WWLA
Williamson Water & Land Advisory
Unit 5A Waimauku Village
11 Factory Road, Waimauku
Auckland, New Zealand
T +64 21 65 44 22
E jon.williamson@wwa.kiwi
W www.wwa.kiwi

WSP-Opus International Consultants Ltd

Attention: Chris Frost

5 November 2018

Te Raite Station Groundwater Investigations

1. Introduction

Williamson Water & Land Advisory (WWLA) has been commissioned by WSP-Opus International Consultants to provide technical services to assist in addressing s92 requests from the Northland Regional Council (NRC) in regard to the current groundwater take application for Te Raite Station. The scope and nature of these services are summarised below:

- Prepare an aquifer pump test plan to provide data for an assessment of surface water depletion, well interference, saline intrusion, and land subsidence.
- Supervision of the aquifer pump test programme described above.
- Analysis of the pump test data and subsequent application in a numerical model to be developed to evaluate impacts of the proposed take both individually and cumulatively.
- Prepare an assessment of effects for the proposed groundwater abstractions.
- Develop a monitoring and contingency plan, if needed, to adaptively manage actual effects resulting from groundwater abstractions once pumping is initiated. This monitoring and contingency plan will be based on the modelled effects.

To complete these tasks an aquifer pump test plan was devised and subsequently carried out along with associated data analysis, and a groundwater model was developed and calibrated to simulate conditions in the Te Raite Station area. **Figure 1** provides an overview map that includes the Te Raite Station test pumping locations and proposed bore locations, as well as the groundwater model boundary and the focus area for this investigation.

This letter documents the work that was performed by WWLA and the associated conclusions the as related to the aforementioned s92 request. It is intended to supplement the information reported in the original groundwater take consent application submitted by WSP-OPUS (2018).

Figure 1. Overview map of Te Raite Station groundwater investigation area and test pumping bore locations. (see A3 attachment at rear).

2. Aquifer Test Pumping

Aquifer pump tests were performed by WWLA personnel at the Salvation Road (1,608,940 mE, 6,148,550 mN, NZTM) and Trig Road (1,606,684 mE, 6,150,227 mN, NZTM) bore locations on 6 September 2018. Both bores are included in **Figure 1**.

Test Pumping Methodology

The Salvation Road bore was pumped at an average rate of 2.6 L/s for a duration of 48.1 hours while water level in the pumping well was recorded at 30 second intervals using a Solinst Levelogger.

The Trig road bore was pumped at an average rate of 1.4 L/s for a duration of 30.7 hours, while the water level in the bore was recorded manually at an average interval of 1.7 minutes over the first 15 minutes, and an average interval of 3 hours for the remaining duration of the test.

Test Pumping Results

Drawdown data for the Salvation Road and Trig Road bores in **Figure 2**. Initial drawdown occurs rapidly in both bores and then proceeds at a slower rate for the remainder of the test duration. The later time data was used for analysis by fitting a curve to the data on a semi-log plot (**Figure 3).** The slope of the fitted drawdown per log cycle curve was applied to calculate aquifer transmissivity and hydraulic conductivity using the Cooper-Jacob equation (Cooper & Jacob, 1946).

Transmissivity and hydraulic conductivity values calculated for the two bores are shown in **Table 1**. The horizontal conductivity values calculated for the two bores of 32.1 m/day and 32.8 m/day for the Salvation Road and Trig Road bores respectively, align with the results of previous investigations in the Aupouri shell bed aquifer (WWA, 2017; SKM, 2007a).

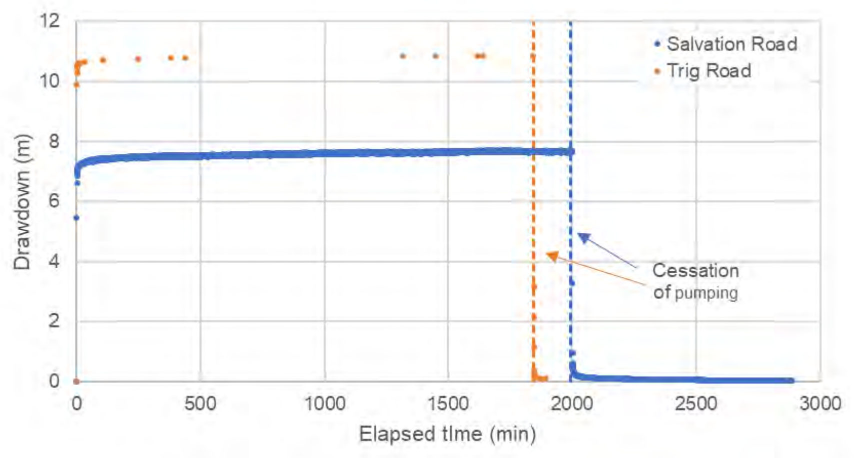


Figure 2. Test pumping drawdown data.

