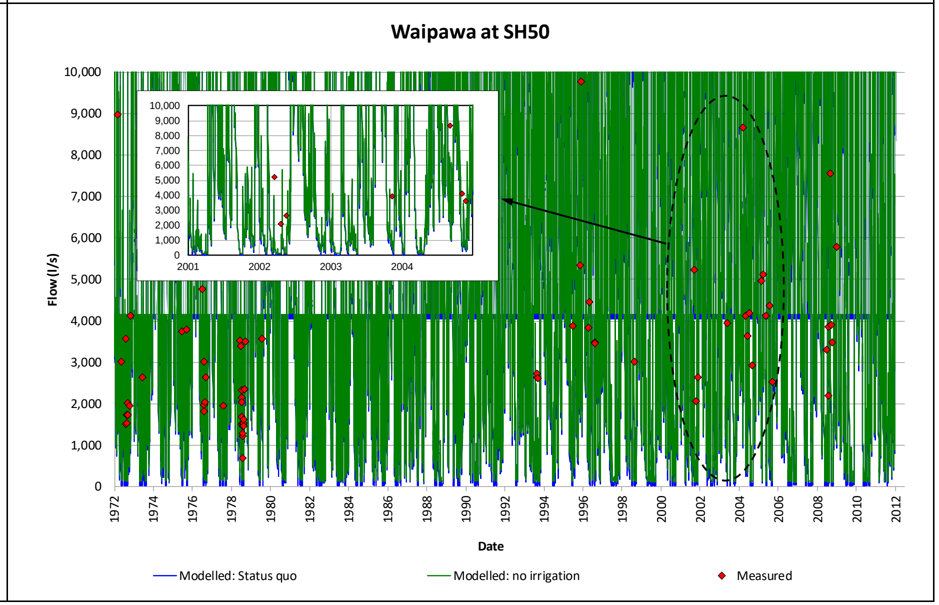

Mangaonuku Stream at u/s Waipawa
Flow (m³/s)
Percentile
Synthesised
Modelled: no irrigation
Modelled: Status quo
50% error bounds

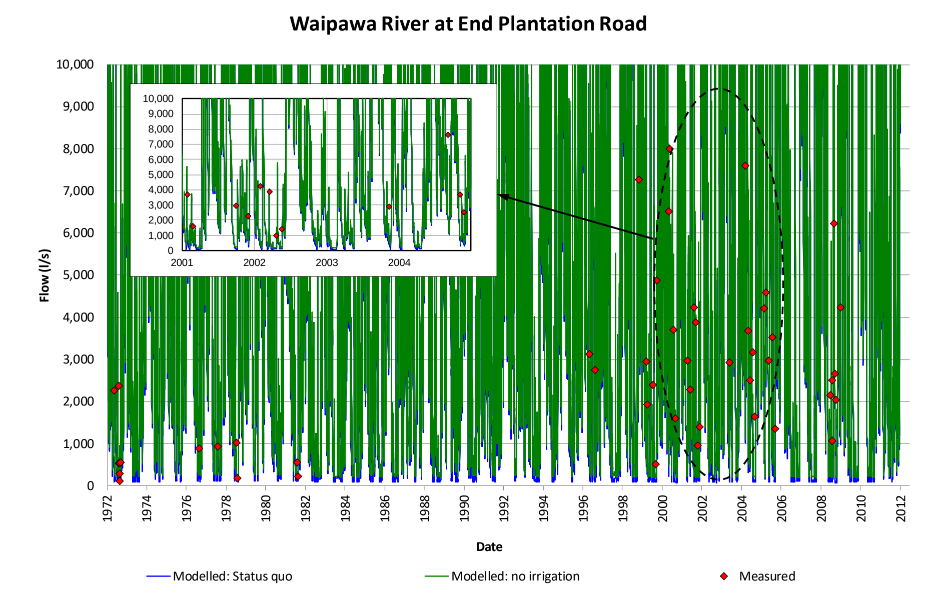
Appendix C: Hydrographs of river flows for gauging sites within the basin

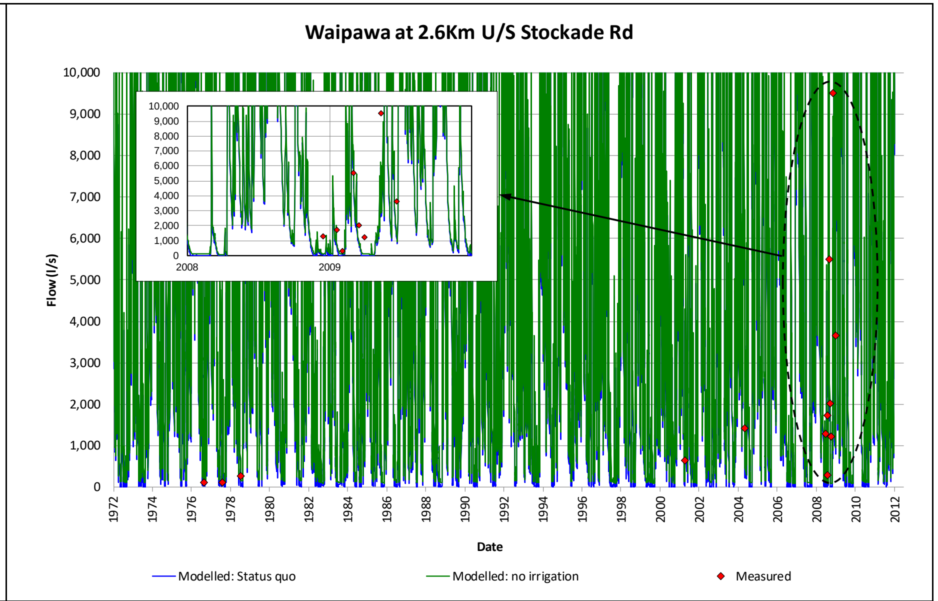

Mangaonuku Stream D/S Mangamauku
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

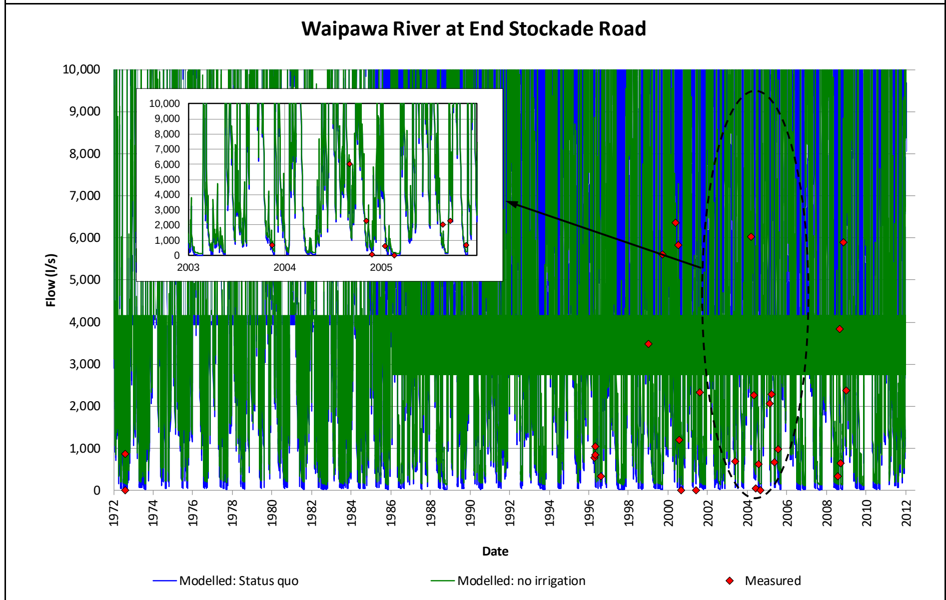

Mangaonuku at Argyll
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

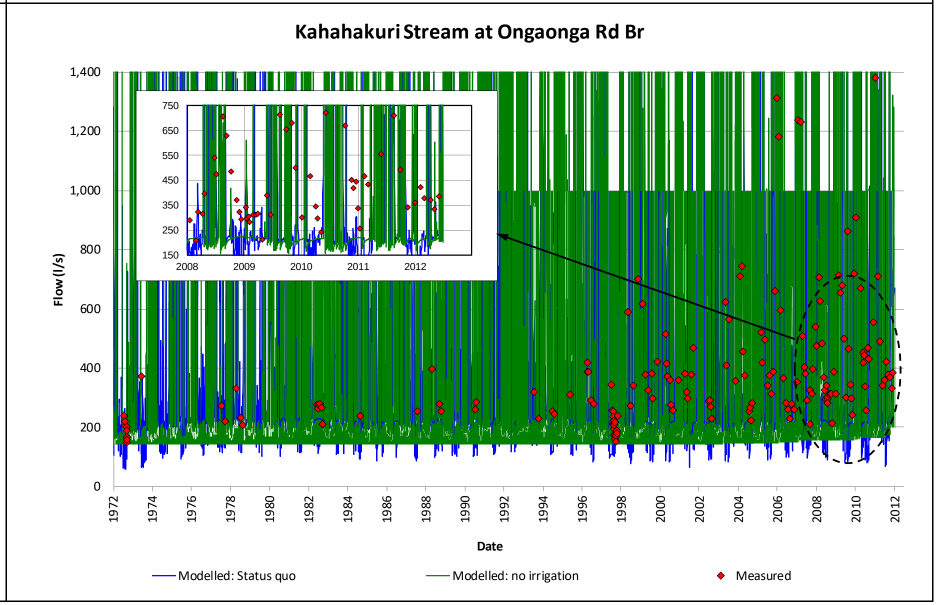

Waipawa at Stewarts
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

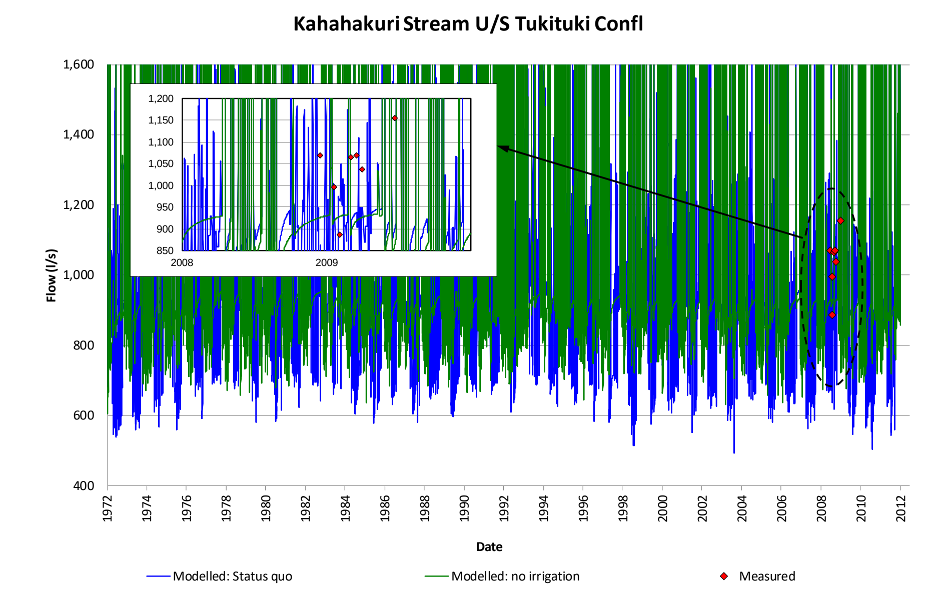

Waipawa at SH50
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

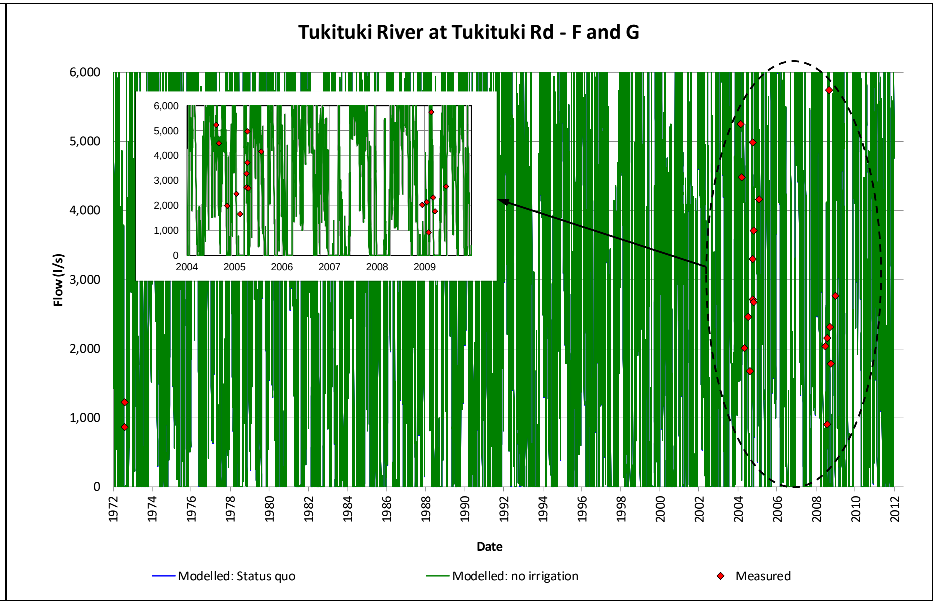

Waipawa River at End Plantation Road
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

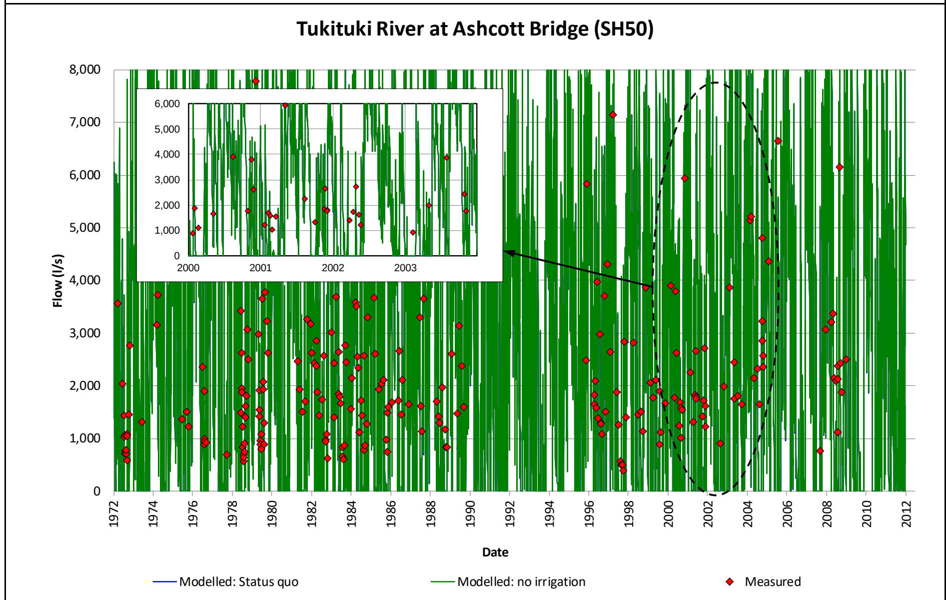

Waipawa at 2.6Km U/S Stockade Rd
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

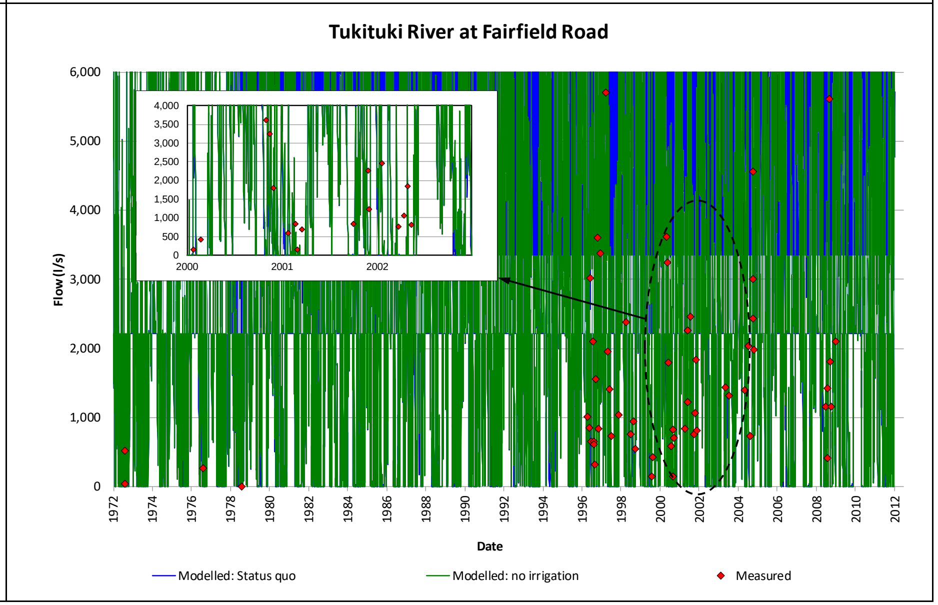

Waipawa River at End Stockade Road
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

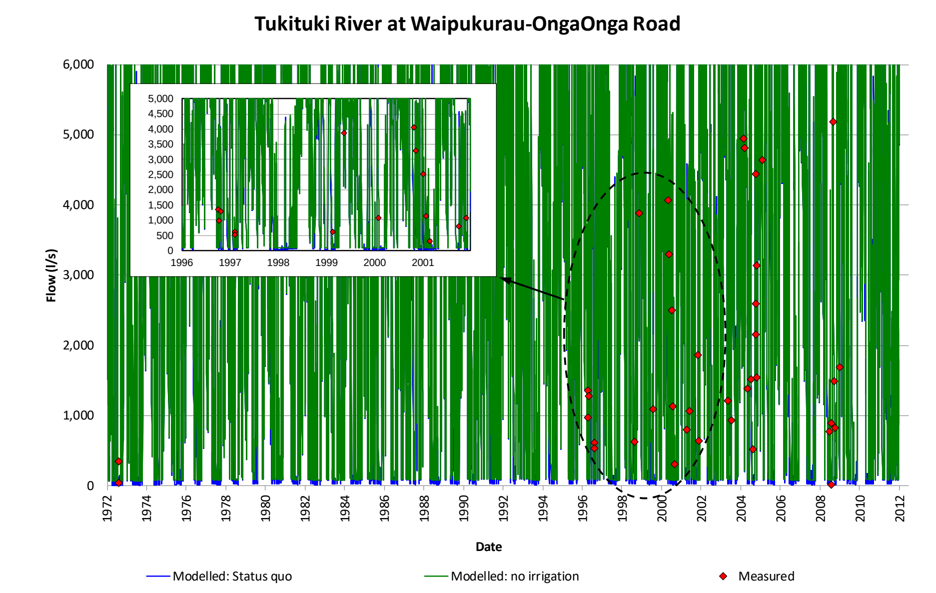

Kahahakuri Stream at Ongaonga Rd Br
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured


Kahahakuri Stream U/S Tukituki Confl
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

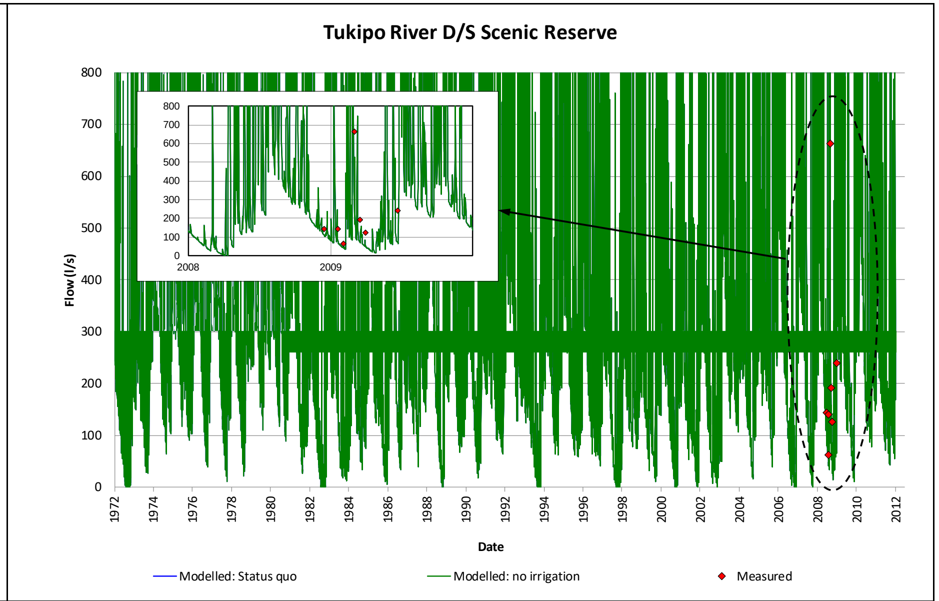

Tukituki River at Tukituki Rd - F and G
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured


Tukituki River at Ashcott Bridge (SH50)
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

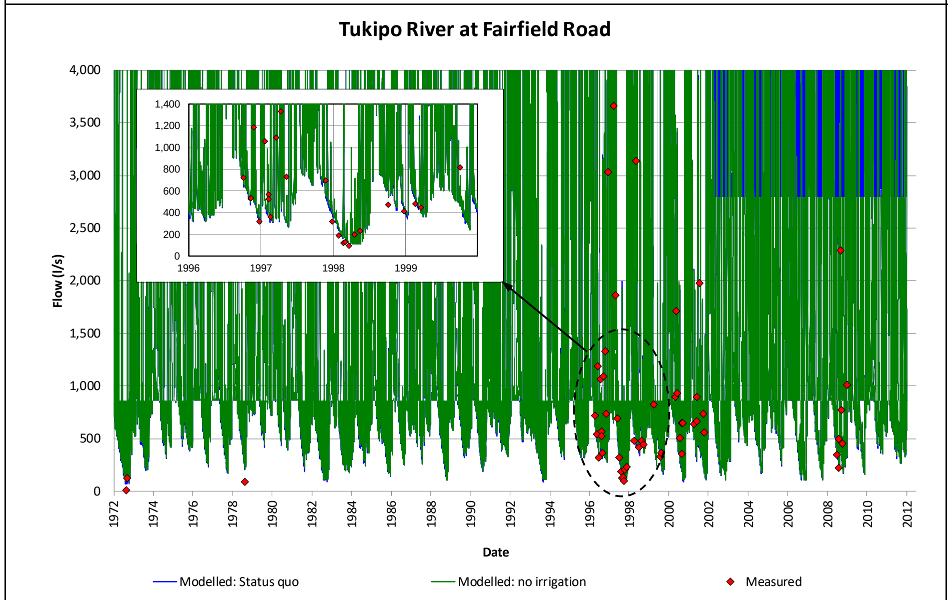

Tukituki River at Fairfield Road
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured



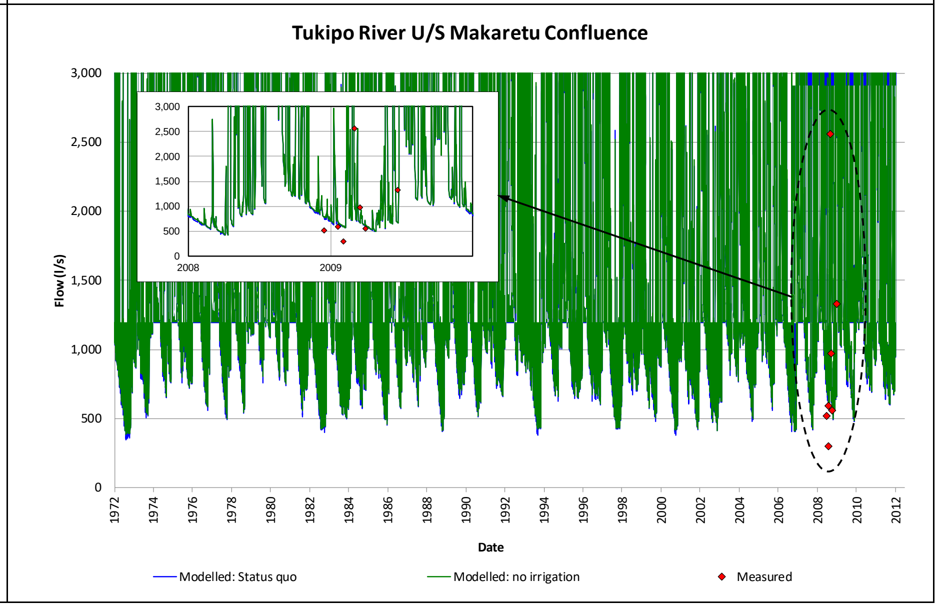
Tukituki River at Waipukurau-OngaOnga Road
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured



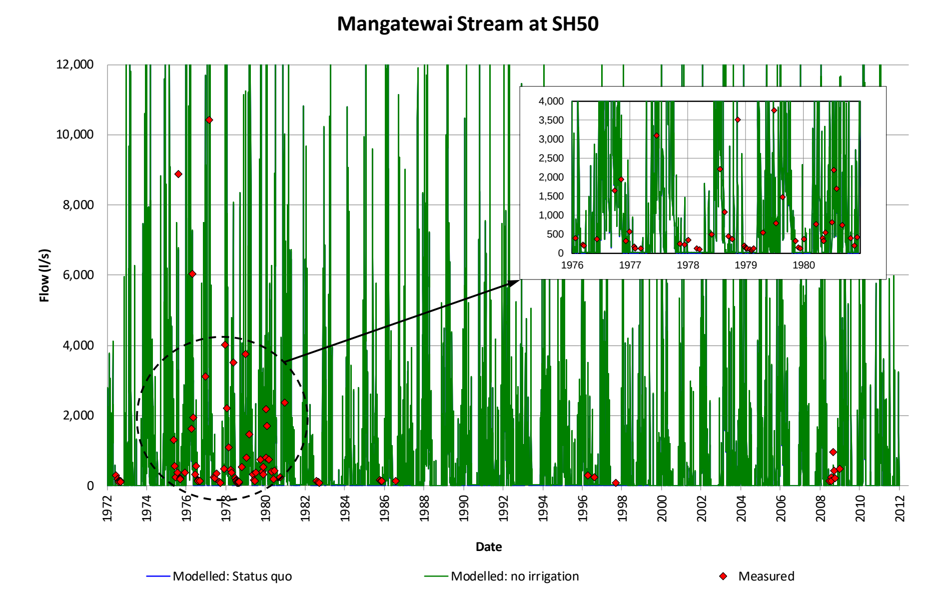
Tukipo River D/S Scenic Reserve
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

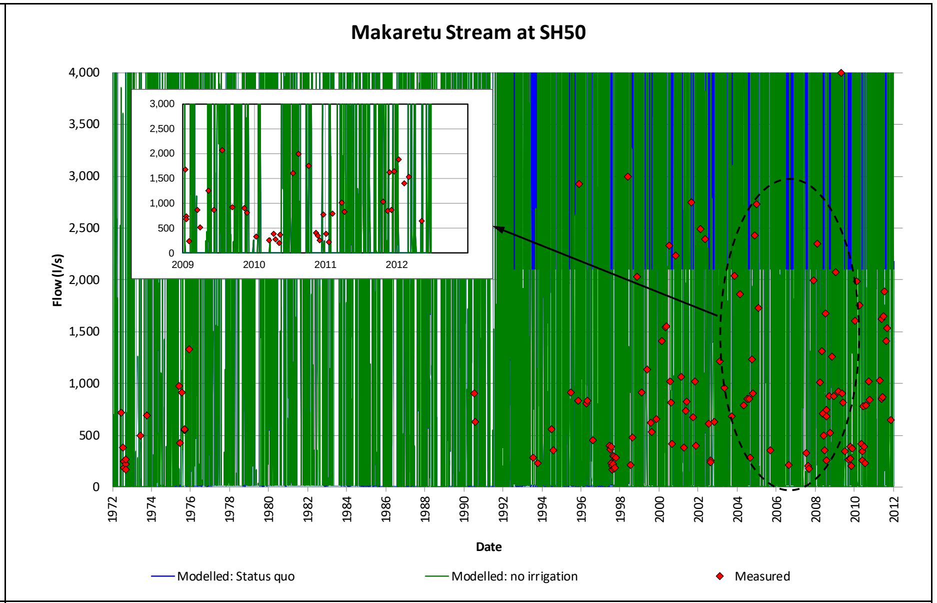


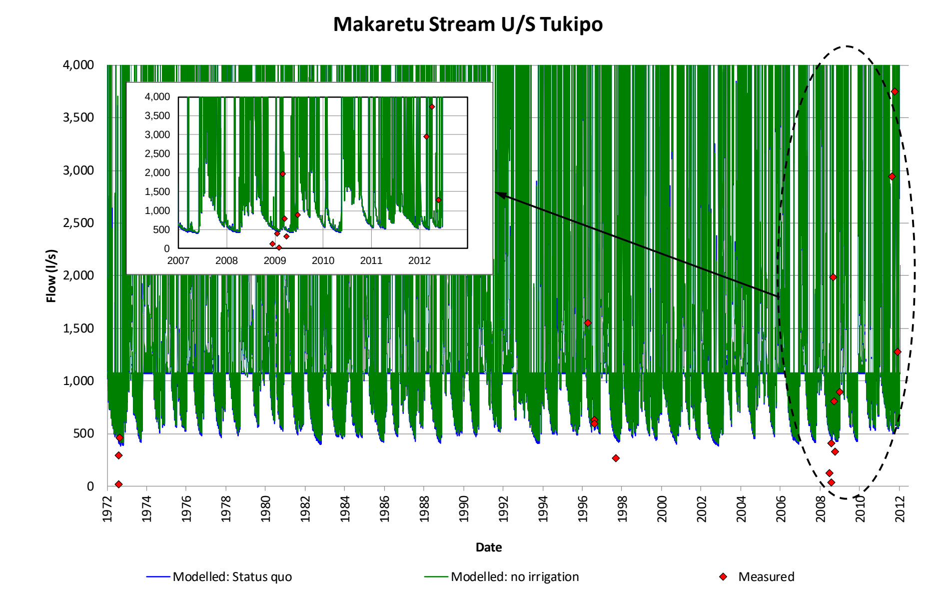
Tukipo River at Fairfield Road
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

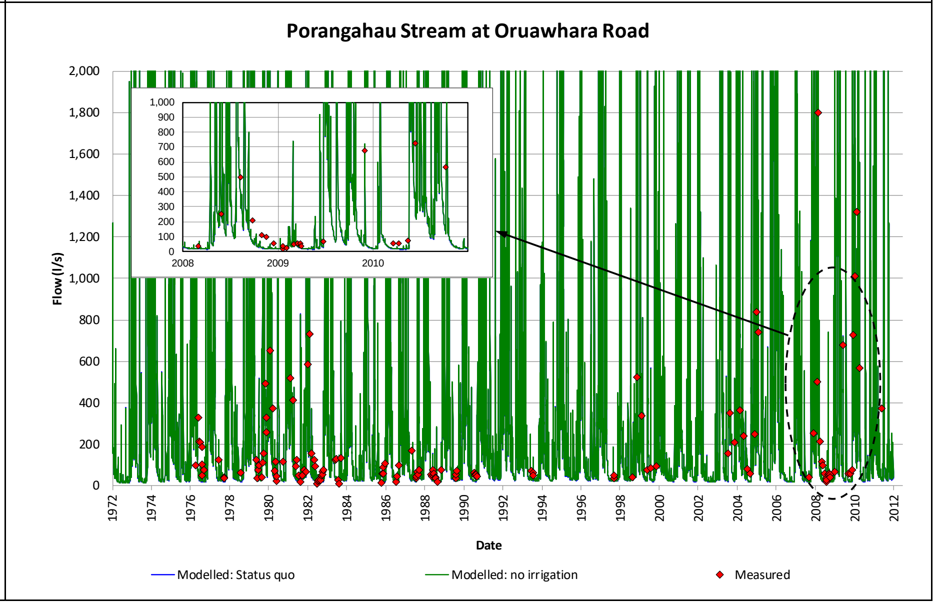


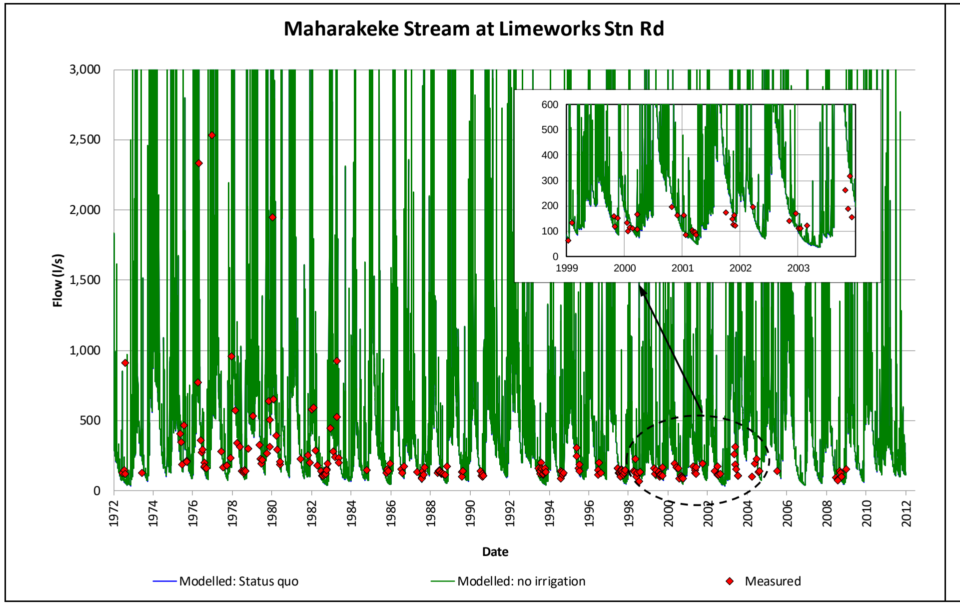
Tukipo River U/S Makaretu Confluence
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured


Mangatewai Stream at SH50
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

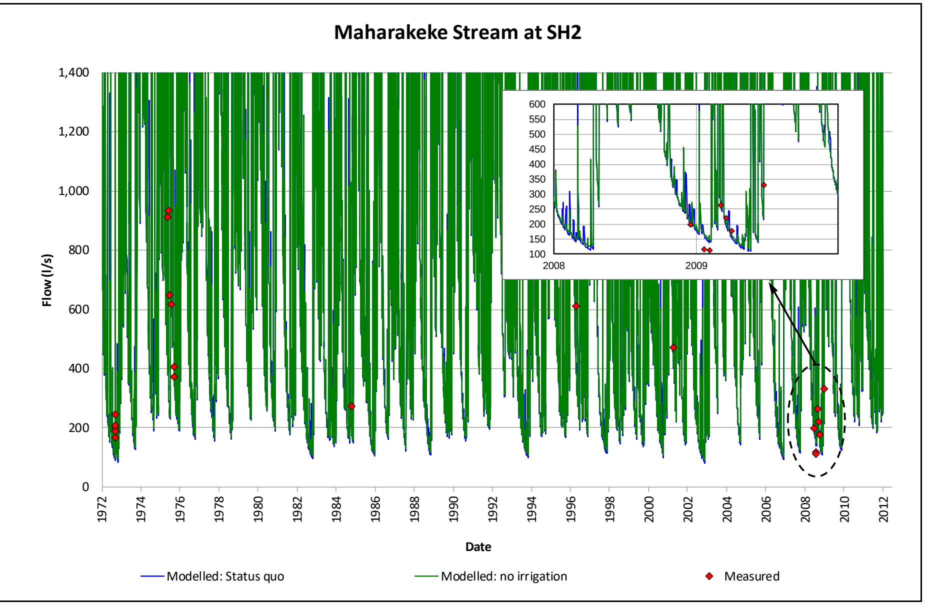

Makaretu Stream at SH50
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured


Makaretu Stream U/S Tukipo
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured


Porangahau Stream at Oruawhara Road
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

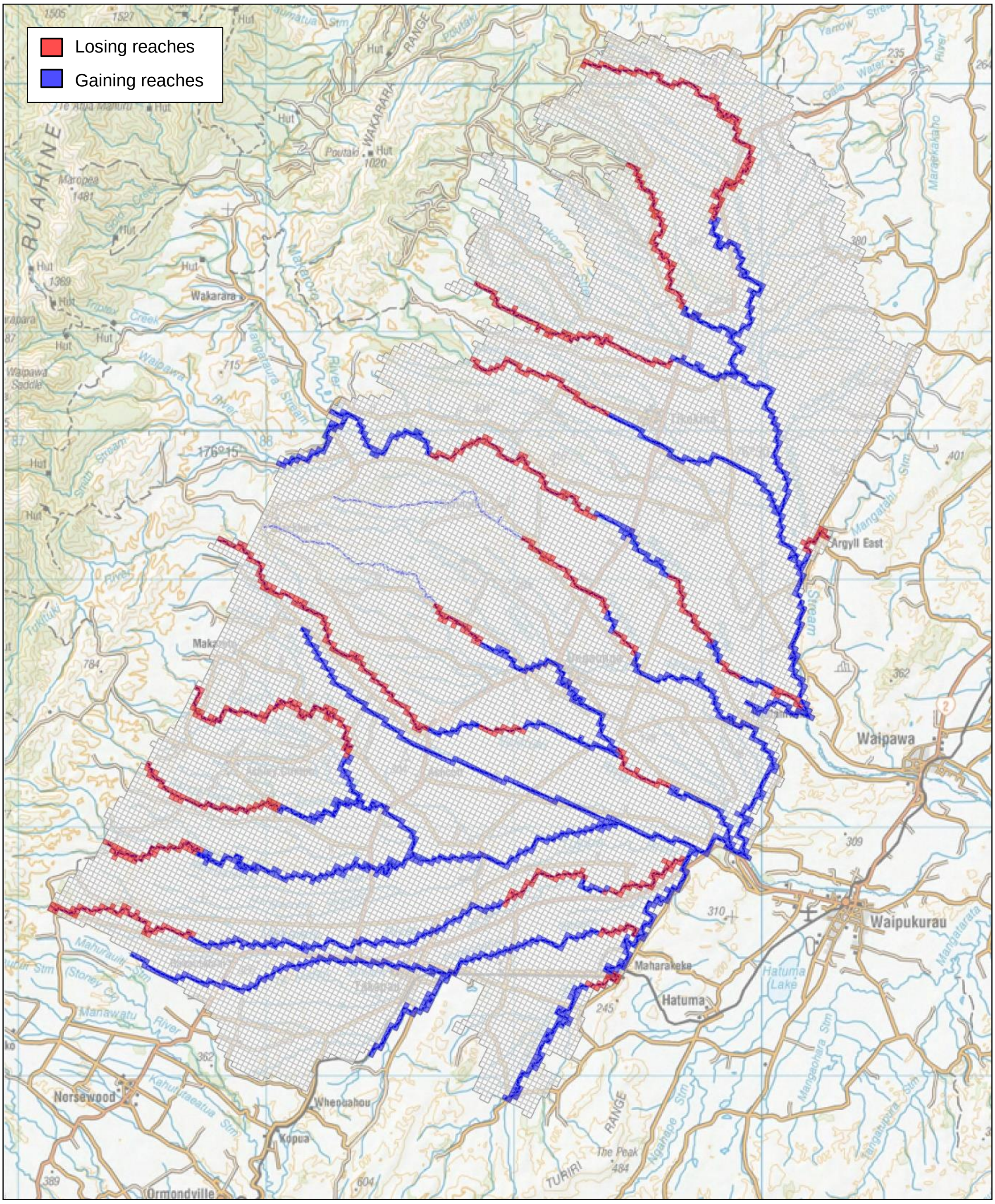


Maharakeke Stream at Limeworks Stn Rd
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

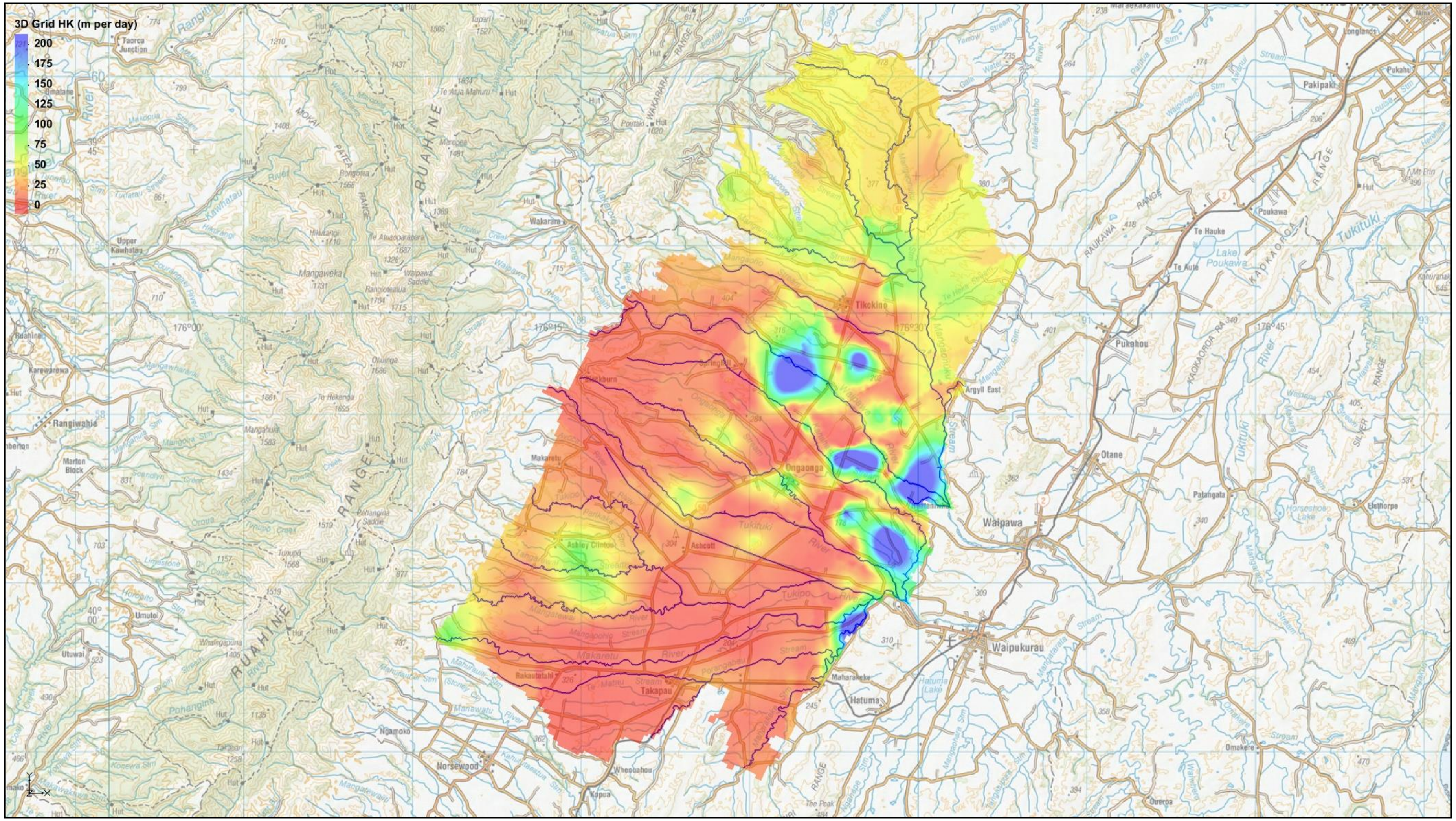


Maharakeke Stream at SH2
Flow (l/s)
Date
Modelled: Status quo
Modelled: no irrigation
Measured

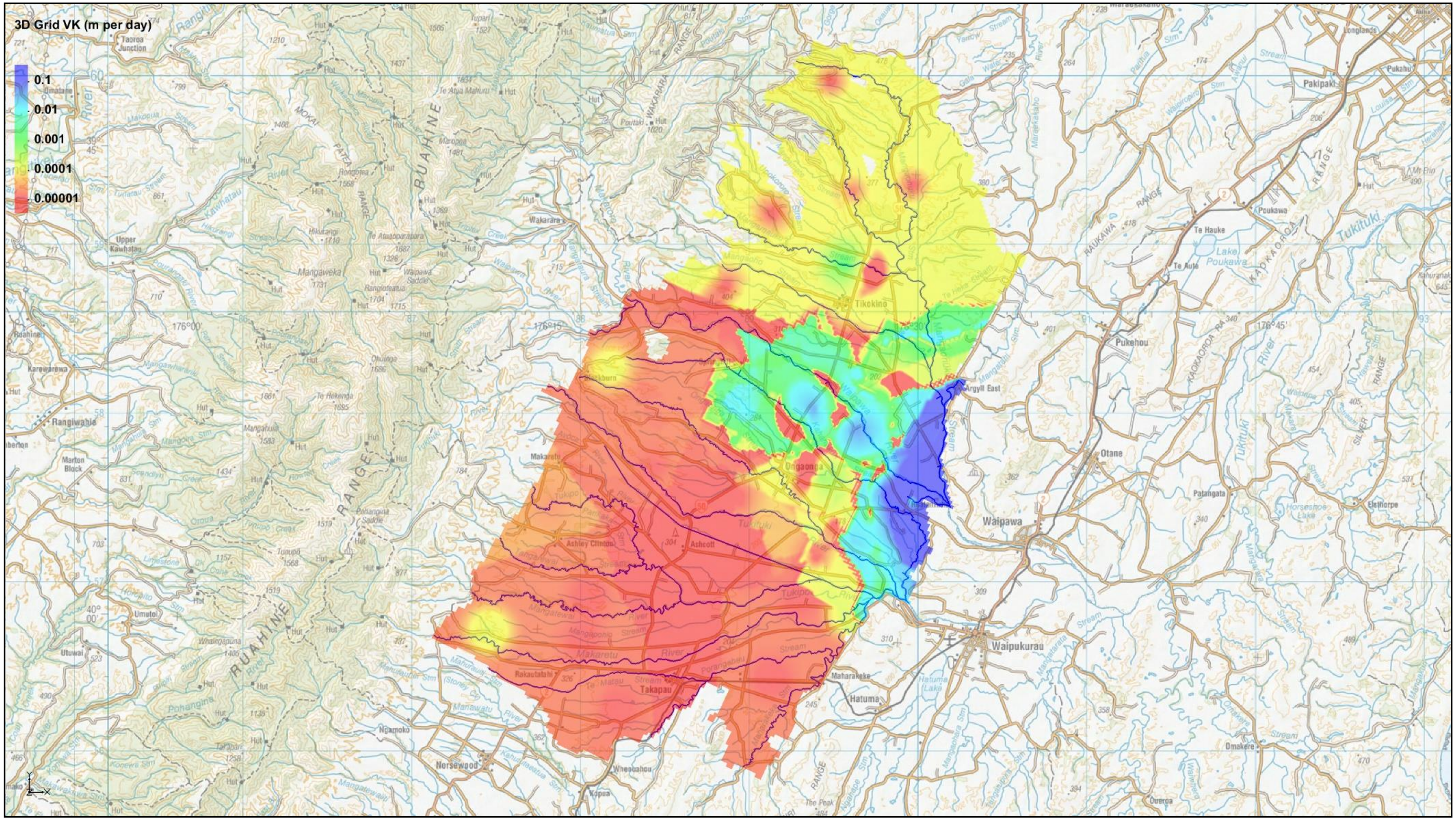
Appendix D: Modelled steady state (average) river flow gain and loss patterns


Losing reaches
Gaining reaches

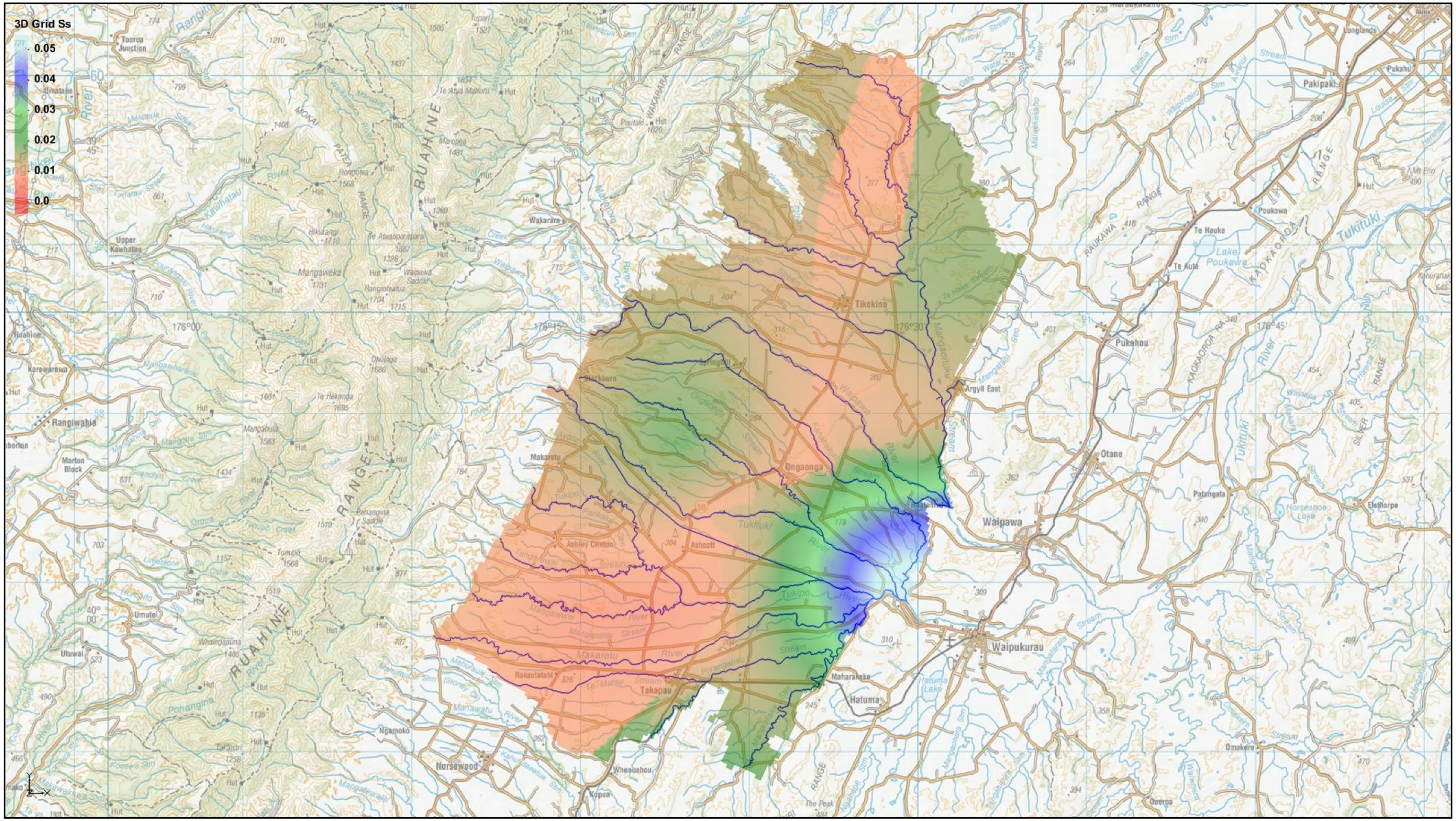
Appendix E: Calibrated Aquifer Parameters



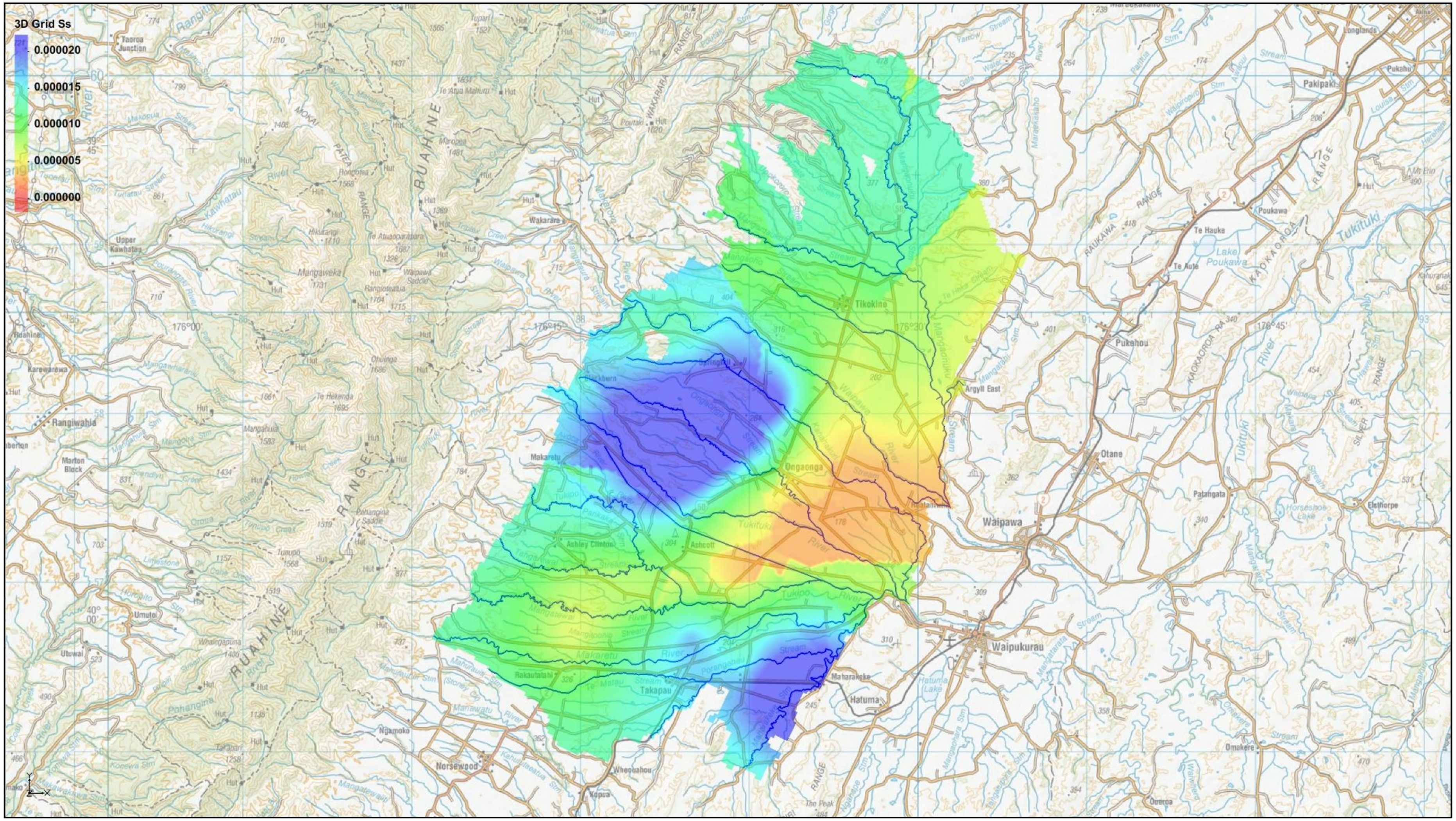
Horizontal hydraulic conductivities (for all layers)