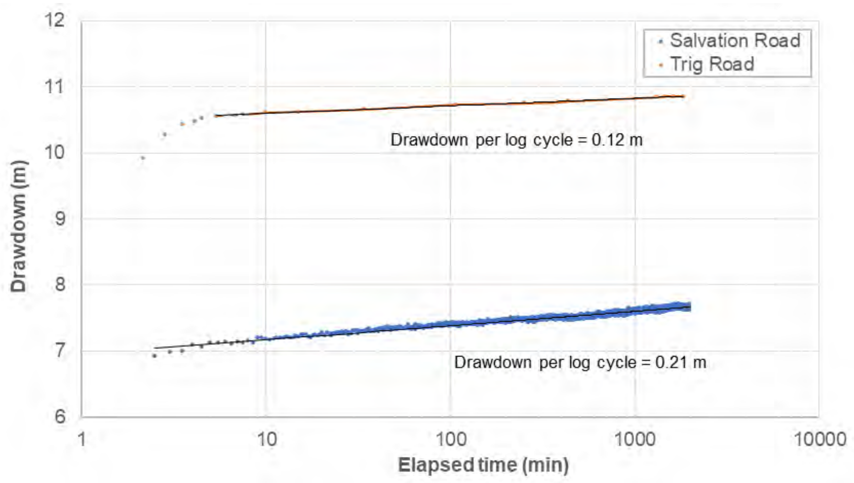


Figure 3. Drawdown results for pump tests at Salvation Road and Trig Road bore.

Table 1. Pumping test data and results.

Bore ID	Pumping rate (L/s)	Test duration (hours)	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Hydraulic Conductivity (m/s)
Salvation Road	2.6	48.1	192.5	32.1	3.7×10^{-4}
Trig Road	1.4	31.5	196.7	32.8	3.8×10^{-4}

3. Groundwater Model Conceptualisation

WWA has developed a groundwater model for the entire Aupouri aquifer from Ahipara to Ngataki. This aquifer consists of shell bed material buried beneath unconsolidated sedimentary materials of Pleistocene and Holocene origin deposited in beach and dune formations (abandoned shorelines and marine terraces) and associated alluvial, intertidal estuarine, shallow marine, lakebed and wetland environments. The Aupouri shell bed aquifer will be the source for the proposed groundwater extraction at Te Raite Station.

Drilling data in the Te Raite Station area indicates that the sedimentary sequence can be broadly classified into two lithological units. The upper bulk layer comprises the fine-grained sands, interspersed with iron pan, peat, lignite, and silt. The lower layer comprises mostly shell beds, although recent drilling has identified the existence of two discrete shell units separated by a thin fine sand or silt layer. The lithological unit classification can be summarized as follows:

- ***Layer 1 – Sand / Silt.*** A sequence of predominately unconsolidated fine sand intersperses with discontinuous layers of alternating iron pan, silt and peat. The layer varies in thickness from approximately 45 m to 110 m with the thickest regions located within the area of maximum topographic elevation.
- ***Layer 2 – Upper Shellbed.*** A sequence of shellbeds comprising medium to coarse shell with a fine sand matrix. The proportion of shell typically varies from 30% to 90%. The layer is typically encountered at a depth of 60 - 110 mBGL and varies in thickness from typically 5 m to 15 m.
- ***Layer 3 – Sand.*** A thin layer of finer sediment separating the upper and lower shellbed.
- ***Layer 4 – Lower Shellbed.*** A sequence of shellbeds typically comprising a higher proportion of shell and coarser grain size than the upper shellbed. In some locales, the shell is more consolidated and described by drillers as shellrock. Drillers also report circulation losses when drilling this formation. The layer is typically encountered at depths of 80 - 145 mBGL and varies in thickness from typically 5 m to 30 m.

Groundwater is found throughout the unconsolidated sedimentary materials that occur within the model area, although these materials vary in their ability to store and transmit water, primarily due to grain size, cementation, weathering and compaction.

In addition to the test pumping described within this document, additional test pumping and numerical modelling exercises for irrigation take resource consent applications have been undertaken over the years and summarised in the reports of HydroGeo Solutions (2000), SKM (2007b), SKM (2010), Lincoln Agritech (2015) and most recently by Williamson Water Advisory WWA (2017) and WWA (2018). Data from these reports are summarised in **Table 2** where it is presented in the context of our conceptual model as described above.

Table 2. Summary of previously measured and modelled hydraulic properties for WWA layer conceptualisation.

Unit	K_x (m/s)			S (-)		
	Min	Max	Arithmetic Mean	Min	Max	Arithmetic Mean
Layer 1 - Sand / silt	$1.0x10^{-5}$	$1.1x10^{-4}$	$8.4x10^{-4}$	$2x10^{-2}$	$1.5x10^{-2}$	$9.6x10^{-3}$
Layer 2 – Upper shellbed	$2.1x10^{-4}$	$7.3x10^{-4}$	$3.65x10^{-4}$	$2x10^{-2}$	$4x10^{-4}$	$3x10^{-4}$
Layer 3 - Sand	Assume same as Layer 1			Assume same as Layer 1		
Layer 4 – Lower shellbed	$1.3x10^{-4}$	$7.3x10^{-4}$	$4.4x10^{-4}$	$3x10^{-4}$	$4.4x10^{-3}$	$1.6x10^{-3}$

The site specific hydraulic testing conducted at Te Raite Station, described in **Section 2**, produced results compatible with previous tests undertaken in shellbed in the Aupouri Aquifer. Hence, the new data combined with previous test results have informed the hydraulic property assignment applied in the model.