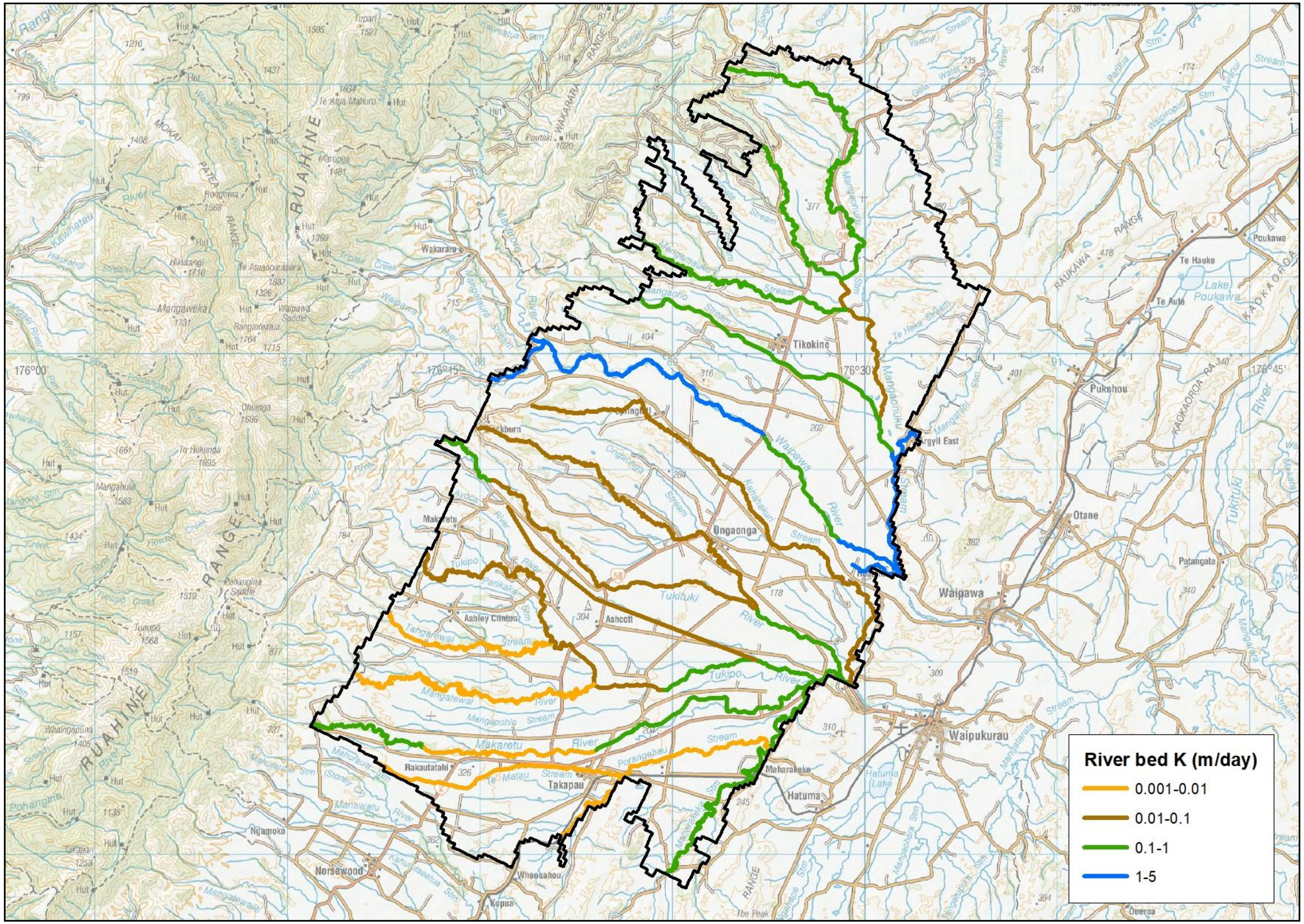
Vertical hydraulic conductivities (for layers 2 and below)



Specific storage for layer 1

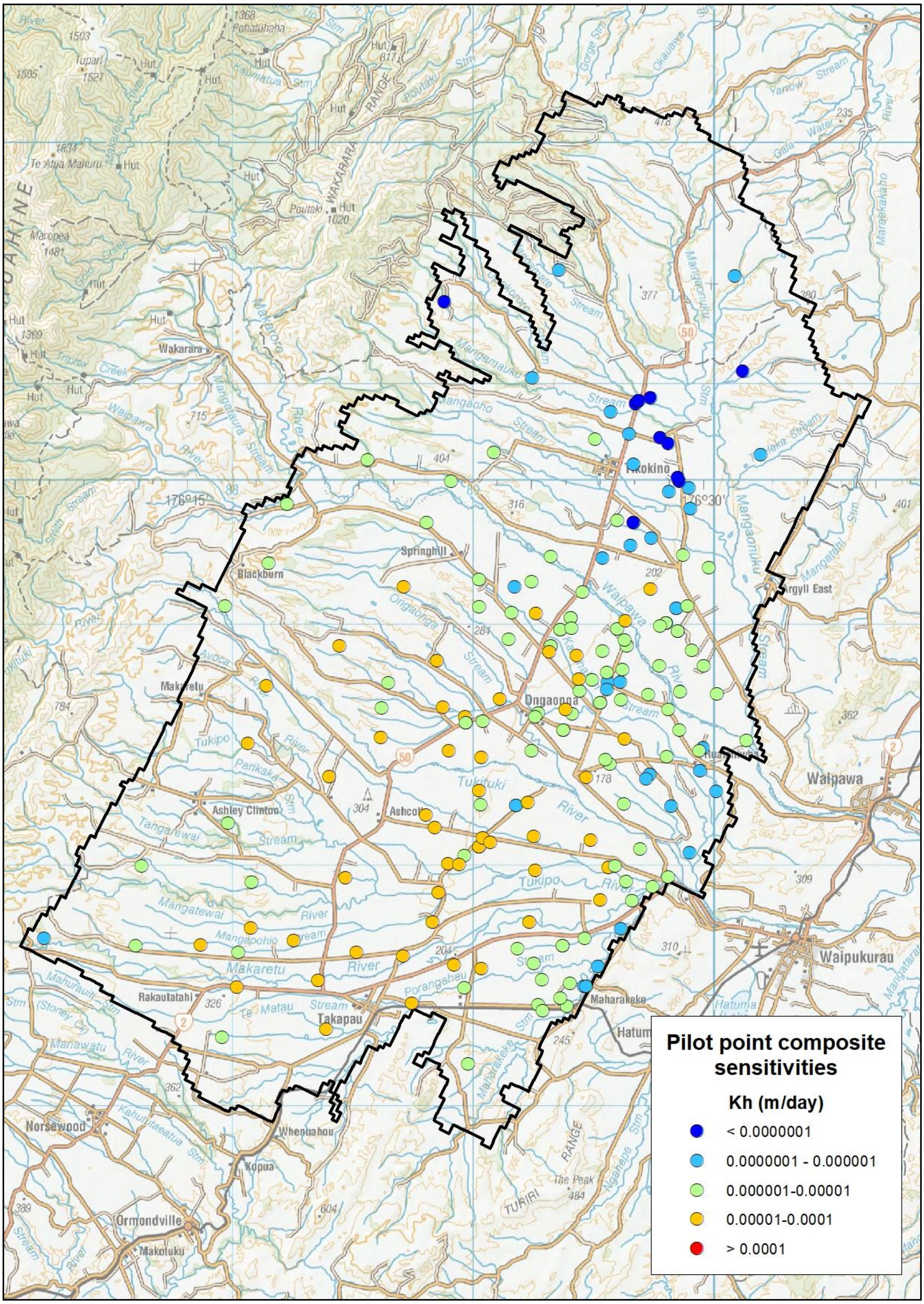


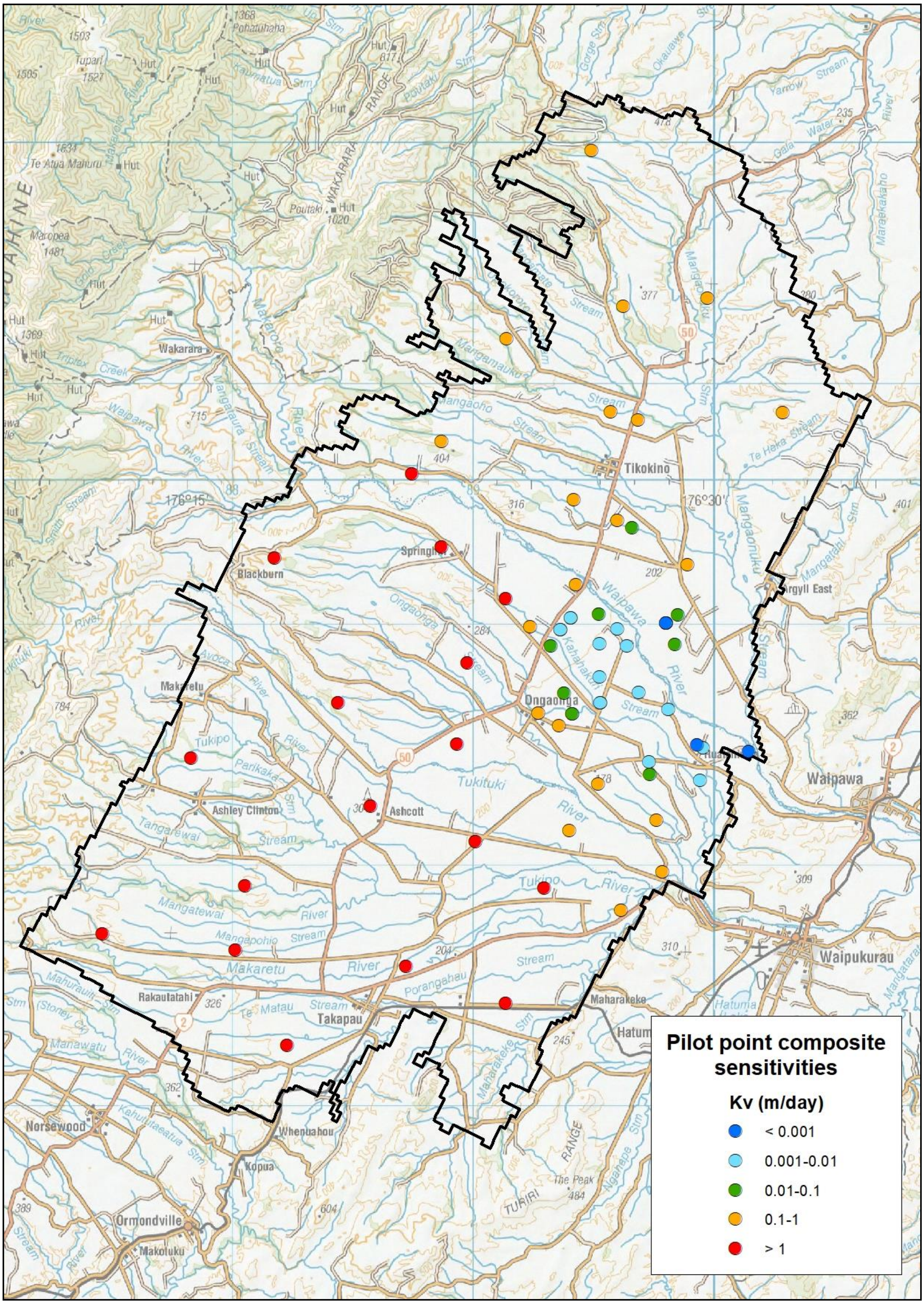
Specific storage for layers 2-10

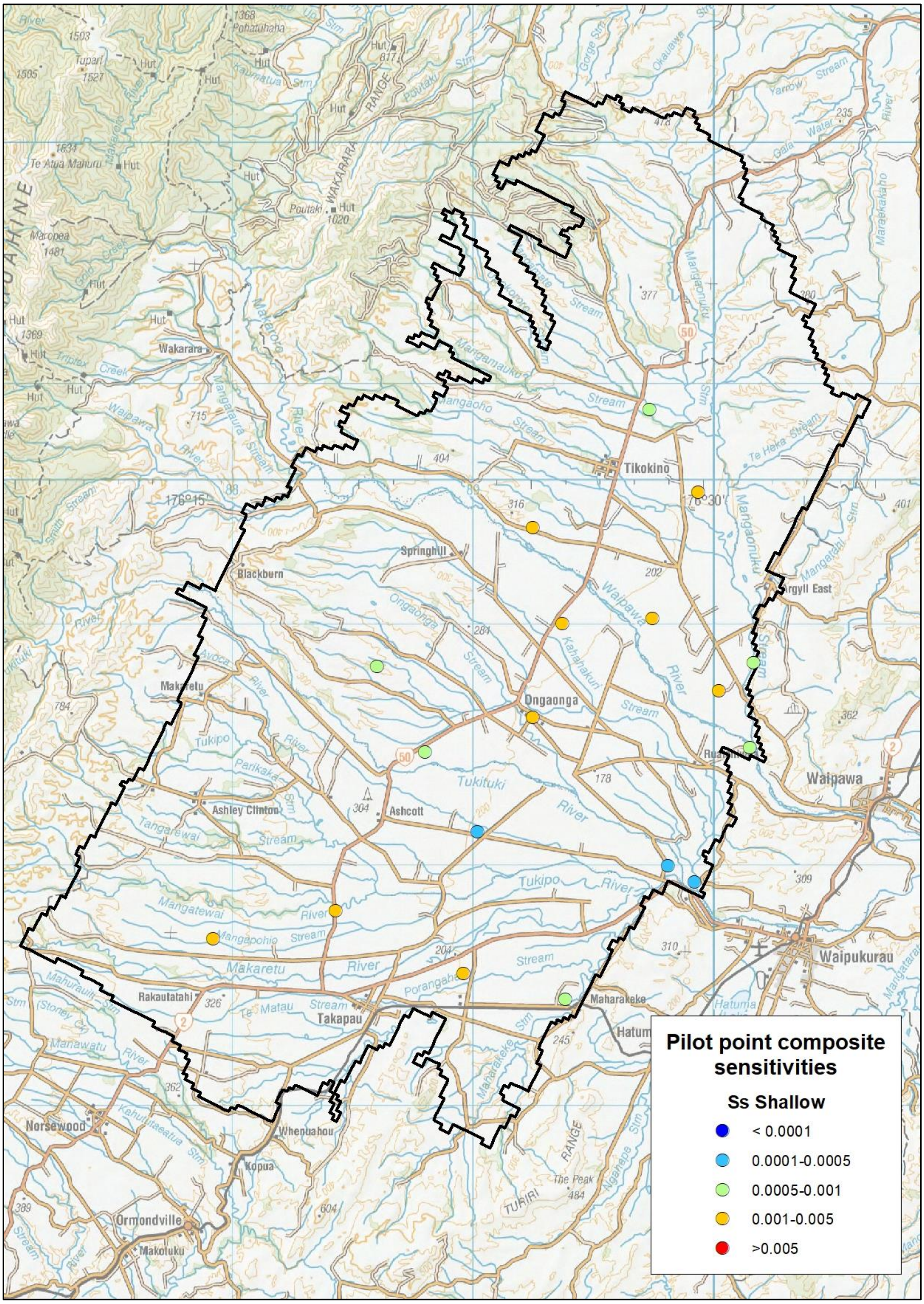


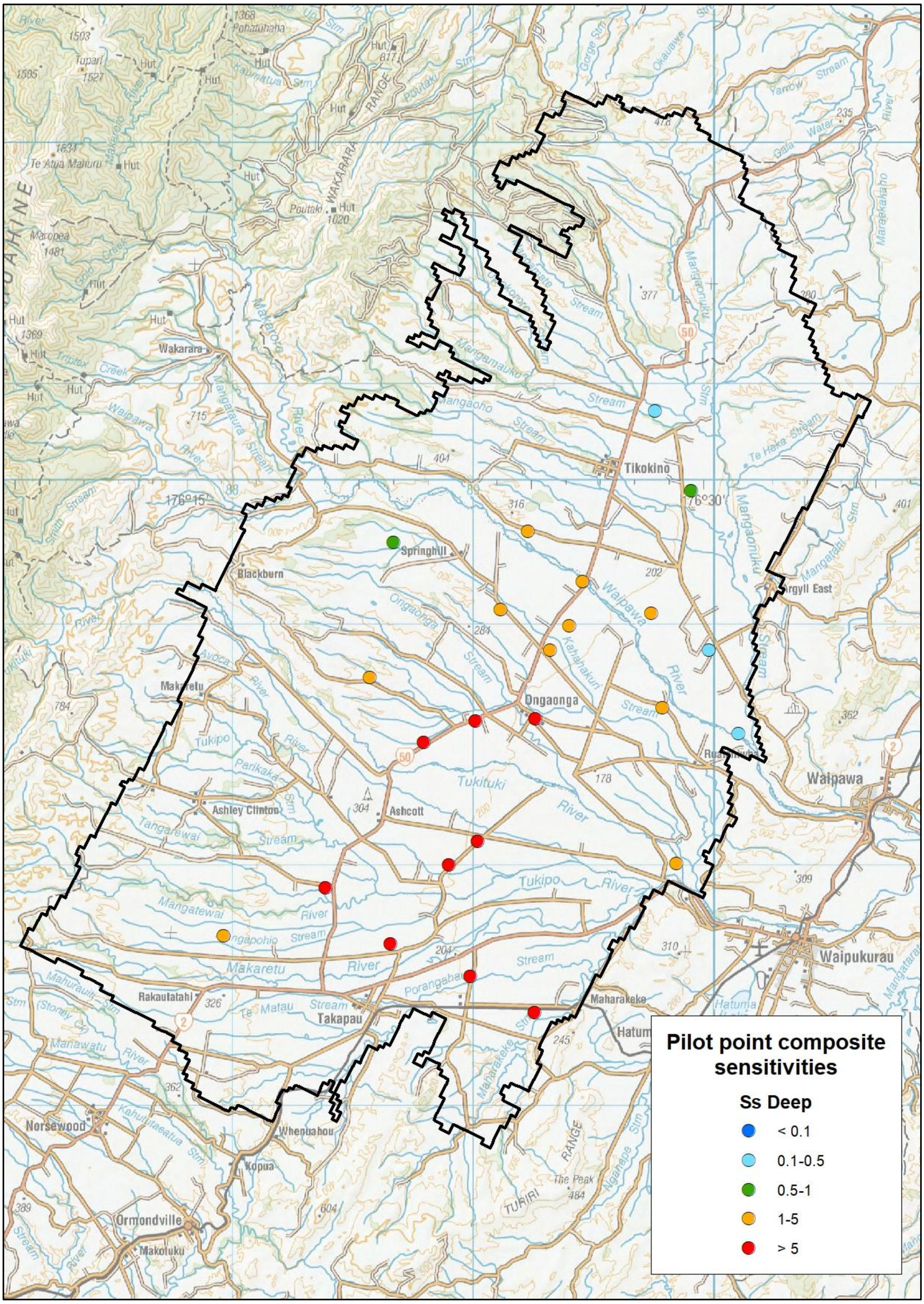
River bed hydraulic conductivities

Appendix F: Pilot point sensitivities

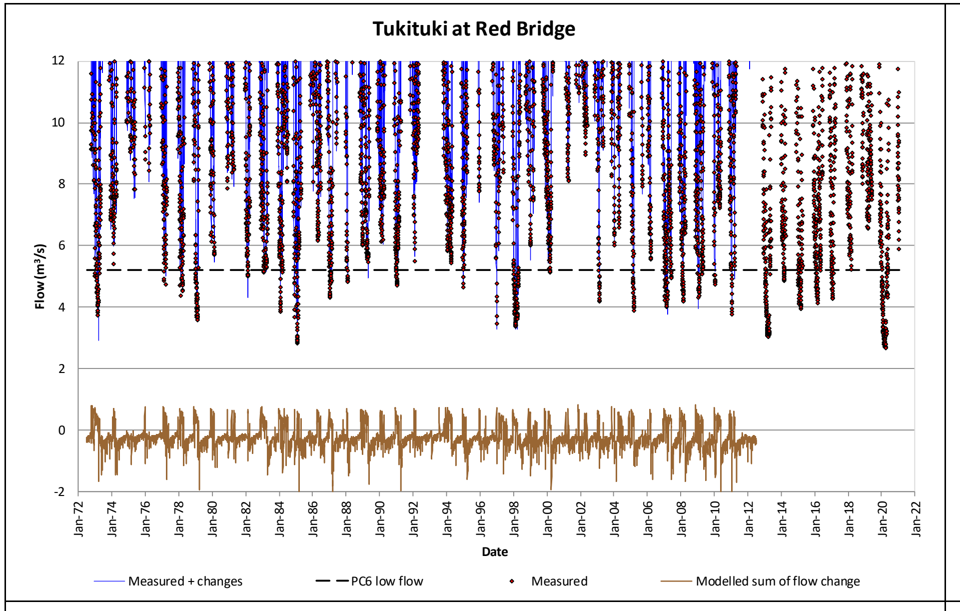

Pilot point composite sensitivities
Kh (m/day)
< 0.0000001
0.0000001 - 0.000001
0.000001-0.00001
0.00001-0.0001
> 0.0001


Pilot point composite sensitivities
Kv (m/day)
< 0.001
0.001-0.01
0.01-0.1
0.1-1
> 1

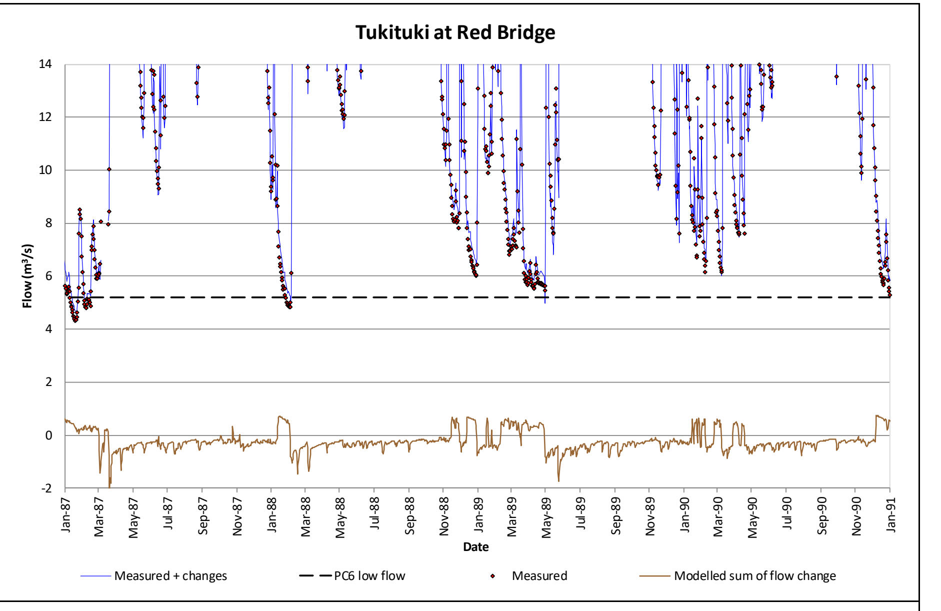

Pilot point composite sensitivities
Ss Shallow
< 0.0001
0.0001-0.0005
0.0005-0.001
0.001-0.005
>0.005
Tikokino
Ongaonga
Takapau
Waipukurau
Waipawa
Ashcott
Springhill
Blackburn
Makaretu
Ashley Clinton
Norsewood
Ormondville
Whenuahou
Maharakeke
Argyll East
Wakarara


Pilot point composite sensitivities
Ss Deep
< 0.1
0.1-0.5
0.5-1
1-5
> 5

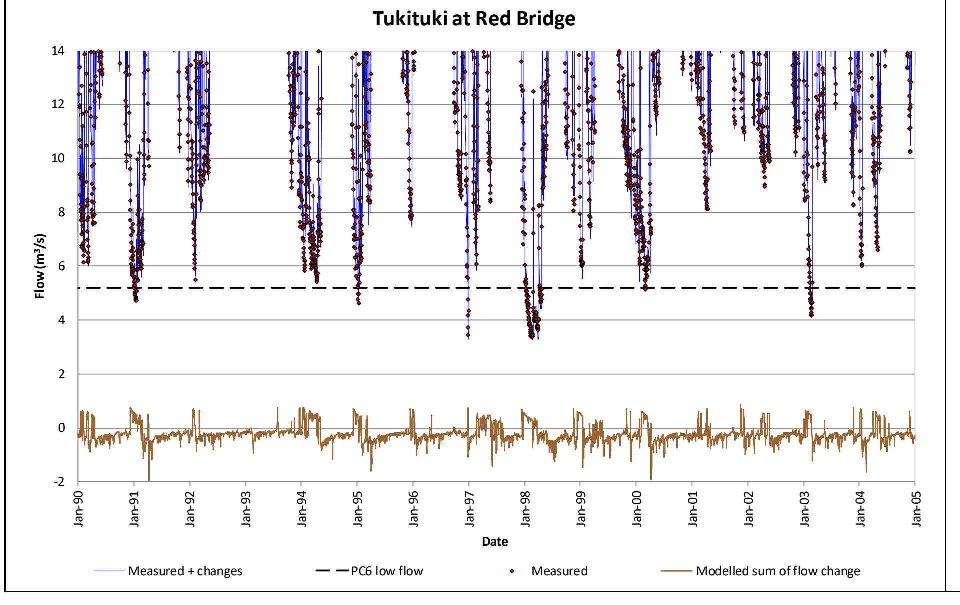
Appendix G: Estimated effects on river flows at Red Bridge



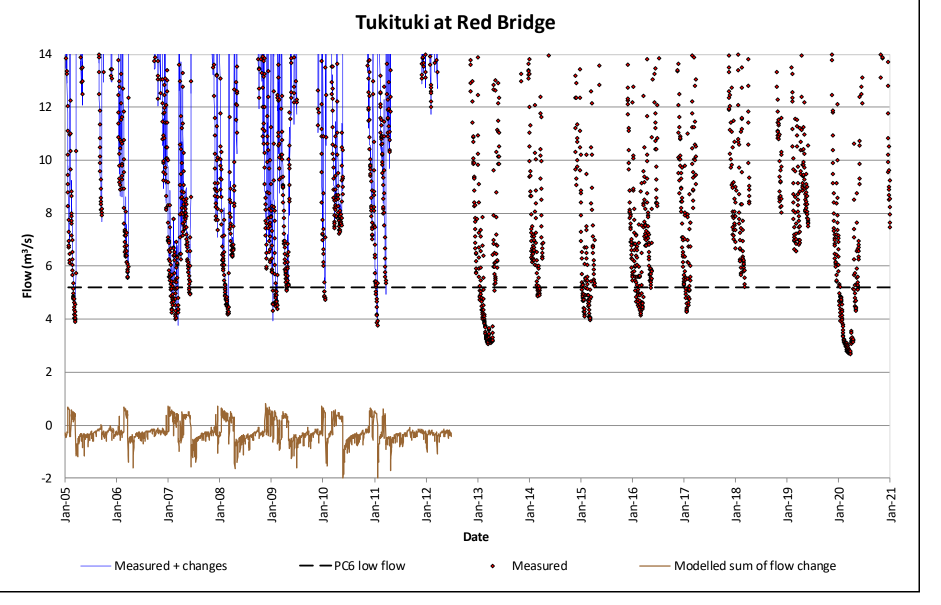
Tukituki at Red Bridge
Flow (m³/s)
Date
Measured + changes
PC6 low flow
Measured
Modelled sum of flow change



Tukituki at Red Bridge
Flow (m³/s)
Date
Measured + changes
PC6 low flow
Measured
Modelled sum of flow change

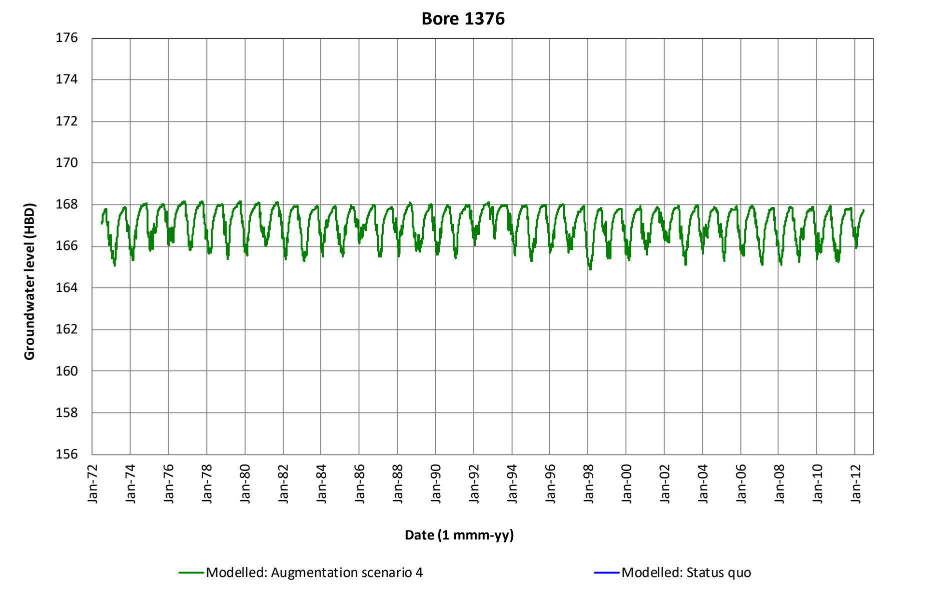


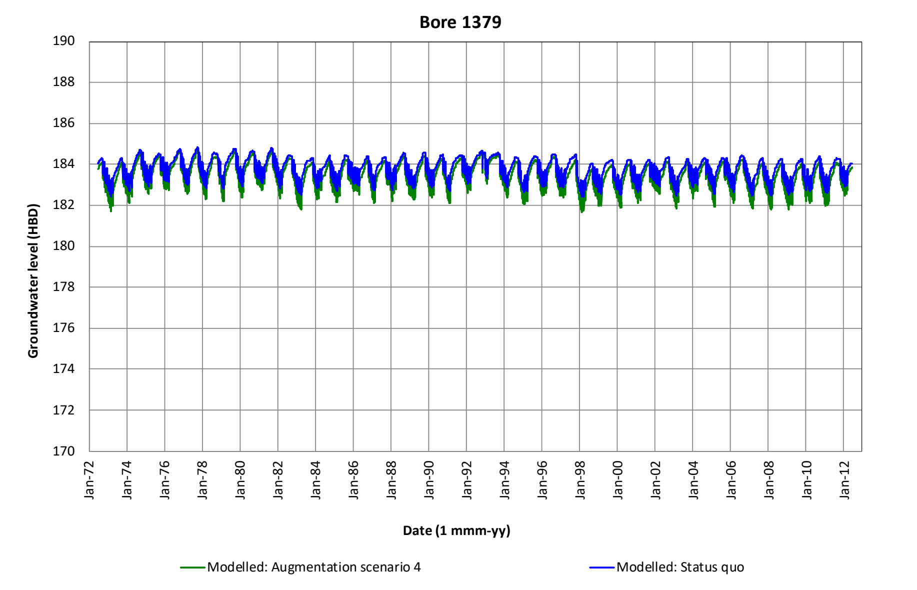
Tukituki at Red Bridge
Flow (m³/s)
Date
Measured + changes
PC6 low flow
Measured
Modelled sum of flow change

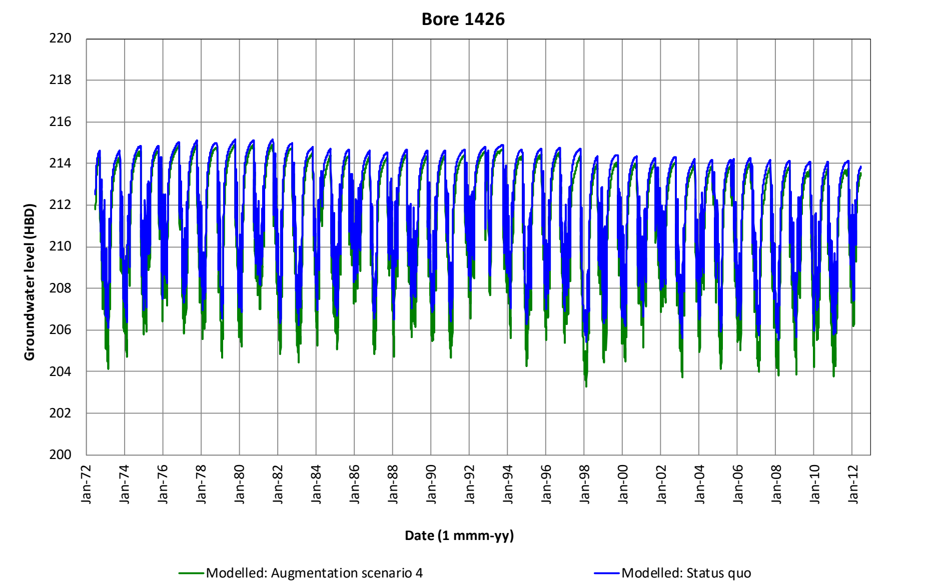


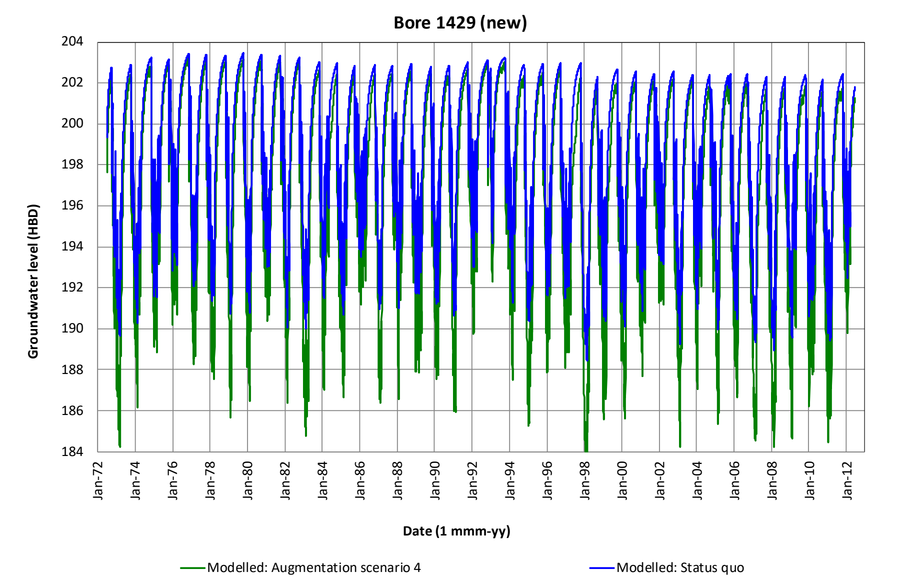
Tukituki at Red Bridge
Flow (m³/s)
Date
Measured + changes
PC6 low flow
Measured
Modelled sum of flow change

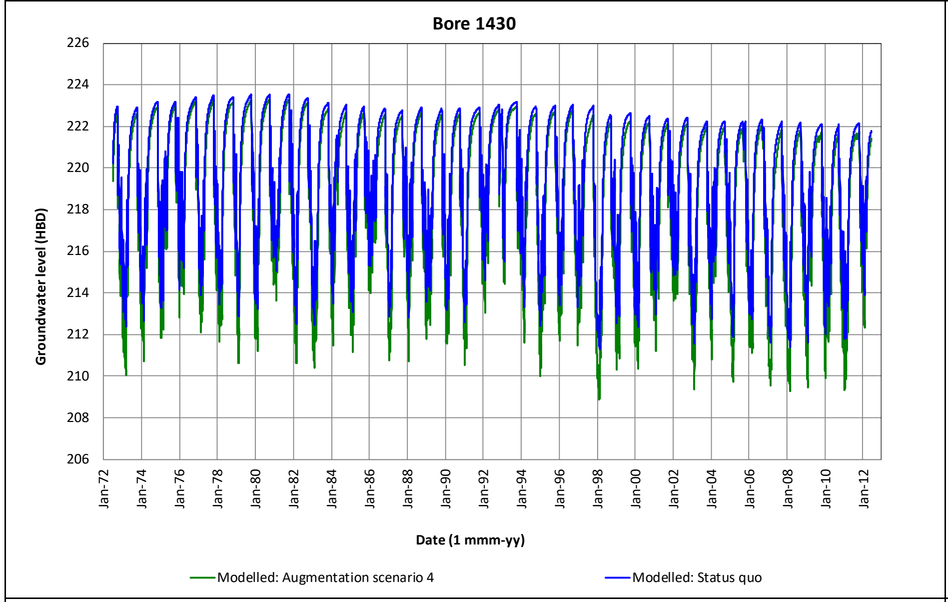
Appendix H: Groundwater level hydrographs for different scenarios

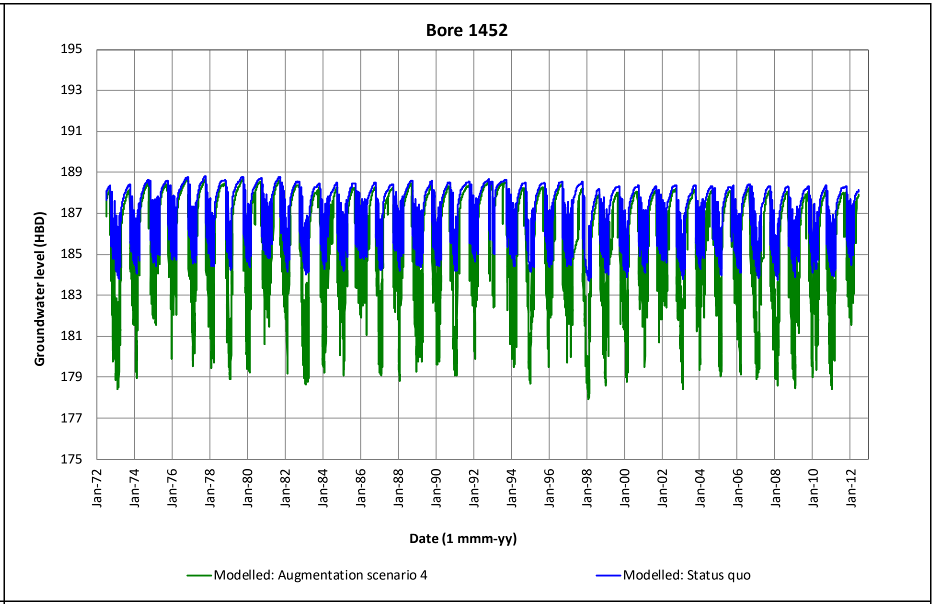

Bore 1376
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

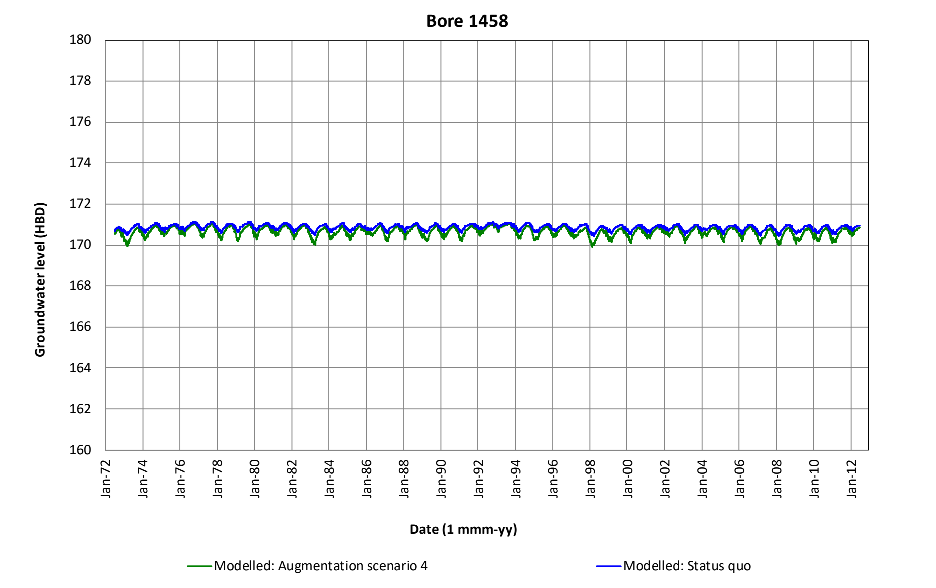

Bore 1379
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

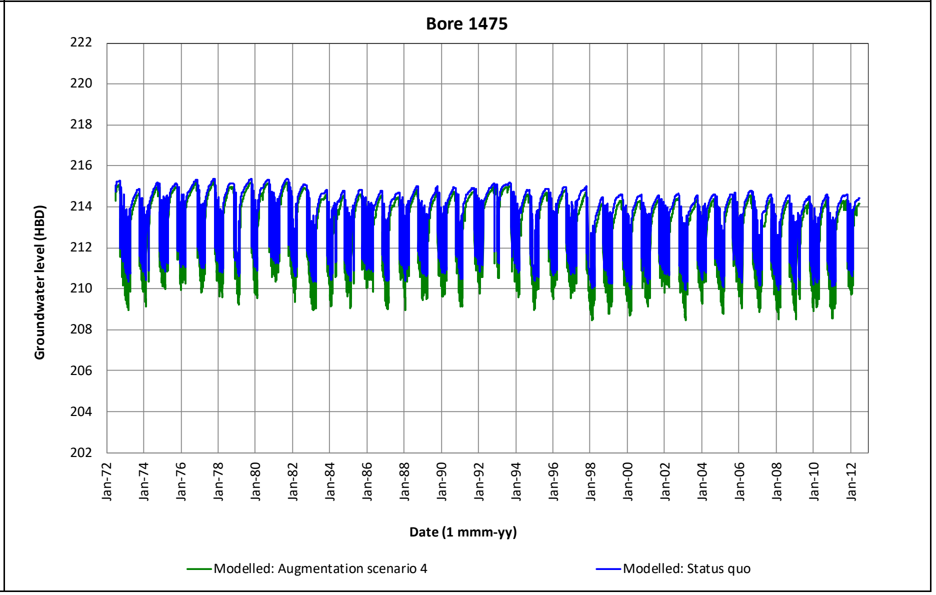

Bore 1426
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

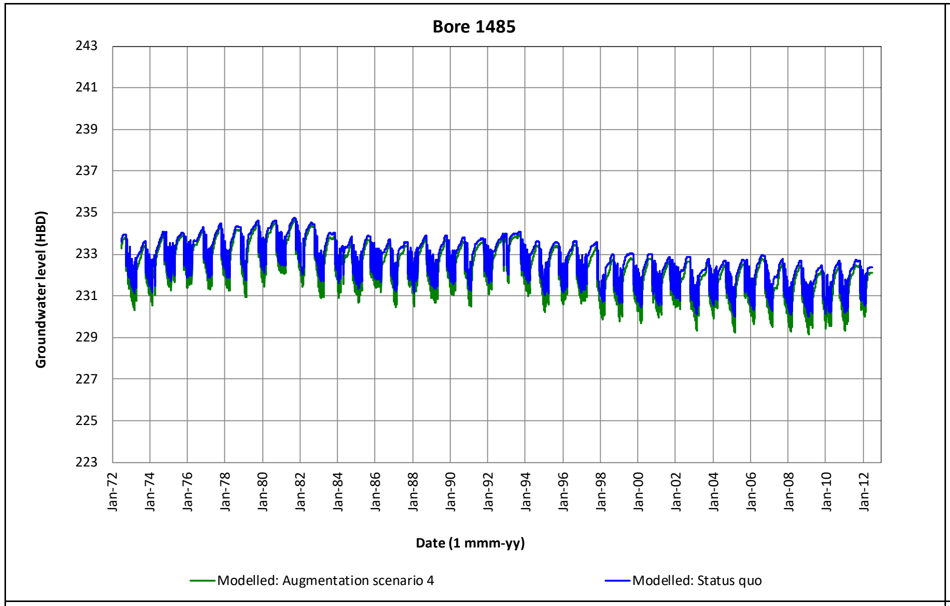

Bore 1429 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

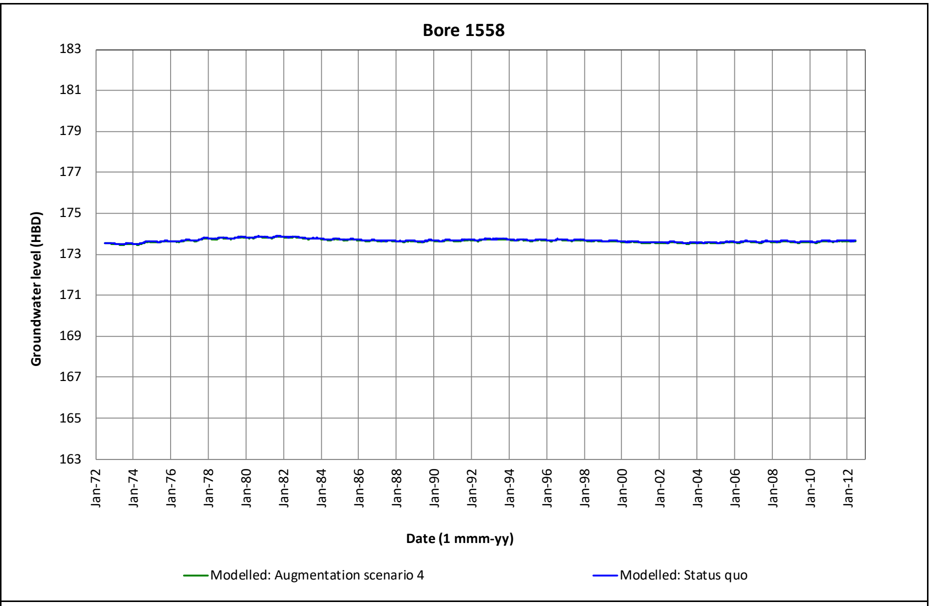

Bore 1430
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

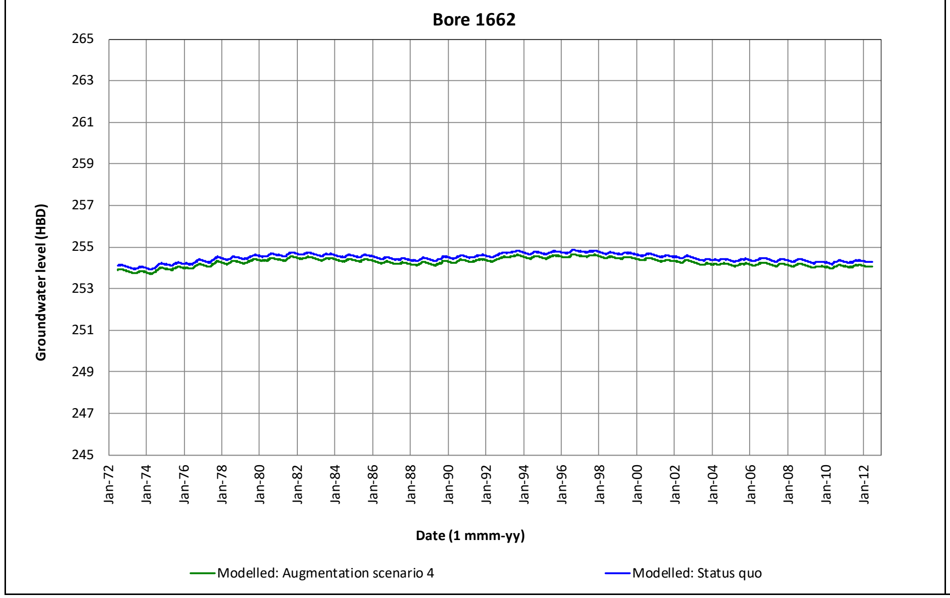

Bore 1452
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

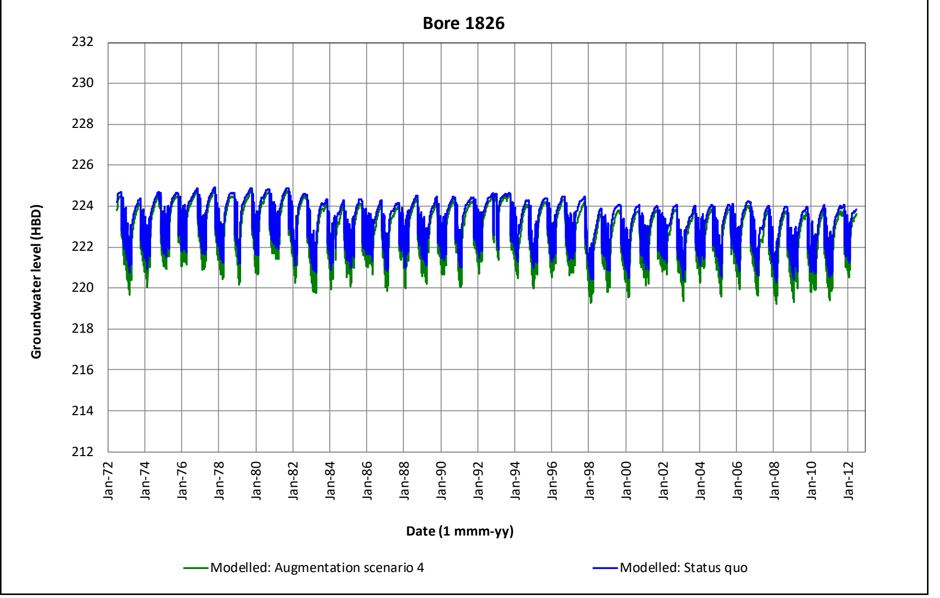

Bore 1458
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

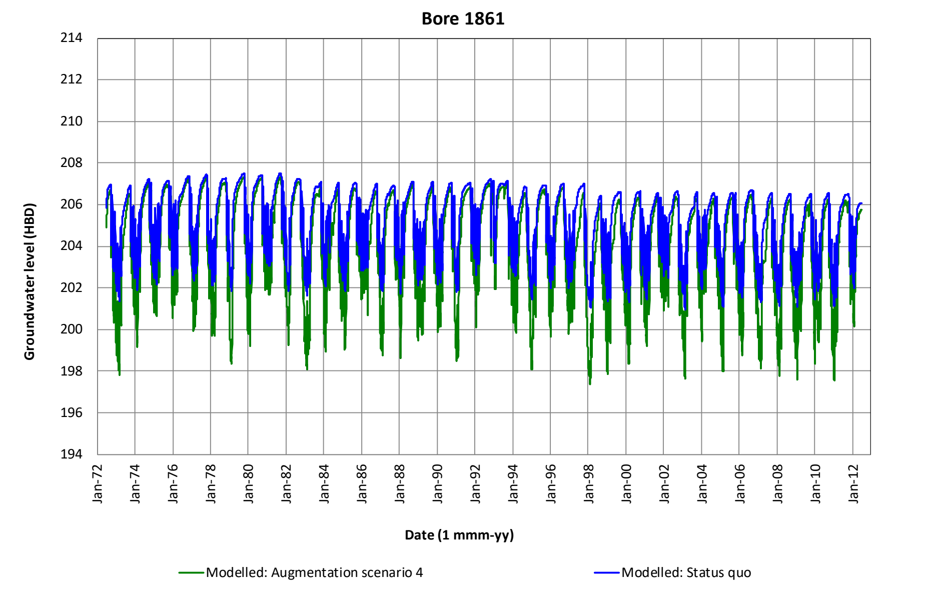

Bore 1475
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

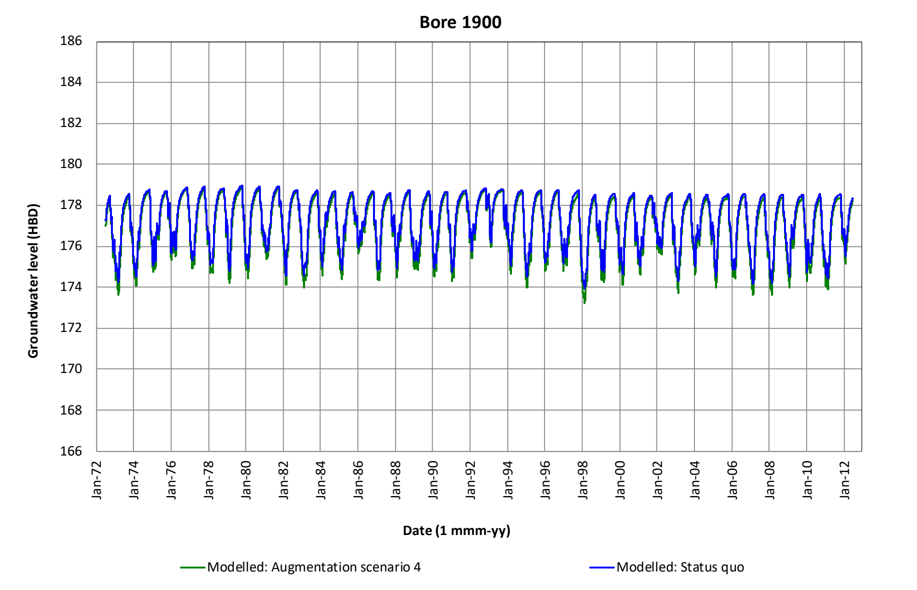

Bore 1485
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

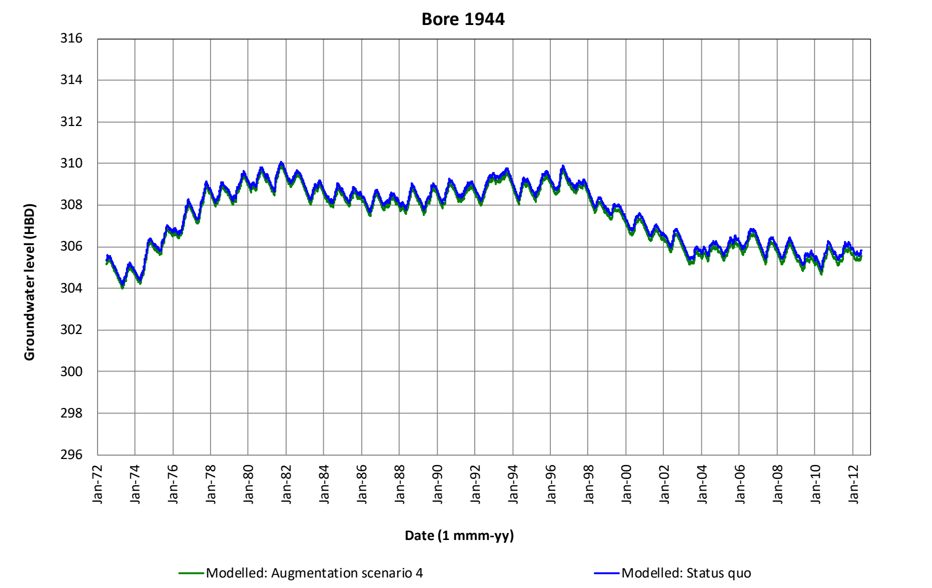

Bore 1558
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

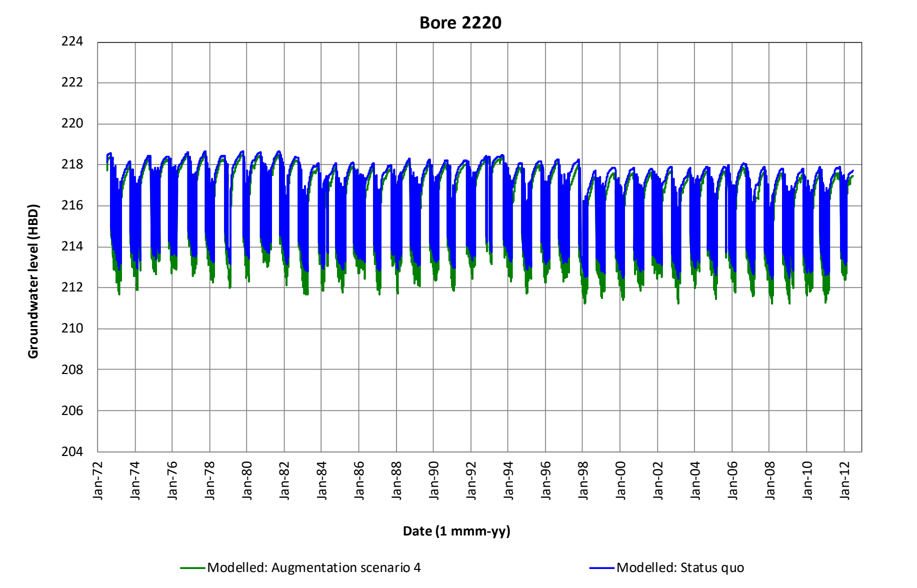

Bore 1662
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

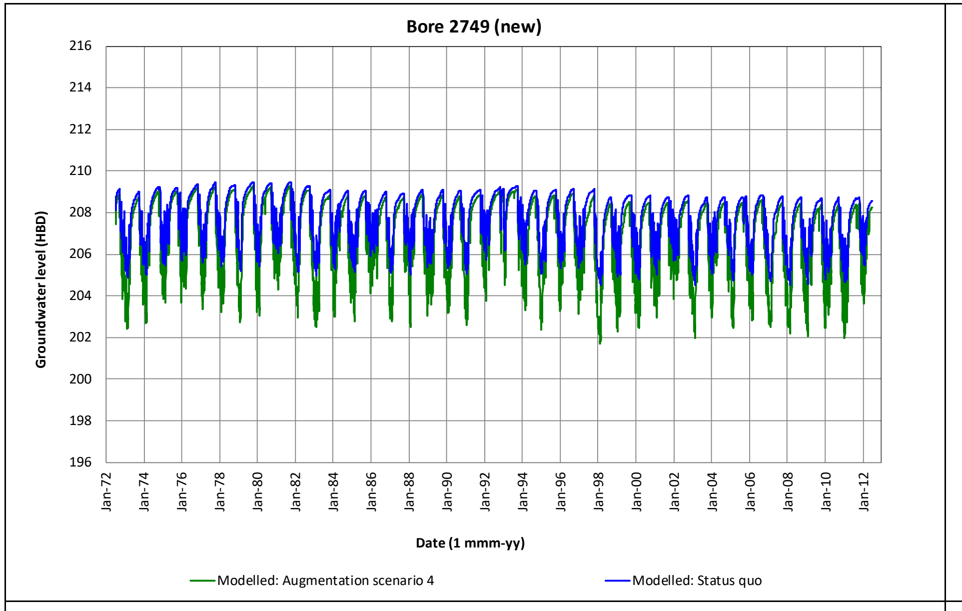

Bore 1826
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

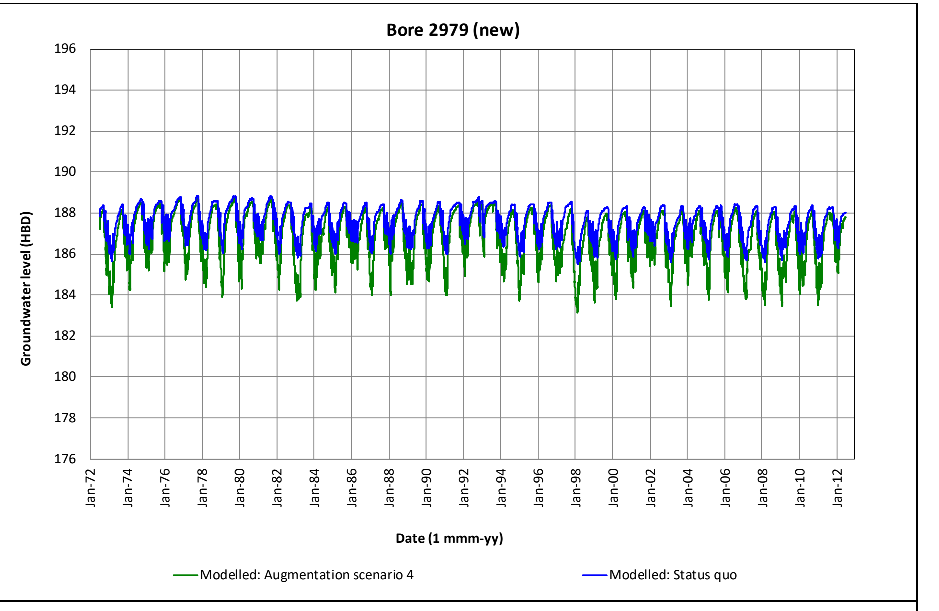

Bore 1861
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

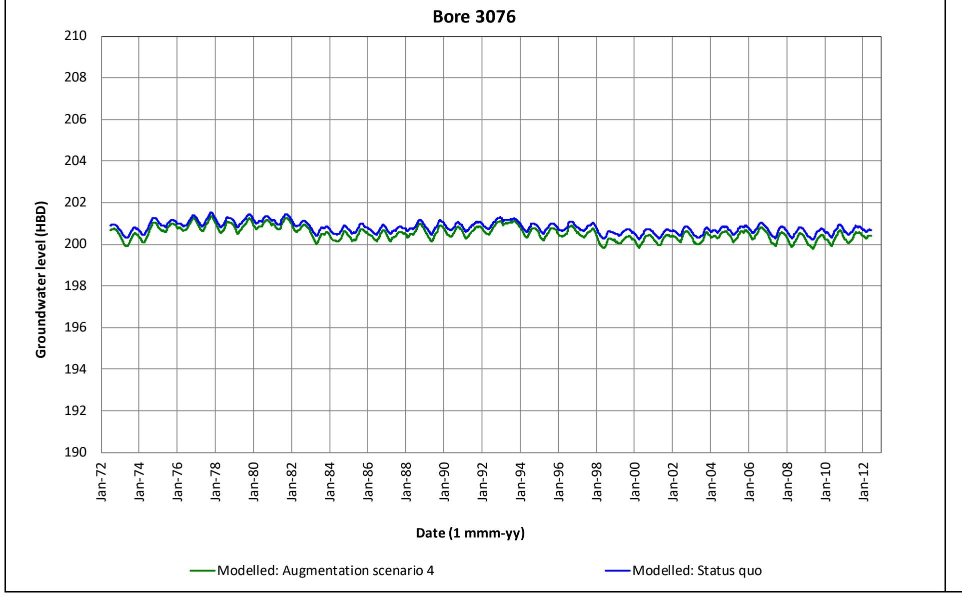

Bore 1900
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

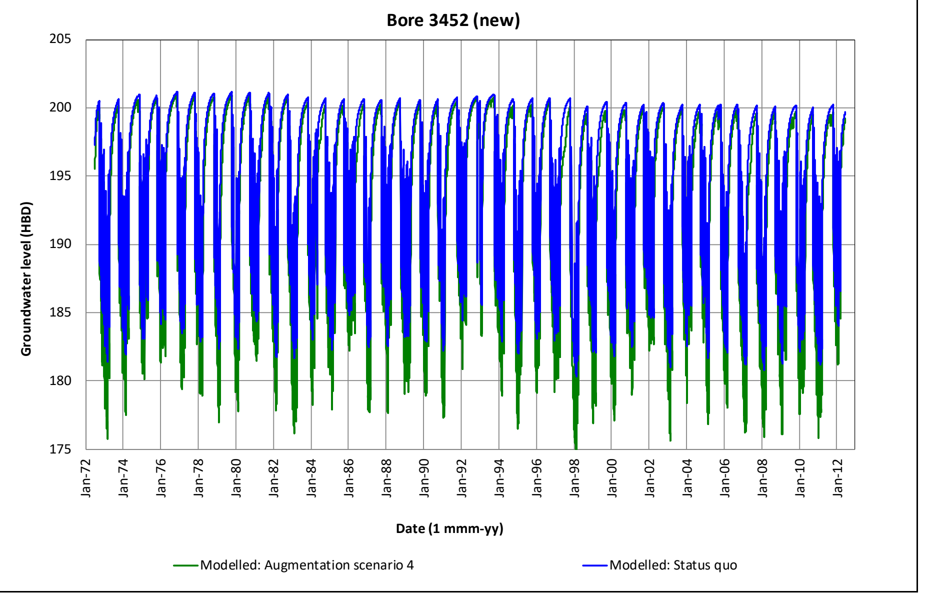

Bore 1944
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

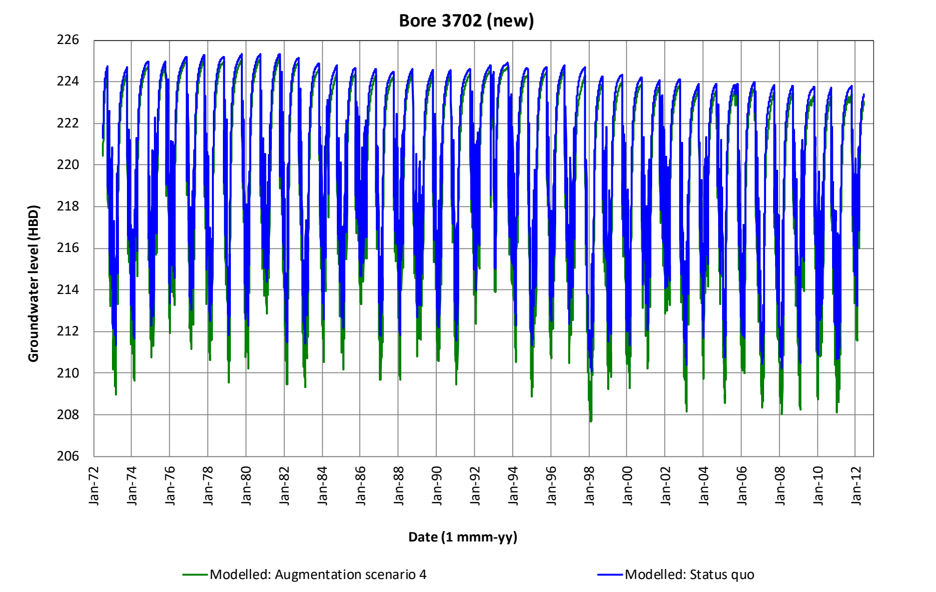

Bore 2220
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo


Bore 2749 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

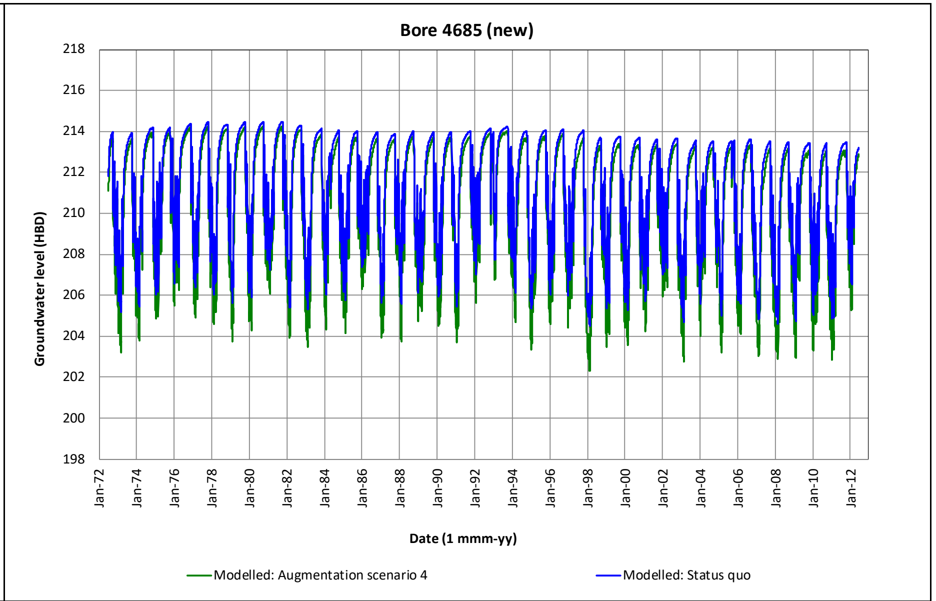

Bore 2979 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo


Bore 3076
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

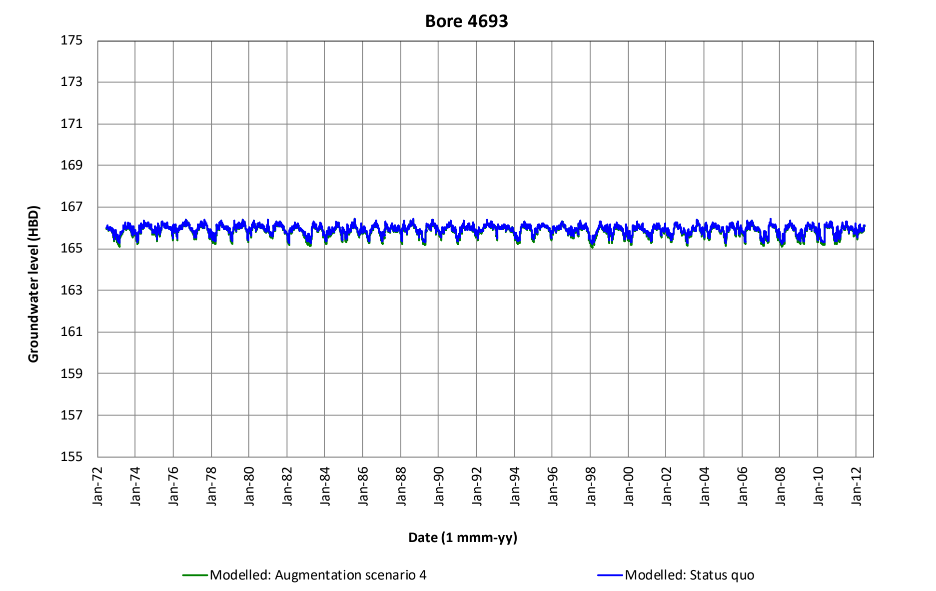

Bore 3452 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo



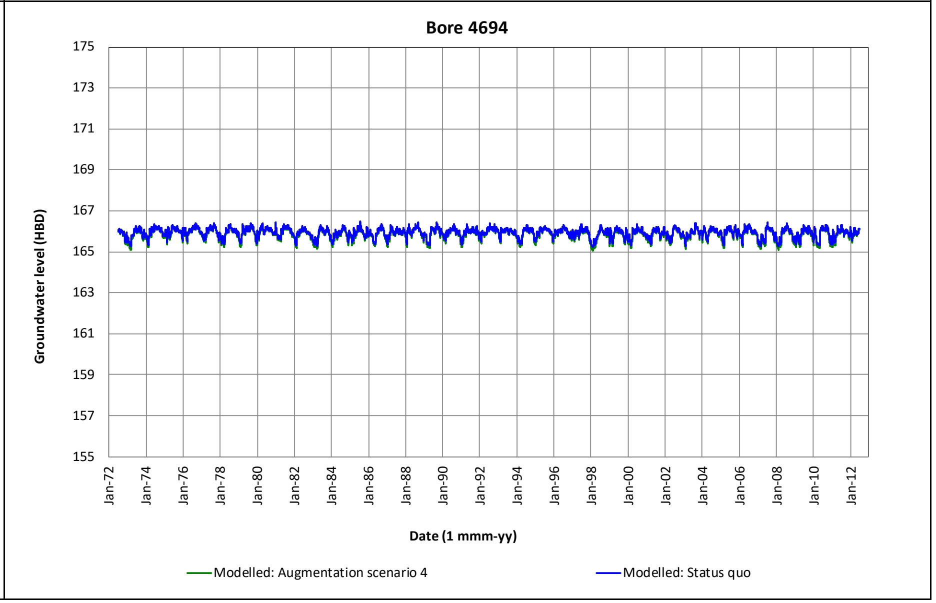
Bore 3702 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo



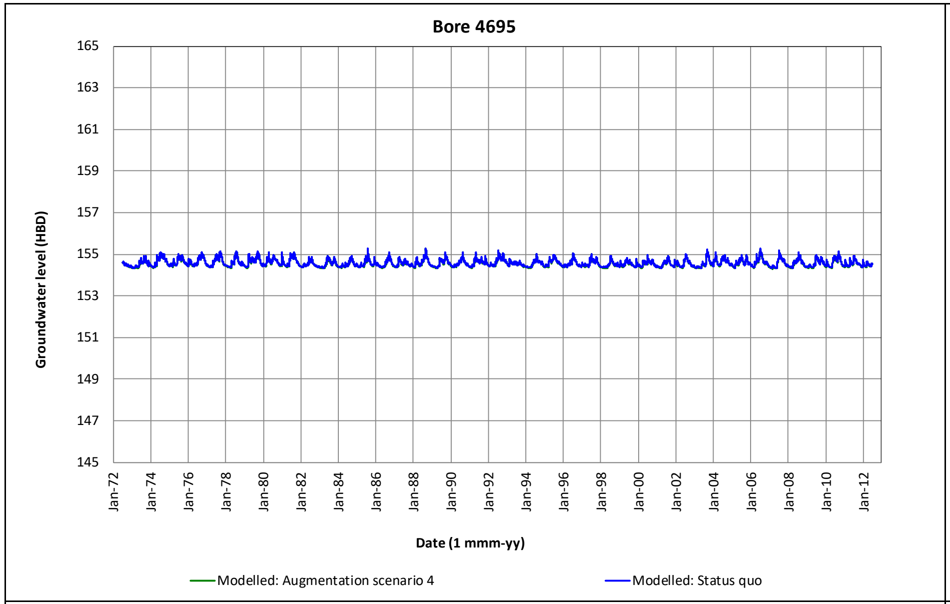
Bore 4685 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

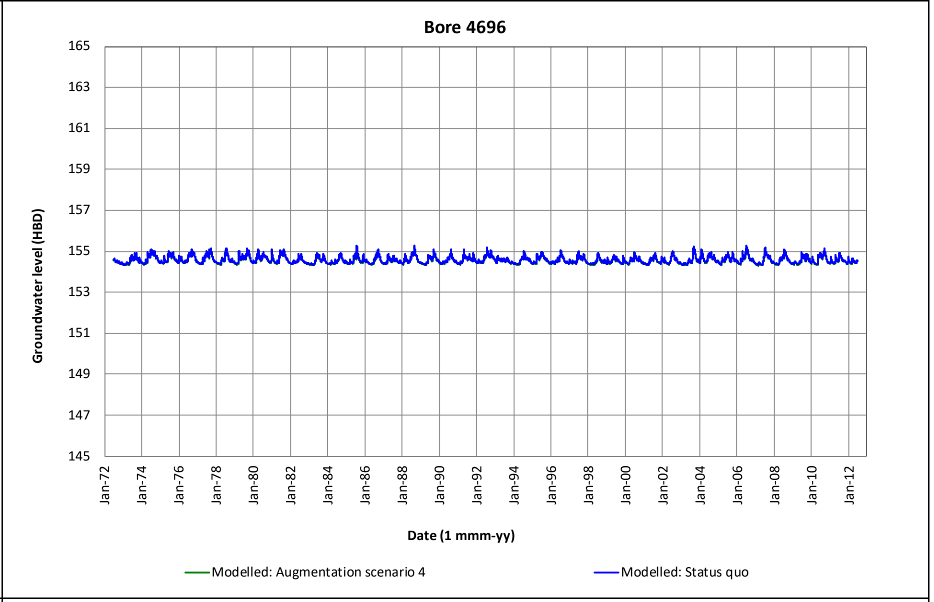


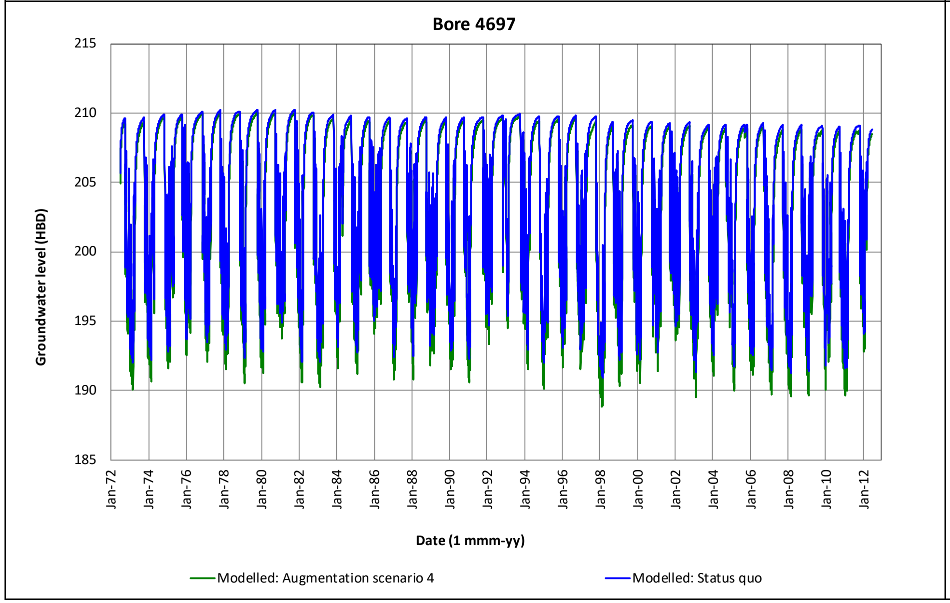
Bore 4693
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

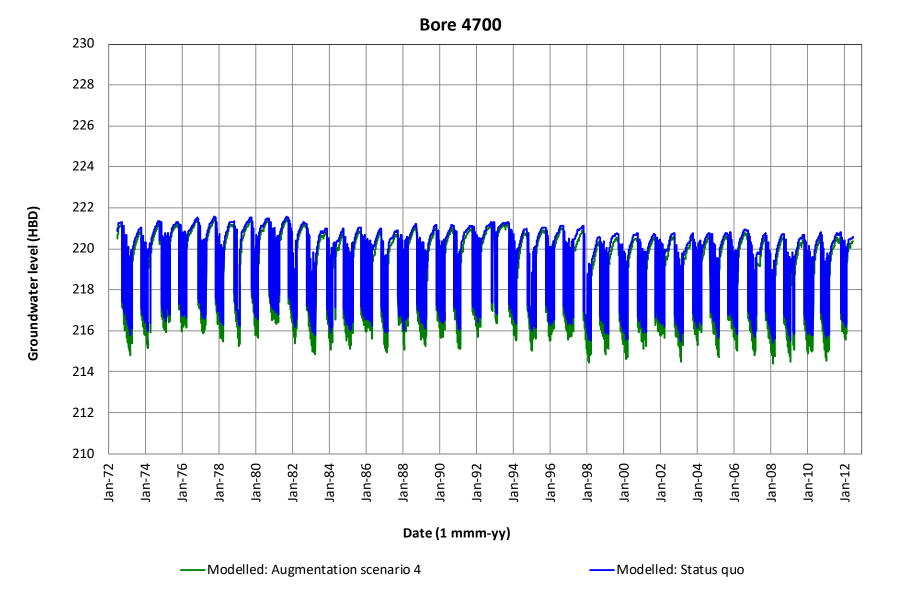


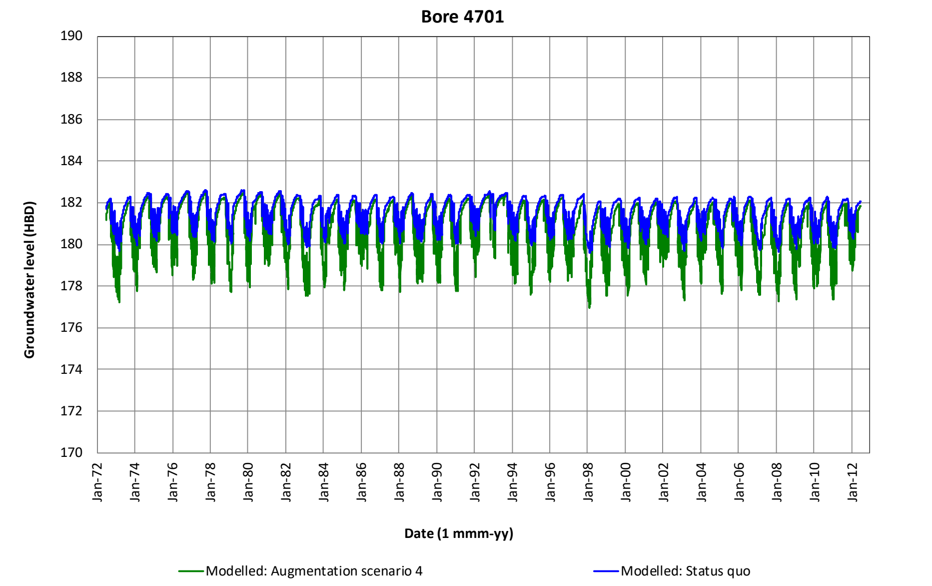
Bore 4694
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

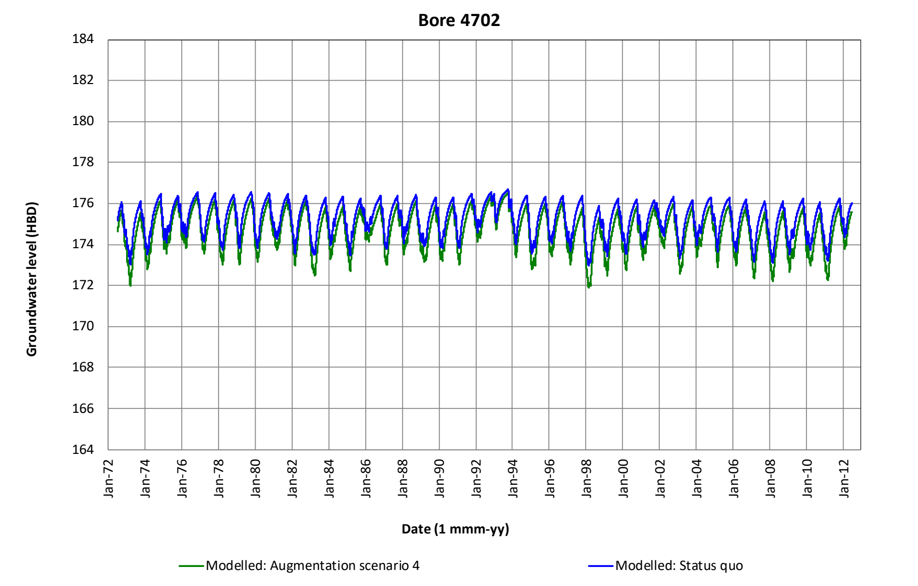

Bore 4695
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

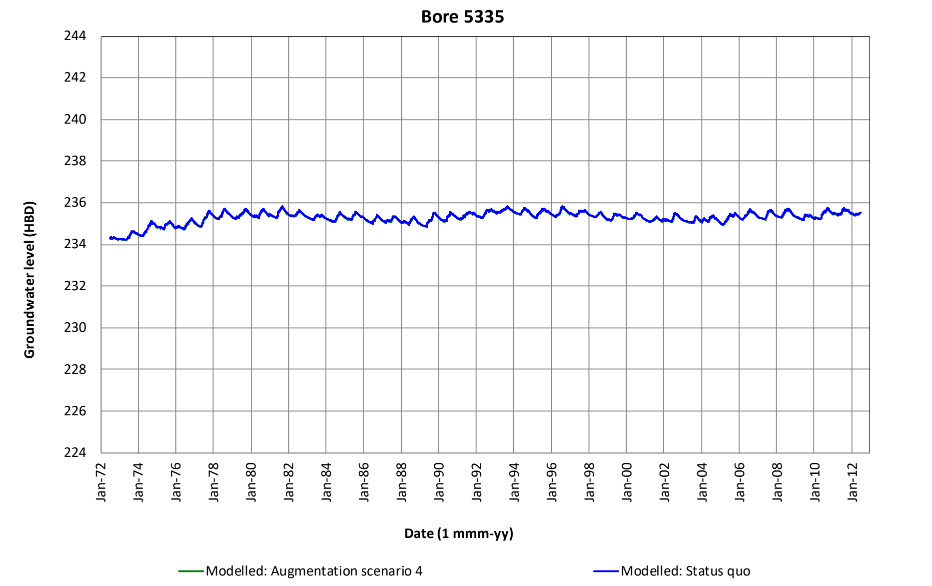

Bore 4696
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

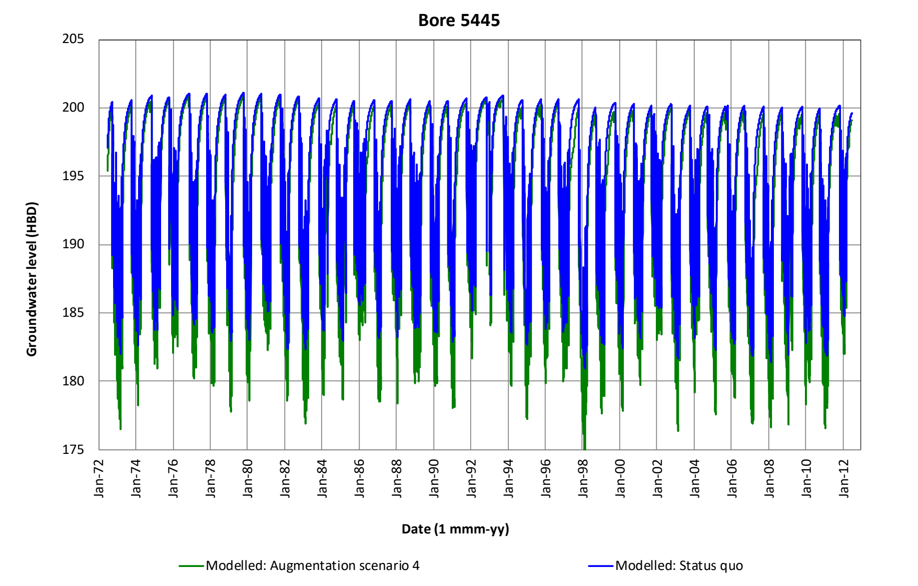

Bore 4697
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

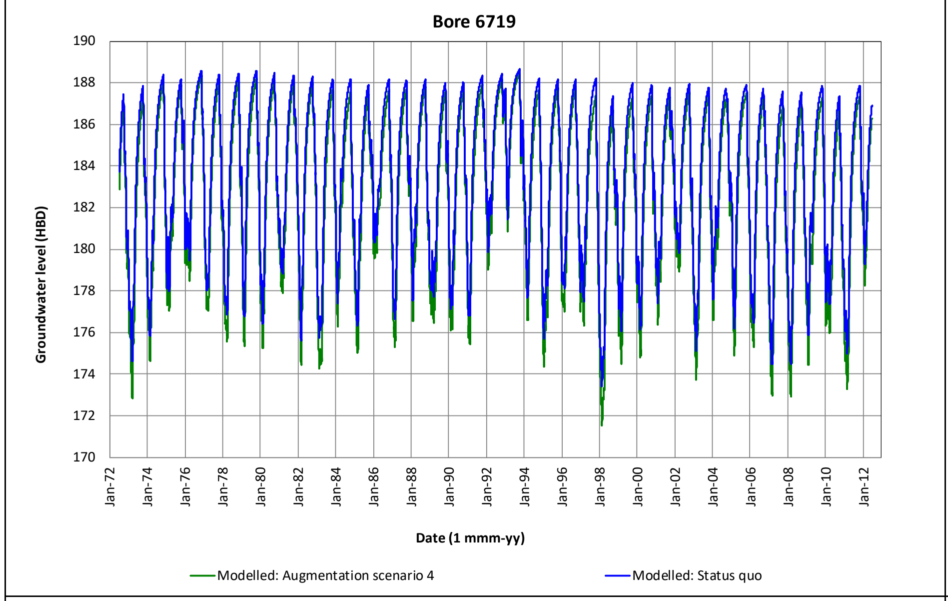

Bore 4700
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

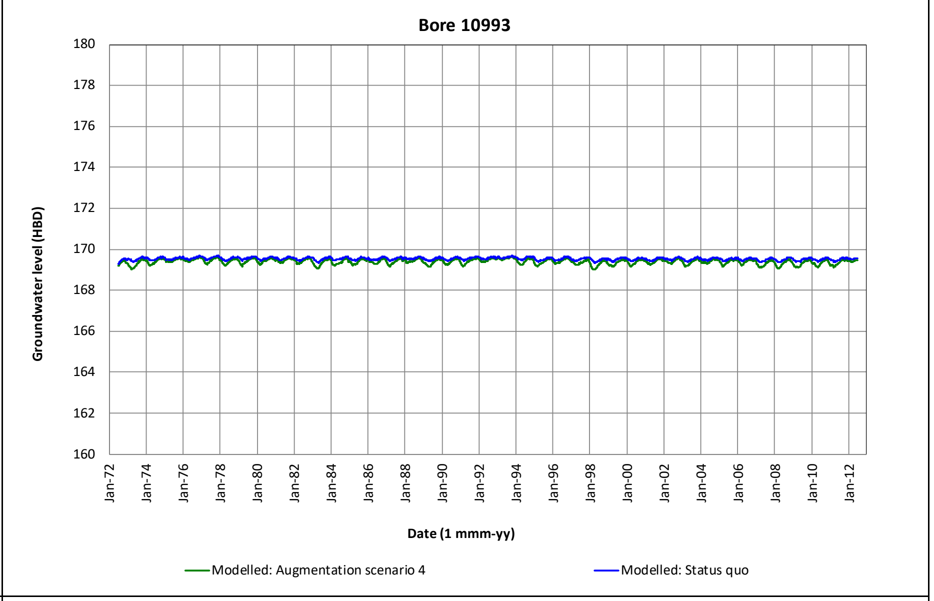

Bore 4701
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

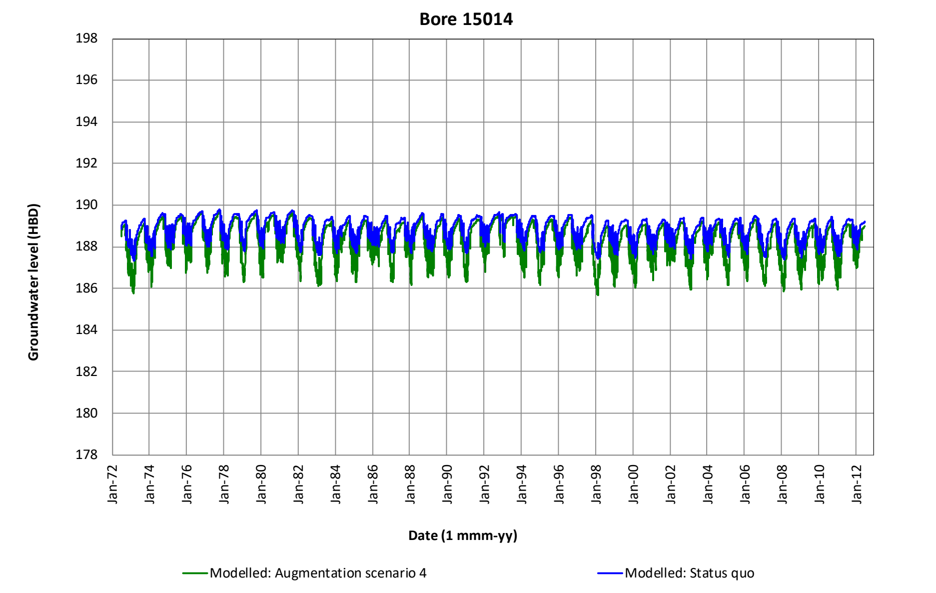

Bore 4702
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

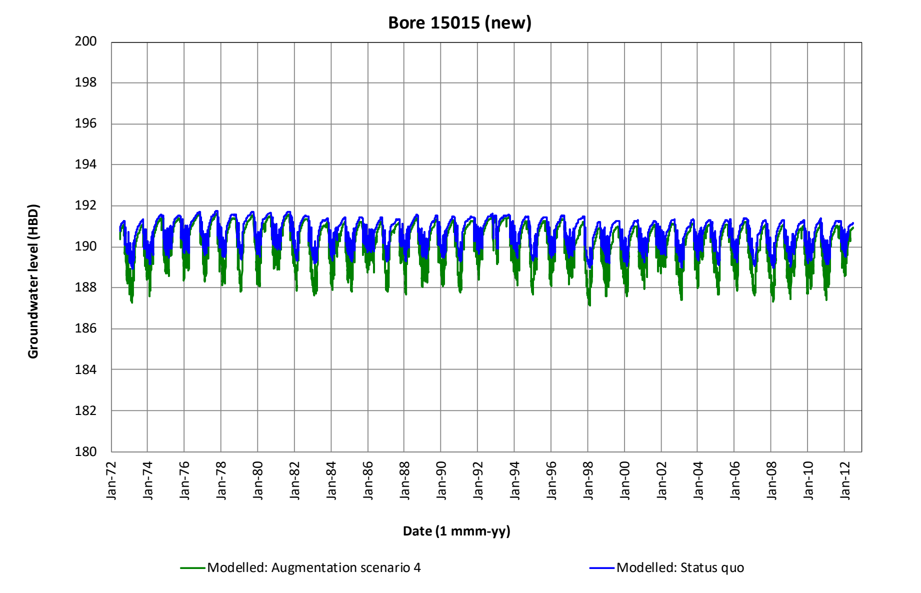

Bore 5335
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

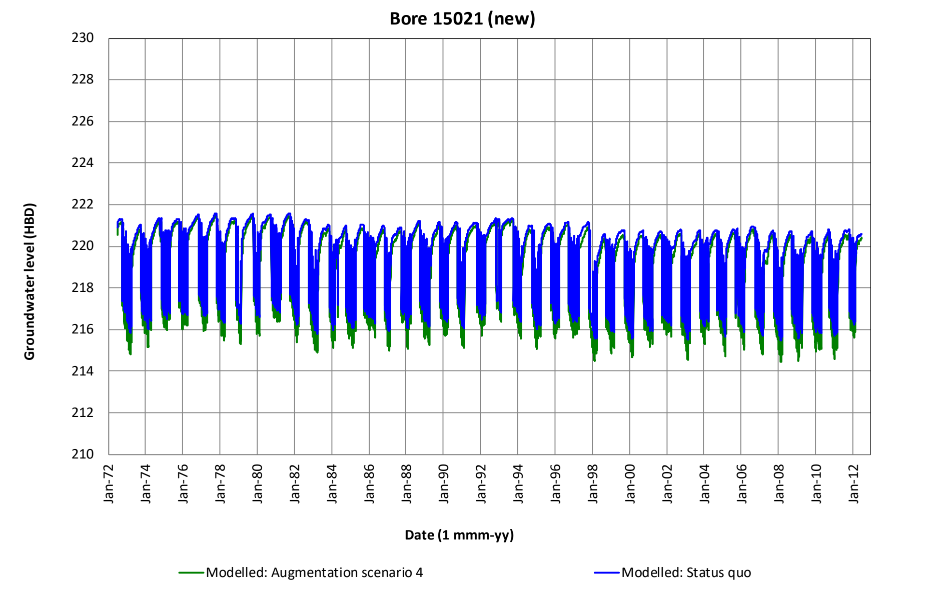

Bore 5445
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

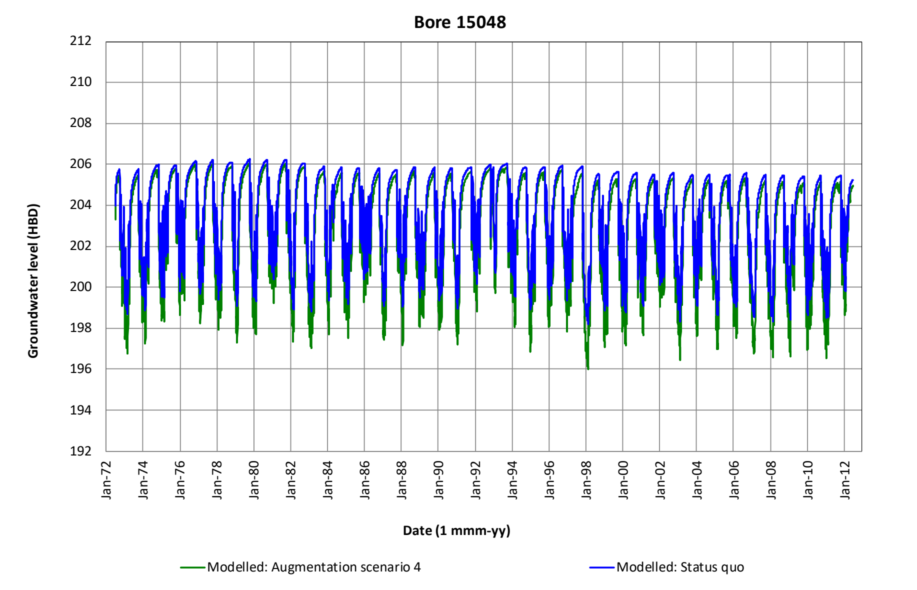

Bore 6719
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

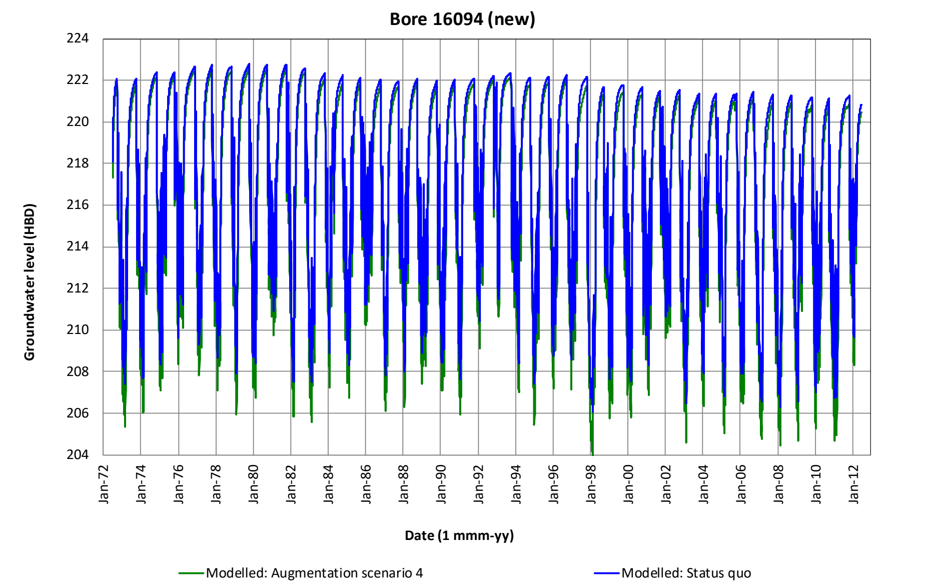

Bore 10993
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

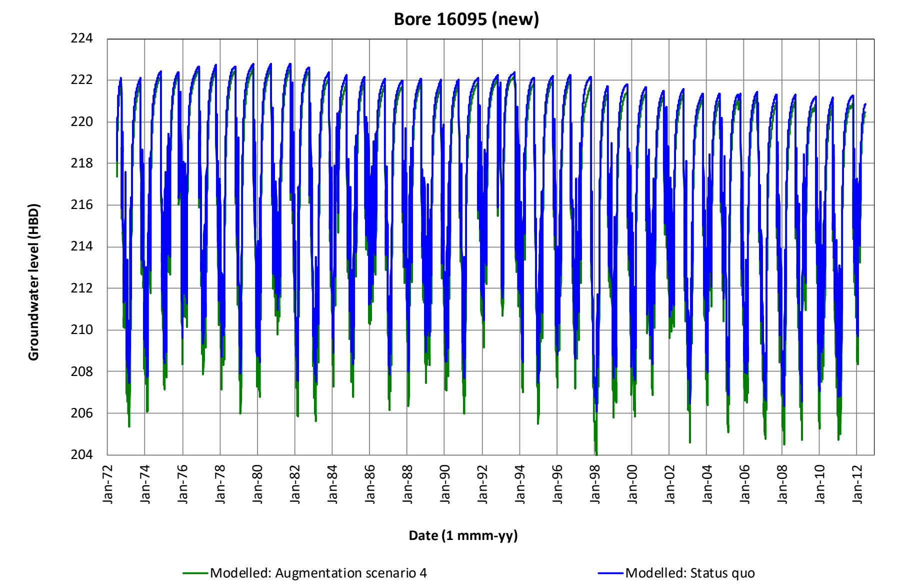

Bore 15014
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

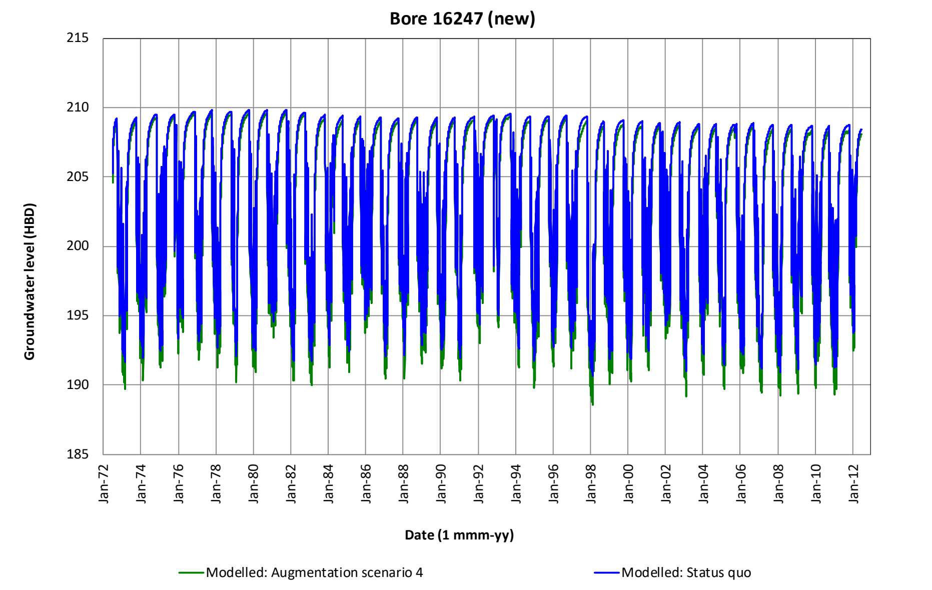

Bore 15015 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

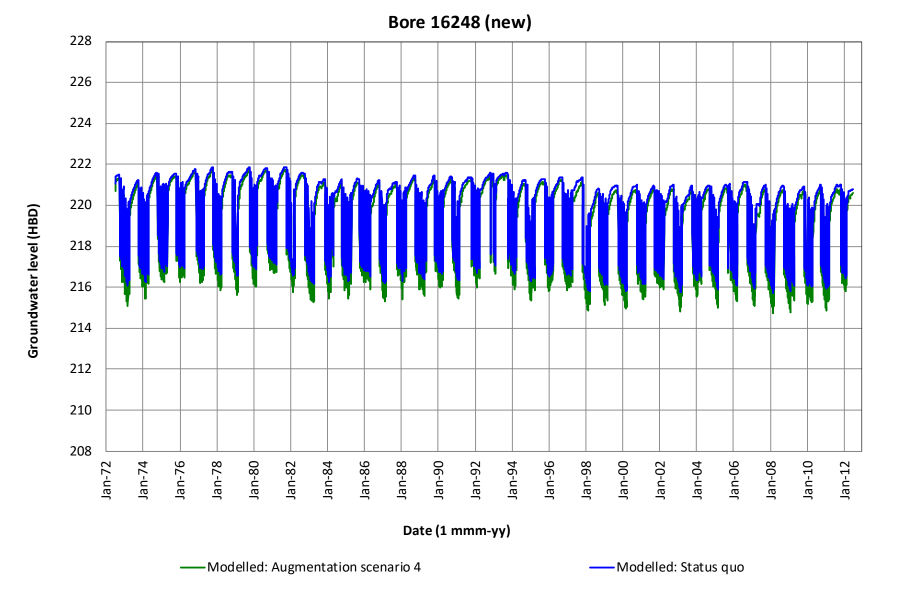

Bore 15021 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

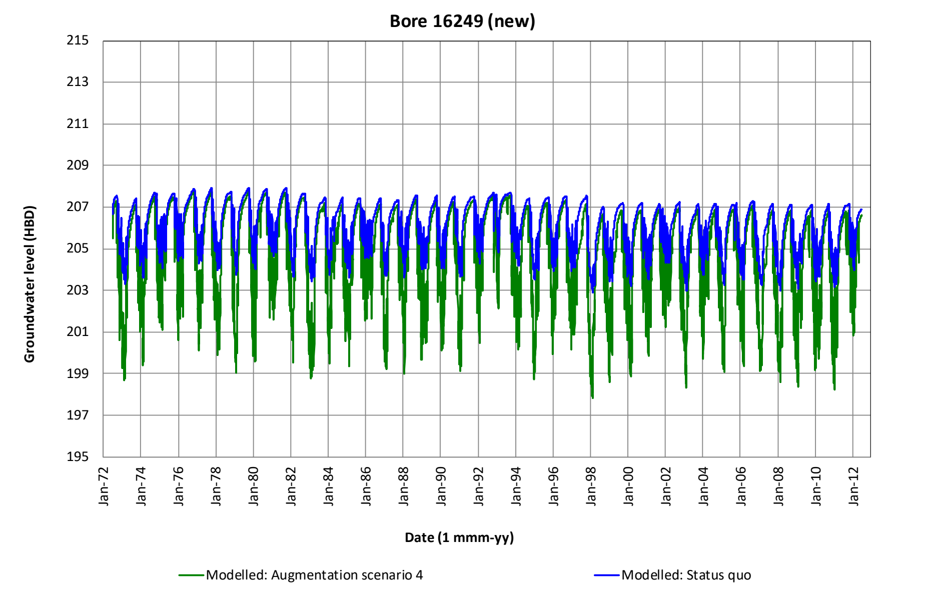

Bore 15048
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

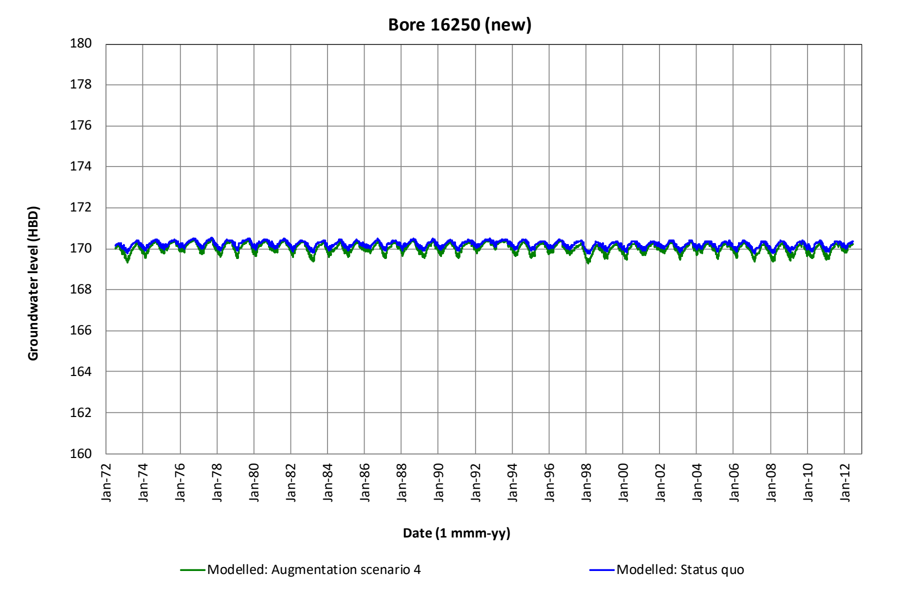

Bore 16094 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

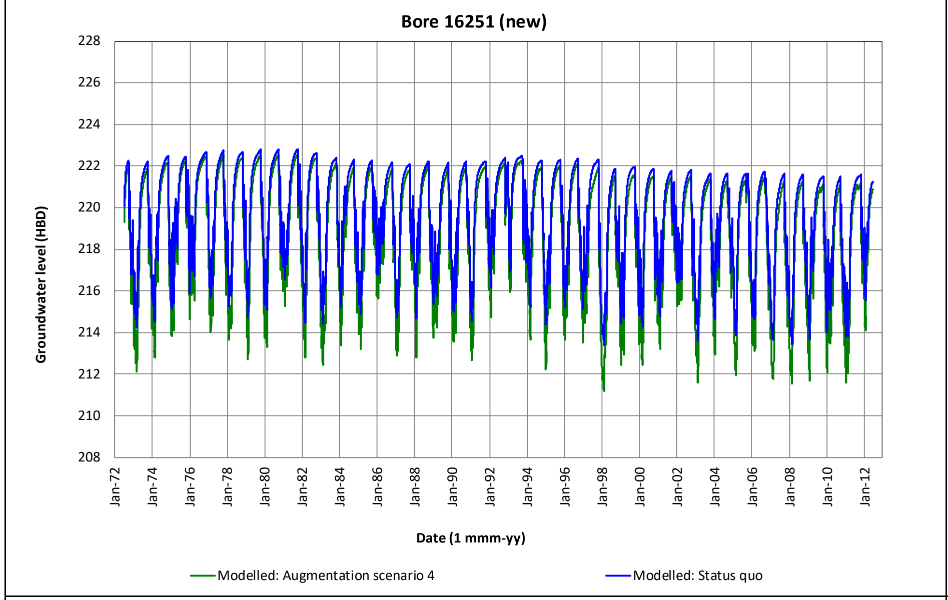

Bore 16095 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

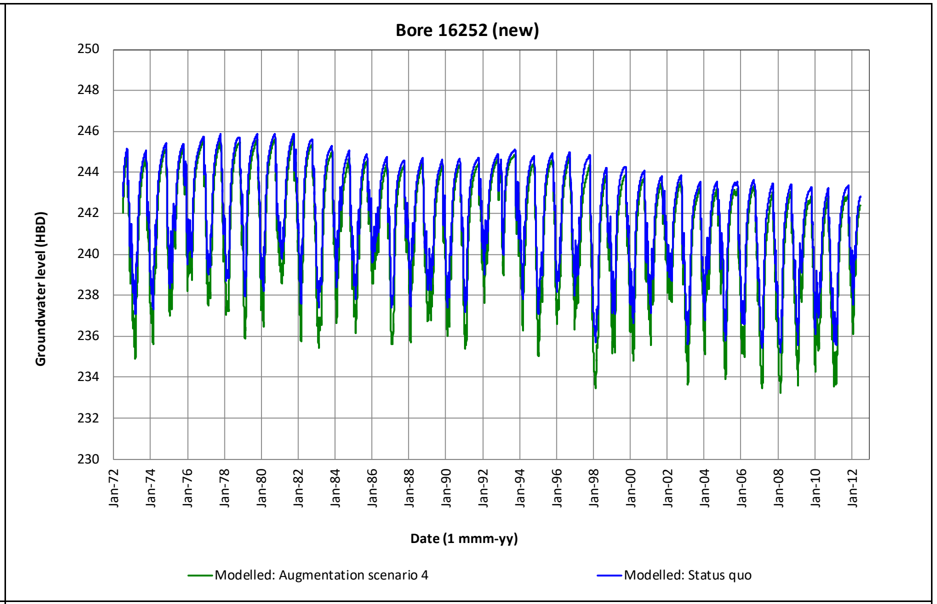

Bore 16247 (new)
Groundwater level (HBD)
215
210
205
200
195
190
185
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

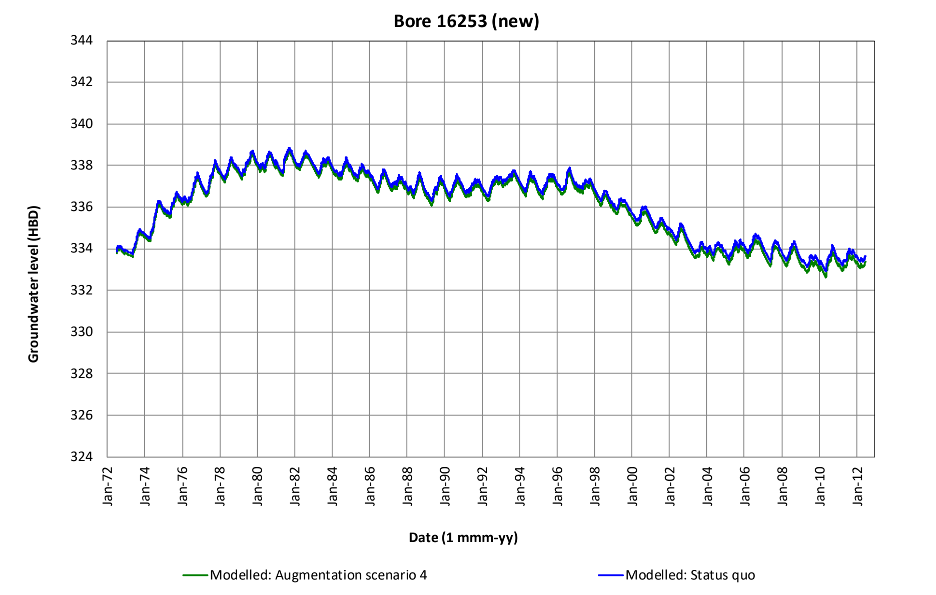

Bore 16248 (new)
Groundwater level (HBD)
228
226
224
222
220
218
216
214
212
210
208
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

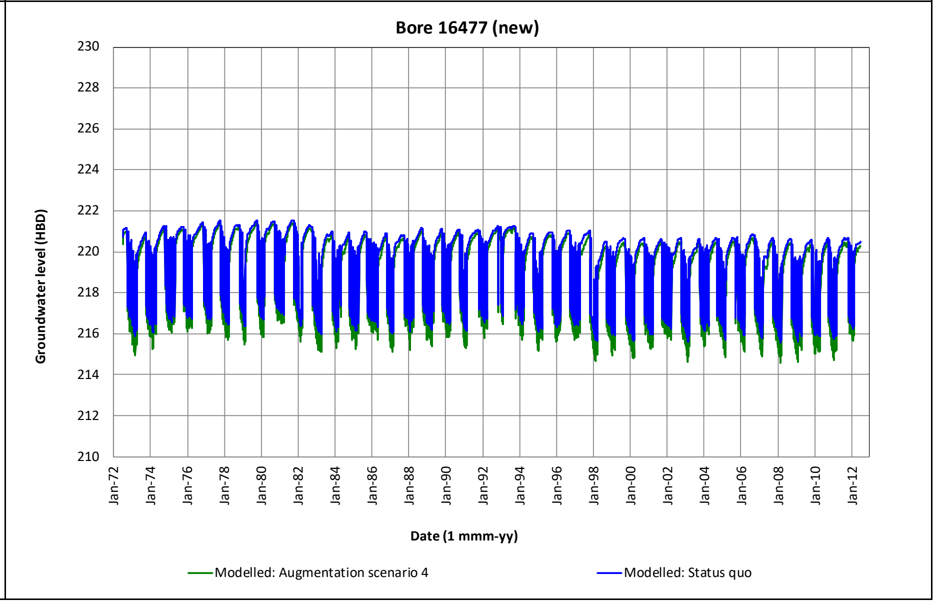

Bore 16249 (new)
Groundwater level (HBD)
215
213
211
209
207
205
203
201
199
197
195
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

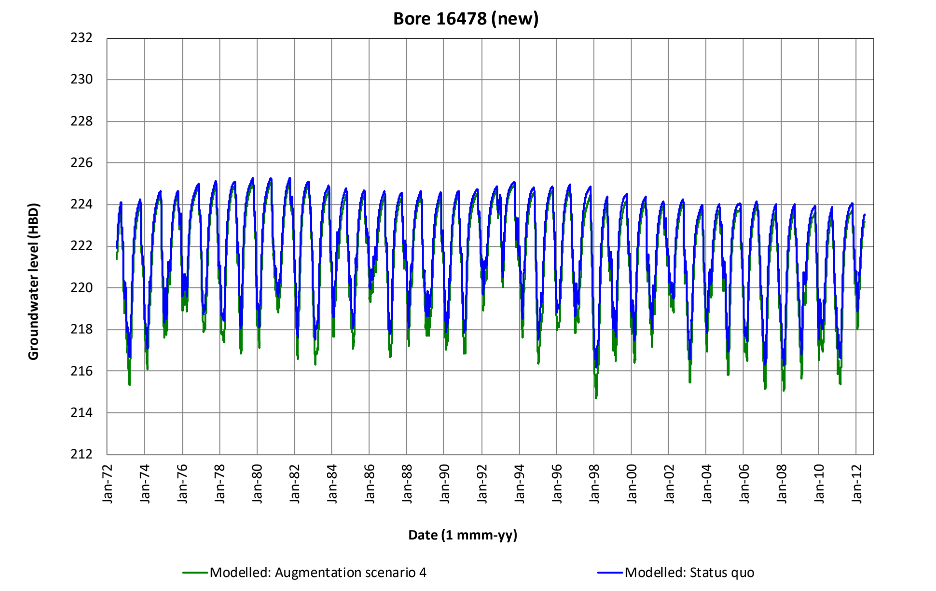

Bore 16250 (new)
Groundwater level (HBD)
180
178
176
174
172
170
168
166
164
162
160
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

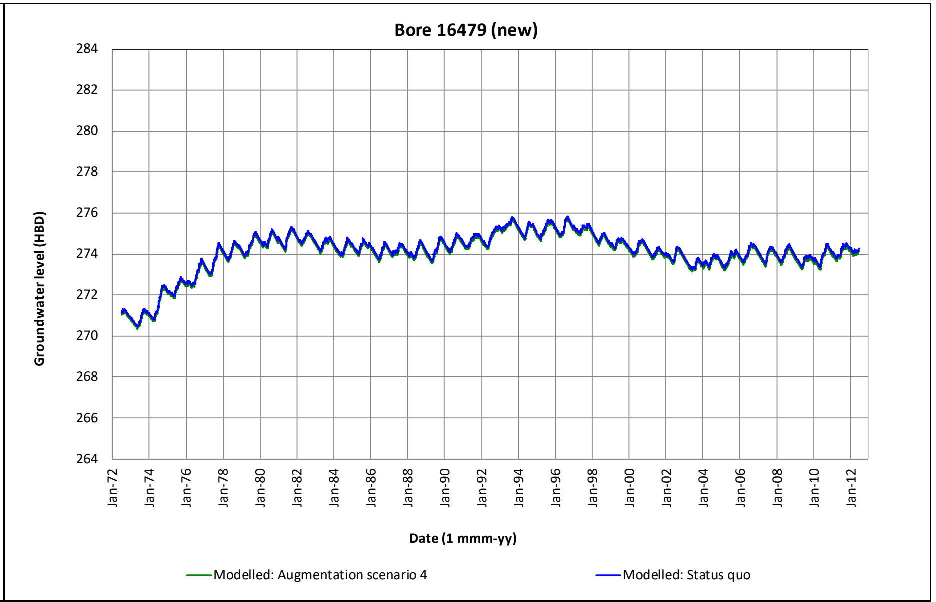

Bore 16251 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

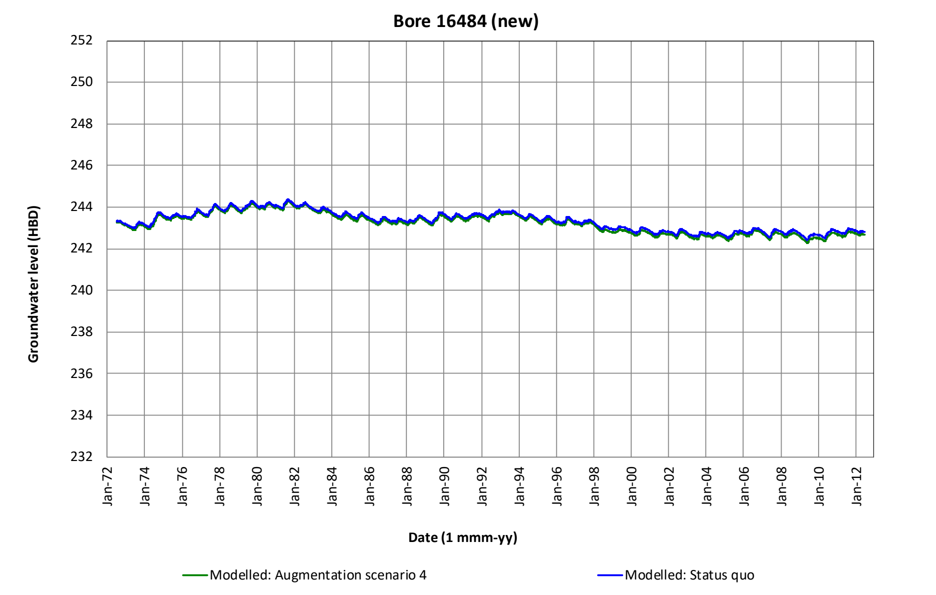

Bore 16252 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

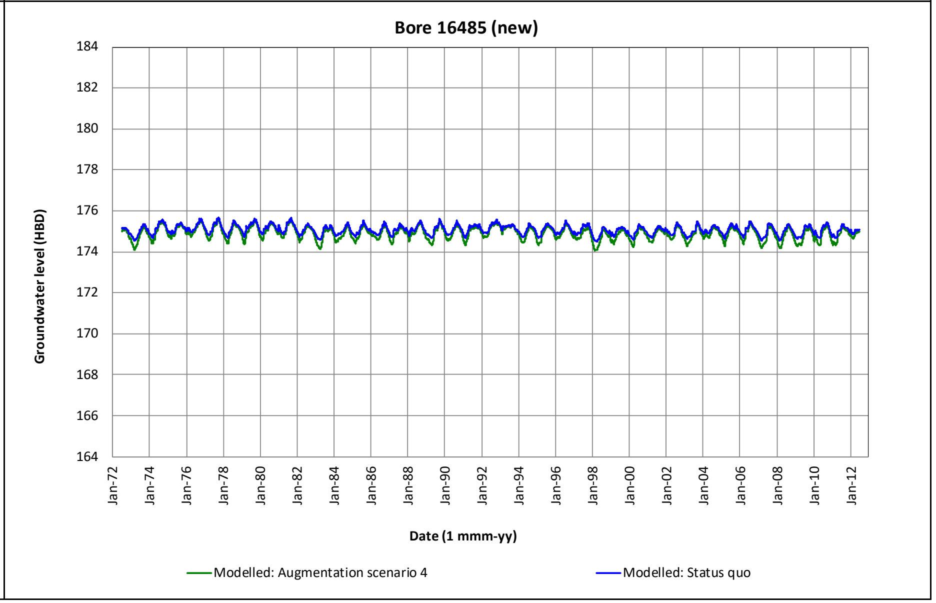

Bore 16253 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

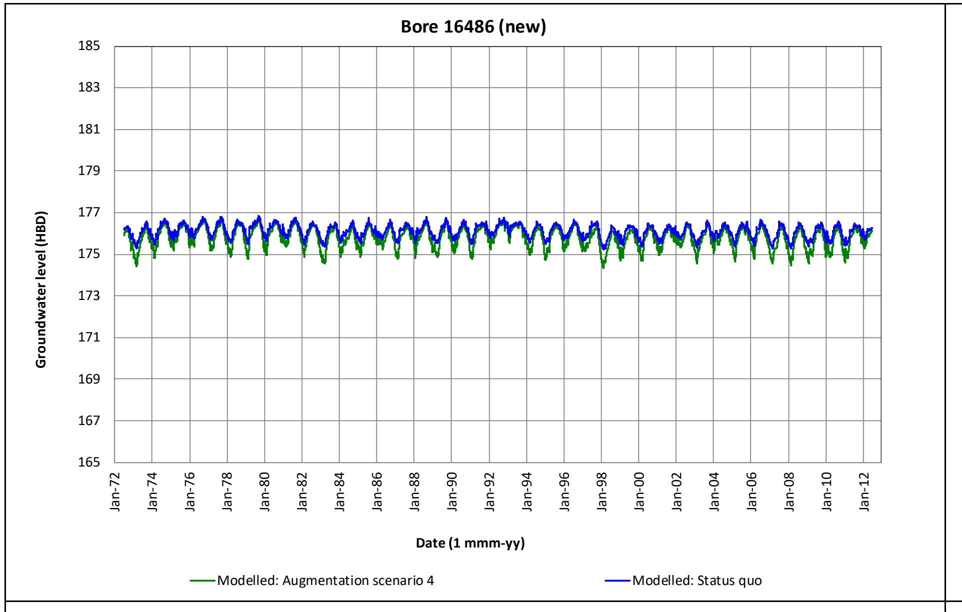

Bore 16477 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

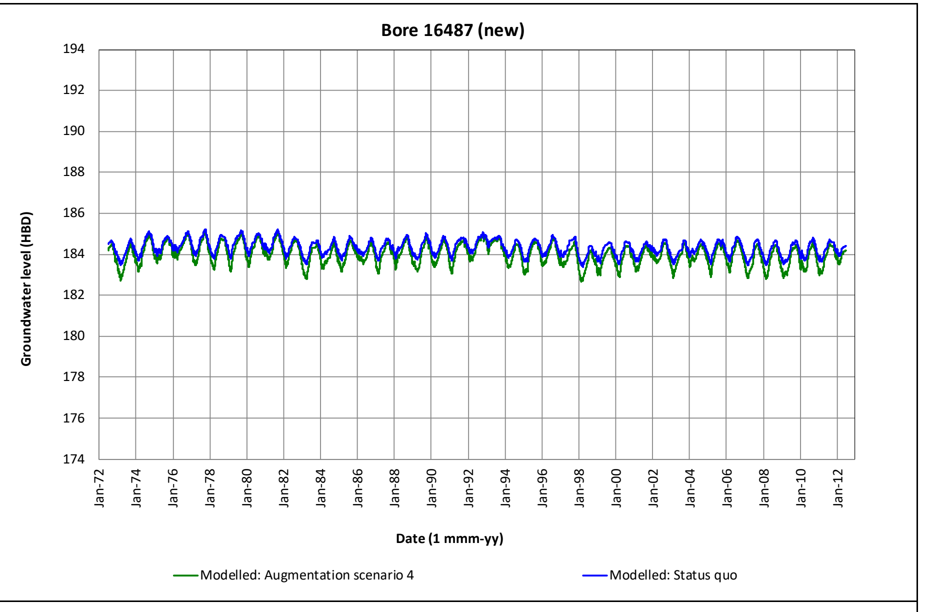

Bore 16478 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

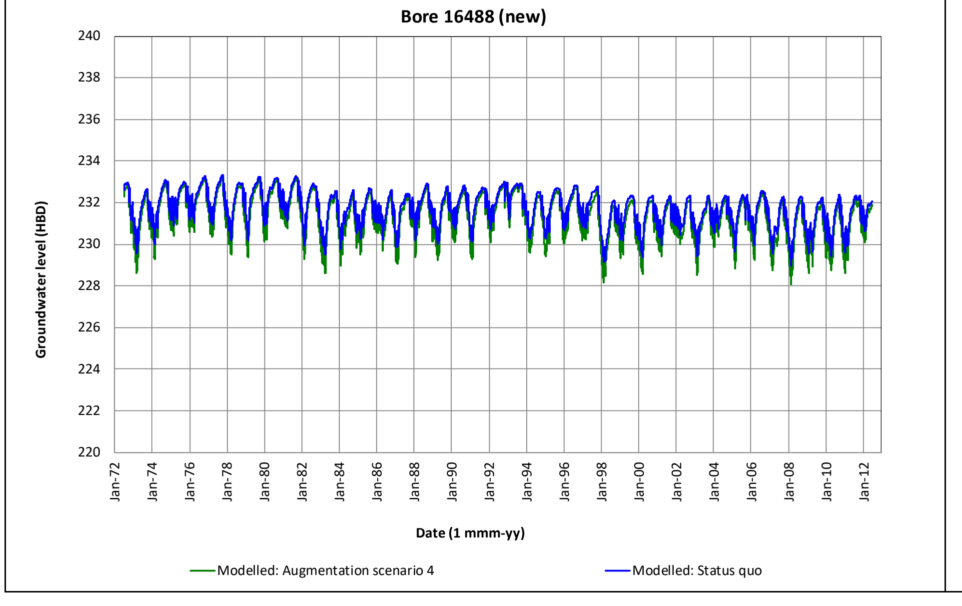

Bore 16479 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

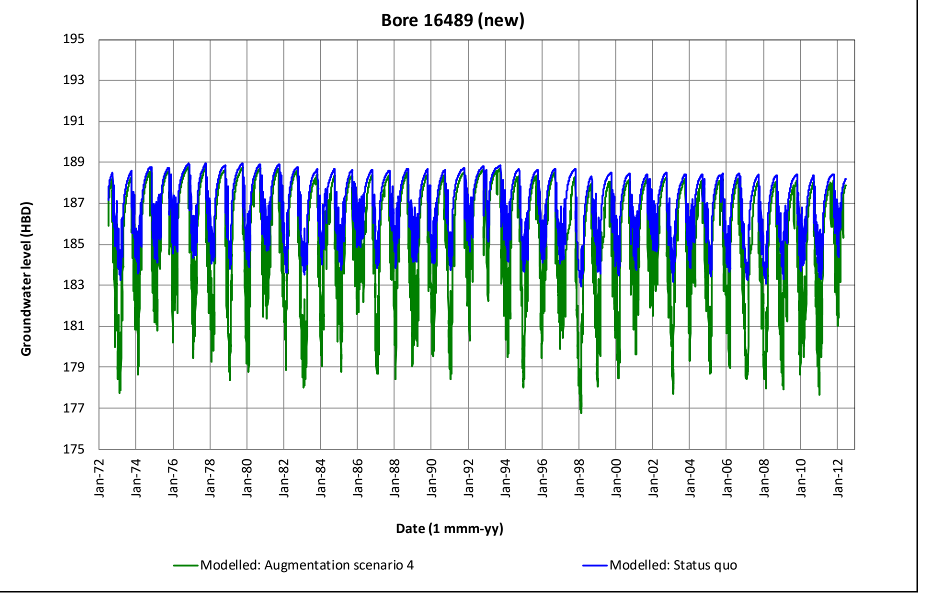

Bore 16484 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

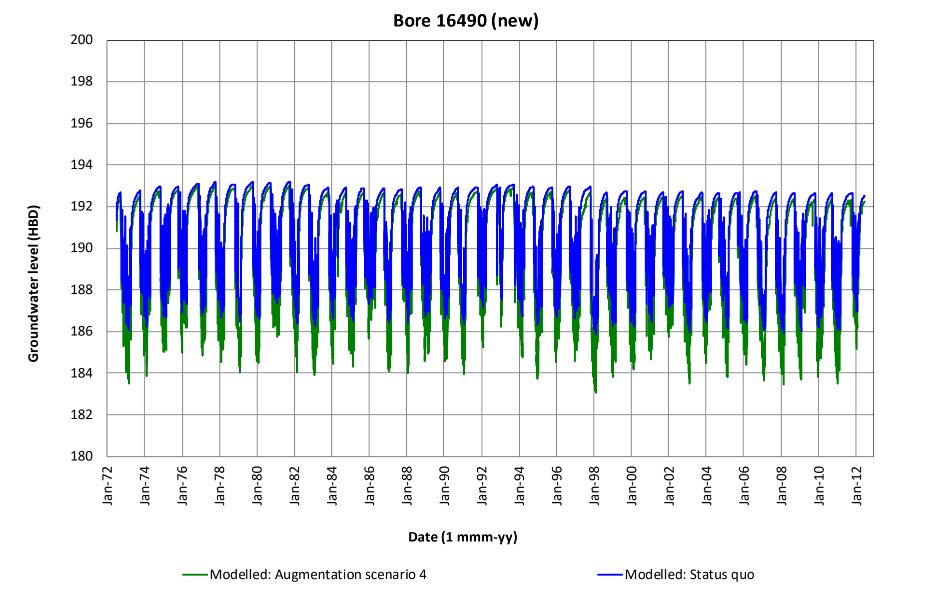

Bore 16485 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

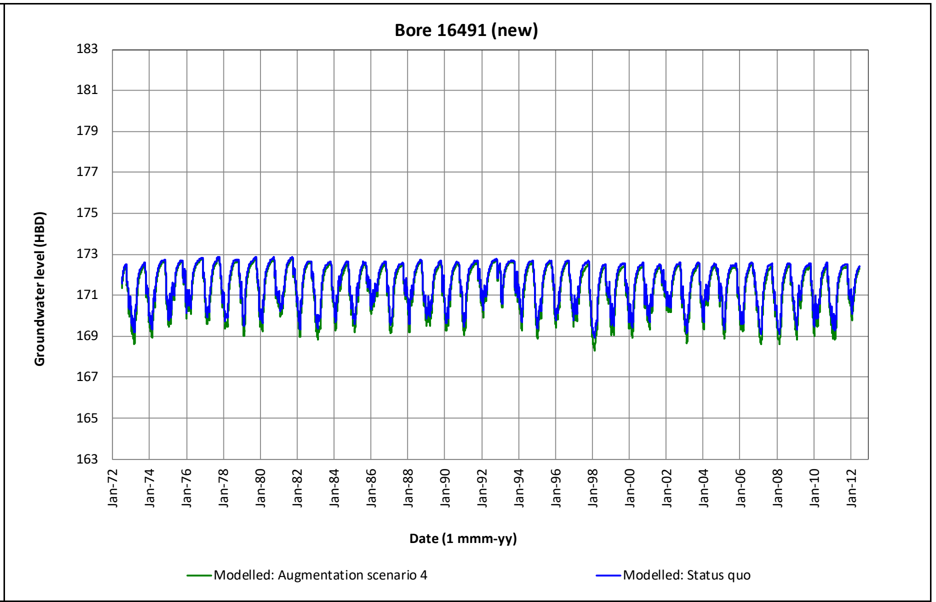

Bore 16486 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

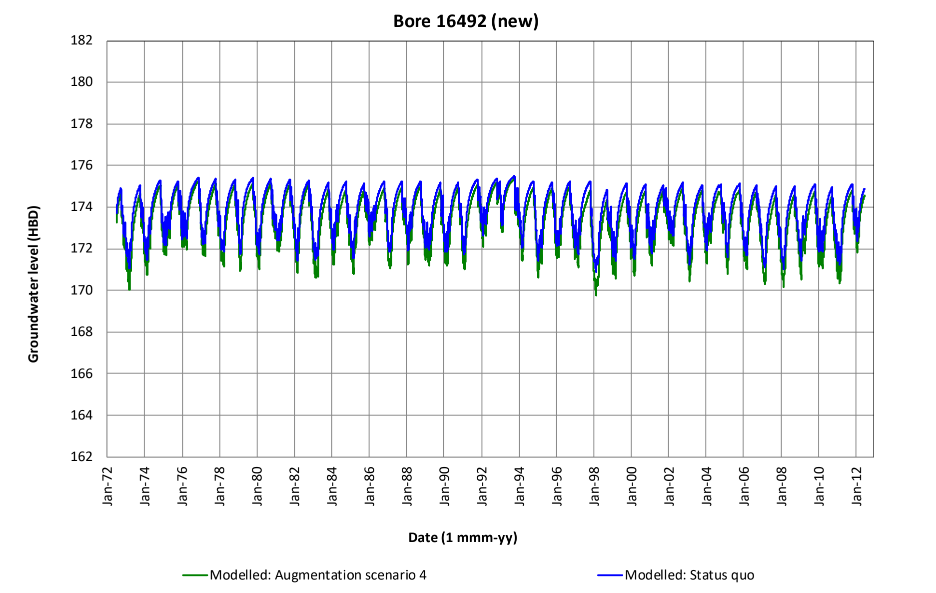

Bore 16487 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

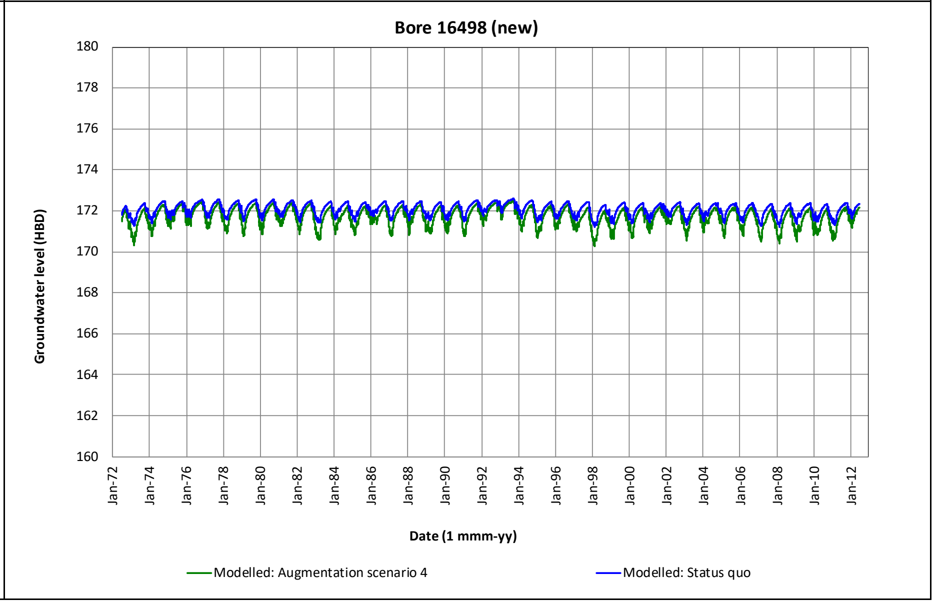

Bore 16488 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

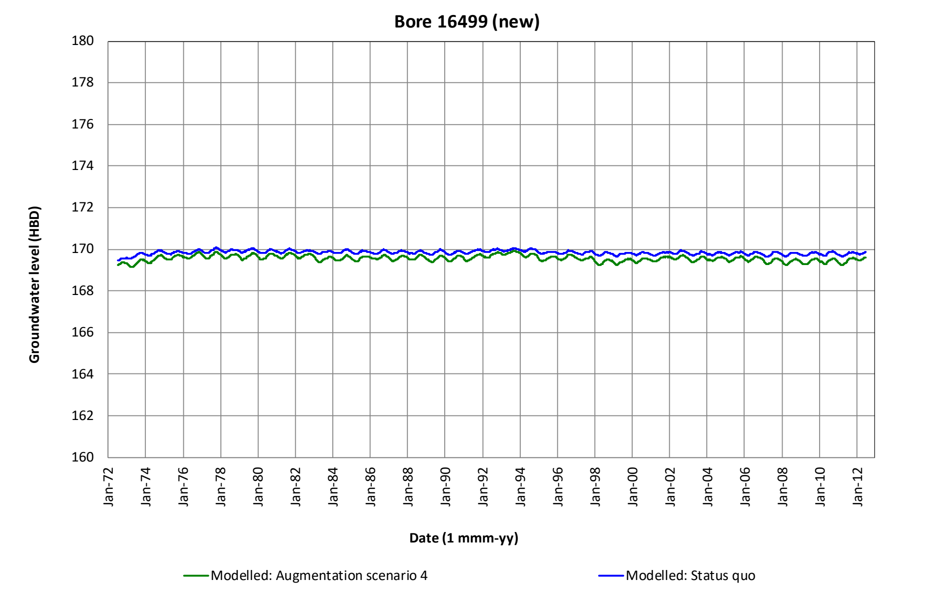

Bore 16489 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

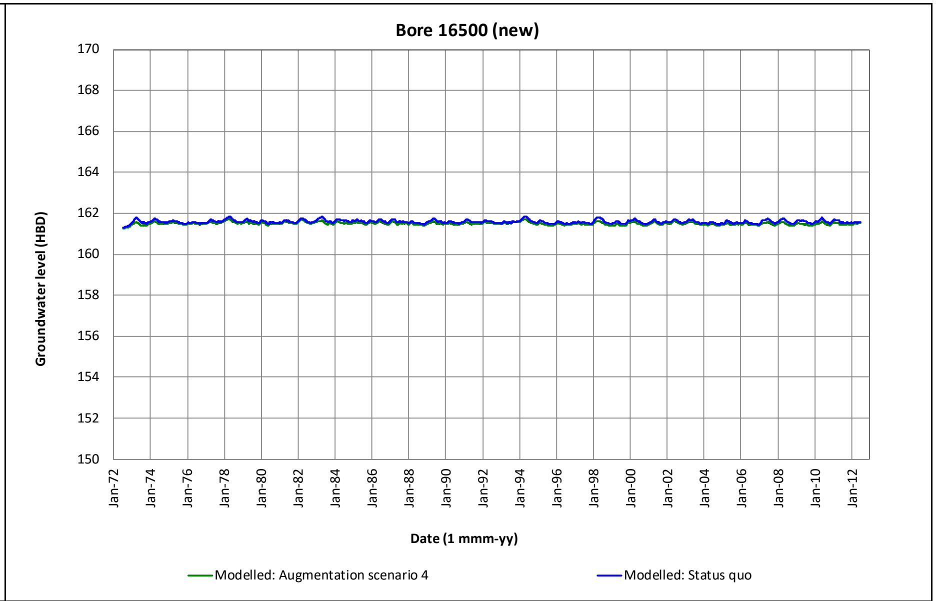

Bore 16490 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

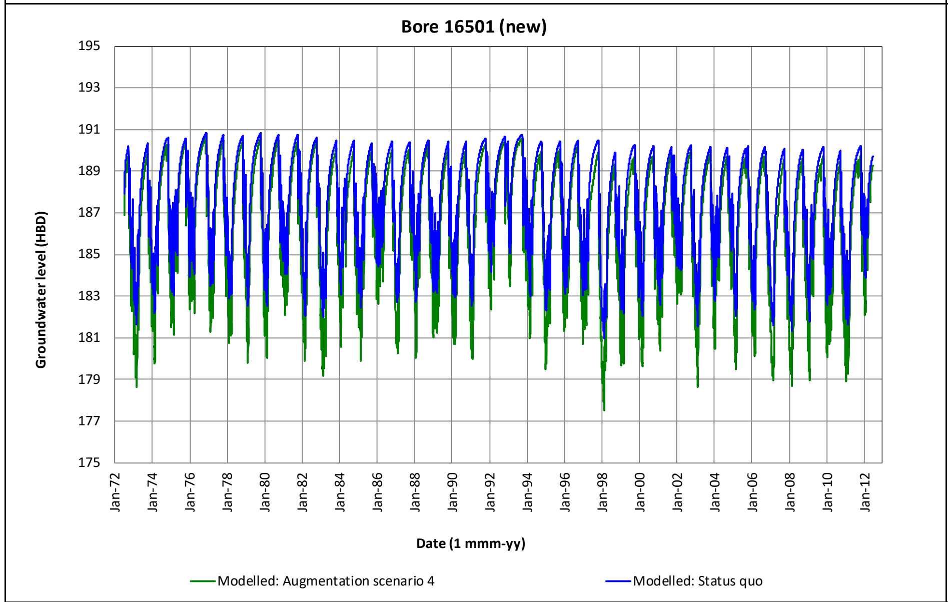

Bore 16491 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

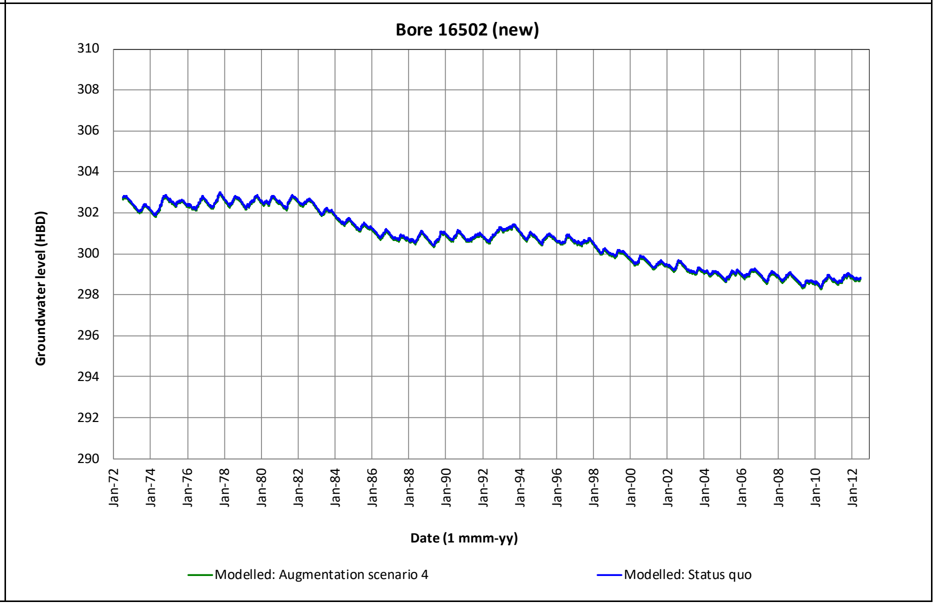

Bore 16492 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

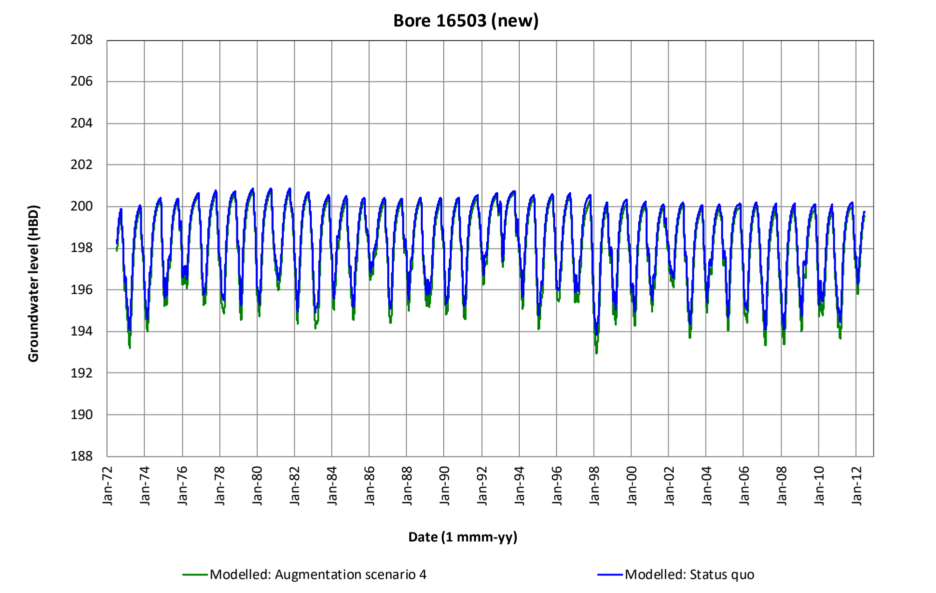

Bore 16498 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo


Bore 16499 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

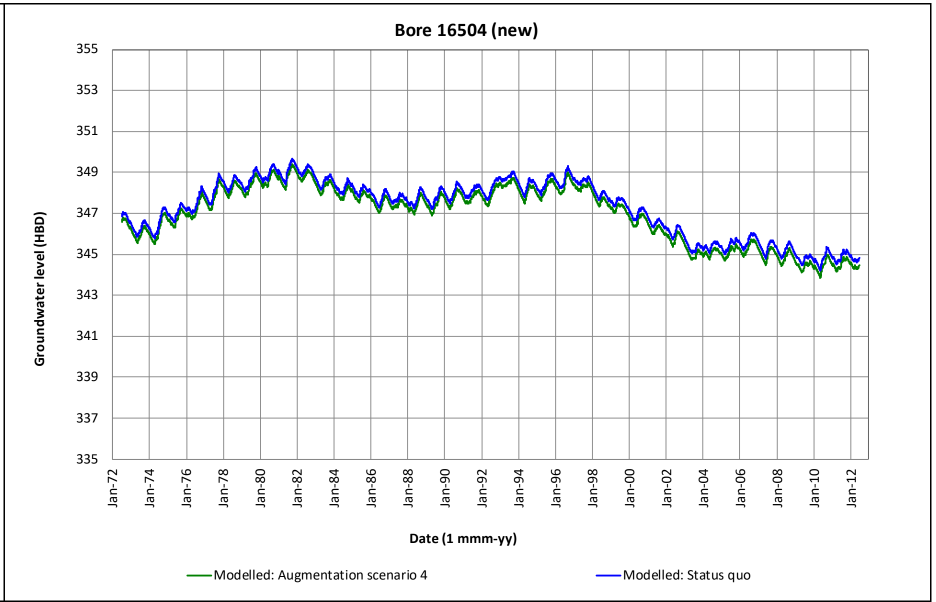

Bore 16500 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo


Bore 16501 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

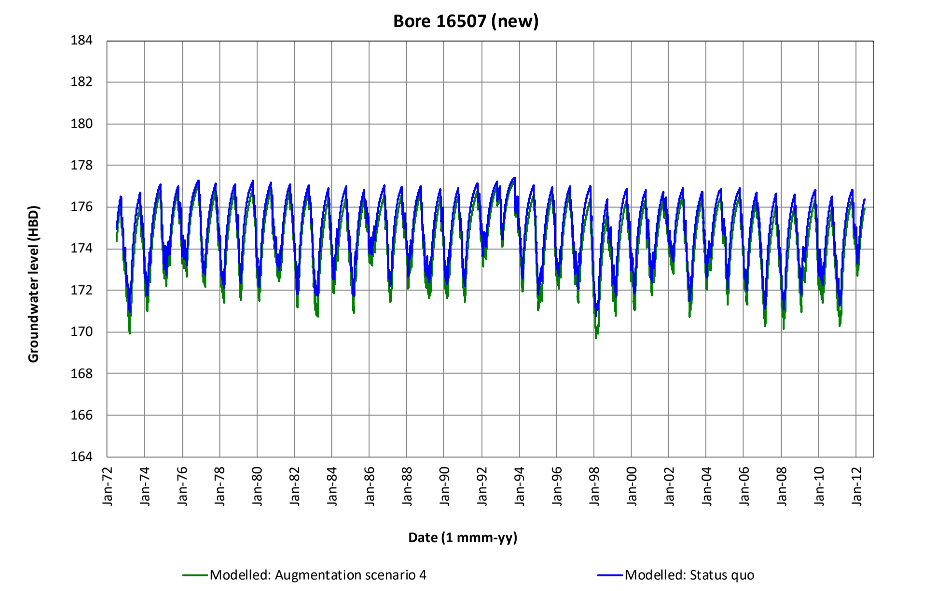

Bore 16502 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo



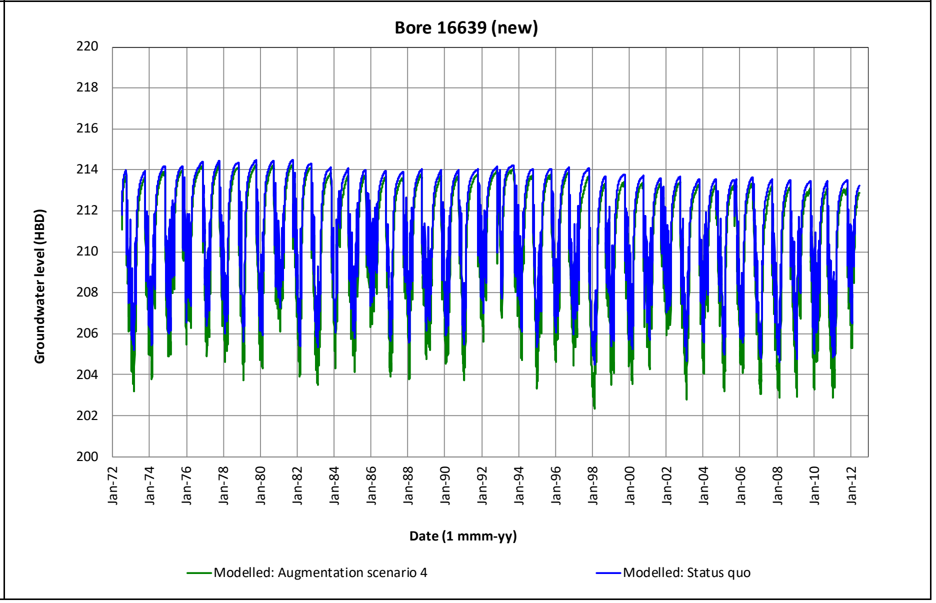
Bore 16503 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo



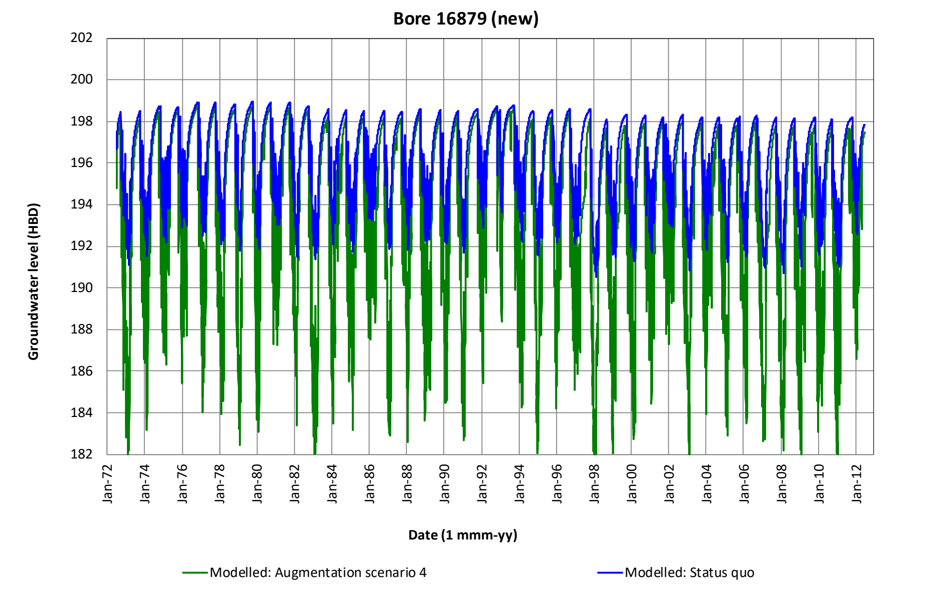
Bore 16504 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

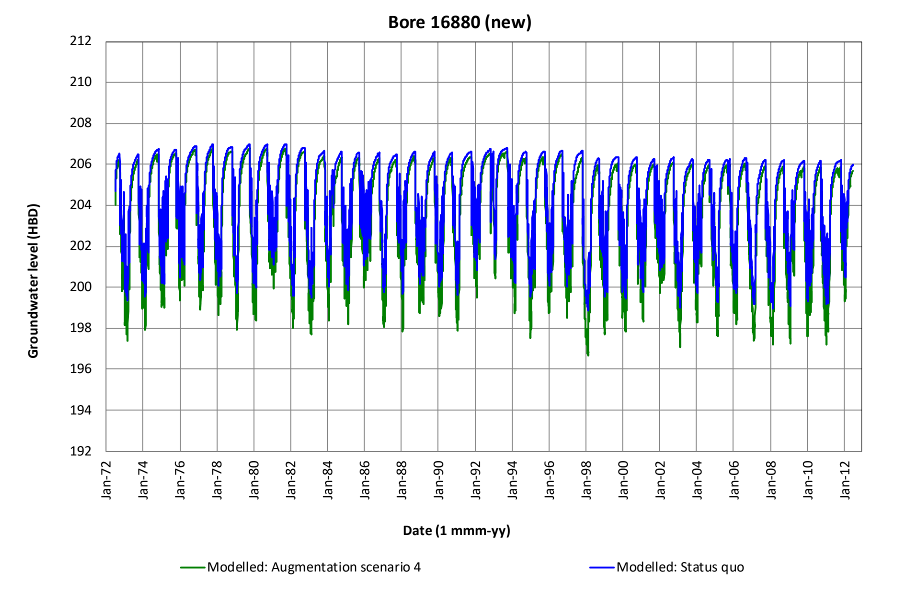


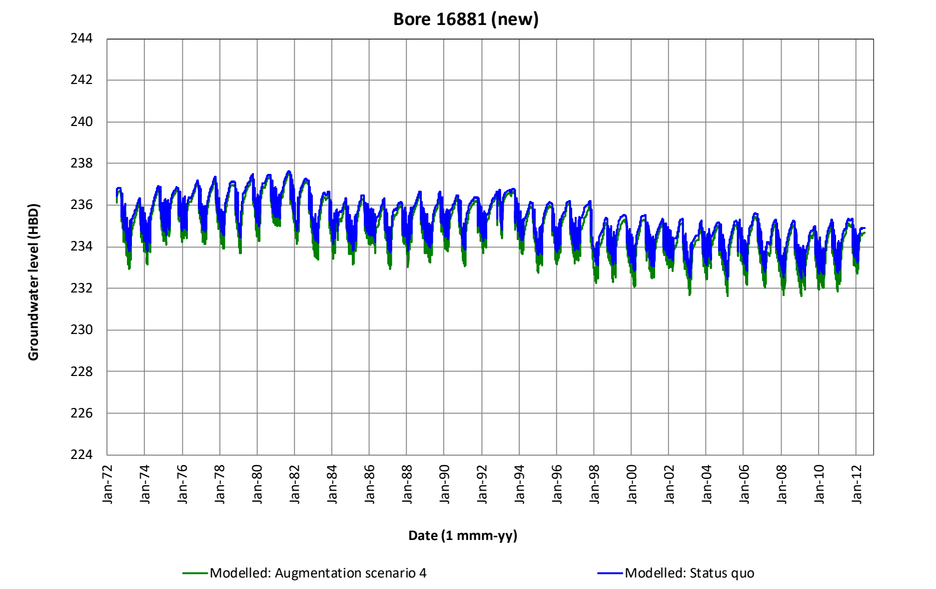
Bore 16507 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

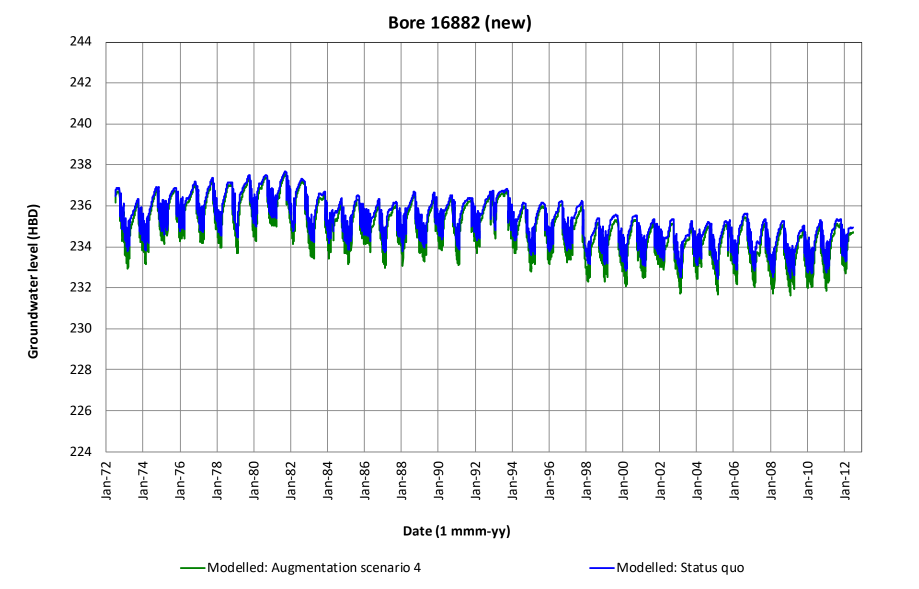


Bore 16639 (new)
Groundwater level (HBD)
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo


Bore 16879 (new)
Groundwater level (HBD)
202
200
198
196
194
192
190
188
186
184
182
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo


Bore 16880 (new)
Groundwater level (HBD)
212
210
208
206
204
202
200
198
196
194
192
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo


Bore 16881 (new)
Groundwater level (HBD)
244
242
240
238
236
234
232
230
228
226
224
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo


Bore 16882 (new)
Groundwater level (HBD)
244
242
240
238
236
234
232
230
228
226
224
Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10 Jan-12
Date (1 mmm-yy)
Modelled: Augmentation scenario 4
Modelled: Status quo

Appendix I: Timing of change

Bore	Time to reach ~0.05 m difference (years)	Time to reach ~90% of total difference (years)
1376	< 1	2
1379	2	2
1426	13	6
1429	5	1
1430	16	6
1452	2	1
1458	1	2
1475	4	4
1485	7	14
1558	< 1	39
1662	40+	40+
1826	4	6
1861	2	1
1900	1	3
1944	33	40+
2220	3	4
2749	8	4
2979	2	1
3076	2	4
3452	5	1
3702	17	6
4685	12	6
4693	< 1	39
4694	< 1	39
4695	< 1	39
4696	< 1	39
4697	10	5
4700	3	4
4701	2	1
4702	2	2
5335	< 1	40+
5445	5	1
6719	3	2
10993	0	2
15014	2	3
15015	2	3
15021	3	4

Bore	Time to reach ~0.05 m difference (years)	Time to reach ~90% of total difference (years)
15048	7	4
16094	15	6
16095	15	6
16247	10	5
16248	3	4
16249	3	1
16250	1	2
16251	17	8
16252	23	9
16253	38	40+
16477	3	4
16478	12	8
16479	13	40+
16484	< 1	38
16485	< 1	2
16486	1	2
16487	1	2
16488	3	5
16489	3	1
16490	5	4
16491	1	3
16492	2	2
16498	1	2
16499	2	4
16500	< 1	3
16501	3	1
16502	6	38
16503	2	4
16504	40+	40+
16507	2	2
16639	12	6
16879	4	< 1
16880	8	5
16881	5	10
16882	5	10