4. Model Configuration

A regional groundwater model was developed for the Aupouri aquifer applying information from the previous modelling efforts listed above.

The model used the MODFLOW Unstructured Grid (MODFLOW-USG) developed by the United States Geological Survey (USGS) applied within the GMS10.3 modelling platform to simulate regional groundwater flow. The unstructured discretisation of the model domain provides the capacity of fitting irregular boundaries into the model, and increasing the resolution around areas of maximum interest and decreasing resolution in other areas, hence increasing the efficiency in model computation compared to the equivalent regular MODFLOW grid.

The model grid for the entire Aupouri Aquifer model is shown in **Figure 4**. It consists of 6 layers, each with 24,542 cells for a total of 147,252 cells. Grid spacing ranges from 40 m at the highest resolution, centred around large groundwater extraction points, to 1,000 m in the northwest portion of the model area where high resolution is unnecessary.

Figure 4. Aupouri Aquifer Model grid (see A3 attachment at rear).

The data and implementation methodology for recharge, drainage, groundwater use and groundwater observations, were primarily derived from the previous WWA models developed for adjacent Motutangi-Waiharara (2017), Waiharara-Paparore (2018a) and the Evans Orchard areas (2018b). A comprehensive report on the Aupouri Aquifer Model development and calibration, and associated outputs is currently in progress.

Figure 5 provides an overview of the Te Raite Station groundwater investigation area, which was effectively treated as a sub-section of the Aupouri Aquifer Model. The figure includes both the proposed bore locations and existing groundwater takes.

Figure 5. Overview of Te Raite Station groundwater investigation area (see A3 attachment at rear).

The Aupouri Aquifer Model comprises six layers that are used to represent the varying geology located in the area. The geological units assigned to each layer of the numerical model are shown in **Table 3**.

Table 3. Geological units in the model conceptualisation.

Model Layer	Strat. Layer	Name	Description	Locality
1-3	1	Coastal sand	Loose coast sand, highly permeable	Western and eastern coastal strips.
	1	Weathered sand	Weathered dune sand, moderately compacted	Inland hilly or rolling country areas.
	1	Plain zone	Peaty and clayey sediments, low permeability	Inland low-lying plain areas.
4	2	Shellbed	Sand presented with shells, highly permeable	Throughout model, albeit thickness varies.
5	3	Fine sand	Old sand deposits, fine sand, moderately permeable	
6	4	Shellbed	Sand presented with more shells, highly permeable	

Surface elevation was incorporated into the Aupouri Aquifer Model using the 8 m digital elevation model available through NZ LINZ (https://data.linz.govt.nz). The thickness of the model layers was determined through a careful review of 171 bore logs, the majority supplied by the NRC.

Each bore log was assessed with regard to the subsurface materials recorded to determine the depth and thickness of the geologic units within the model area. The results were then used to assign an interface elevation for the various materials at each bore location and subsequently interpolated to define the thickness of the stratigraphic layers described in **Table 3**. This process also effectively determined the lower boundary of the model domain, equivalent to the bottom of the lower shellbed.

Model Layers 1-3 are used to represent a complex stratigraphic unit comprising alternating sands, silt, peat, clay and iron pans in a bulk sense (not discretely). It is difficult to define the sub-division in the stratigraphic layers of these deposits, hence for modelling purposes, the base of model Layer 1 was defined as an elevation of -2 mAMSL, while the base of model Layer 2 was defined as the base of model Layer 3 plus 22 m.

The materials for each model layer are divided into 4 zones along the north-south axis to enable incorporation of previous modelling results and allow for a more refined model calibration. The zones, from north to south, are referred to as the Waihopo, Motutangi, Waiharara-Paparore, and Sweetwater.

5. Model Calibration

The model was initially calibrated as a steady state model to simulate average water levels at the seven NRC monitoring locations along the Hukatere Transect (**Figure 6**). These piezometers include nested piezometer configurations at the Waterfront, Browne, and Forest monitoring locations where groundwater levels are monitored at multiple depths. Monitoring piezometer details are provided in **Table 4**.

Figure 6. Observation bore locations. (see A3 attachment at rear).

Table 4. Summary of NRC monitoring piezometers used in model calibration.

Site	Piezometer	Mean groundwater level (mAMSL)	Standard deviation (m)	Top of screen elevation (mAMSL)	Model Layer
Waterfront	4	3.45	0.36	-6	2
	3	3.98	0.36	-24.2	2
	2	5.32	0.28	-44.5	3
	1	5.29	0.29	-60.9	4
Hukatere	3	13.7	1.17	4.8	1
	2	12.6	1.08	-12.6	2
	1	12.18	1.05	-34.8	2
Forest	4	20.37	1.01	21.3	1
	3	19.37	1.21	0.8	1
	2	18.12	1.1	-27.2	2
	1	18.1	1.1	-41.8	3
Burnage	4	16.14	0.71	6.5	1
Browne	3	18.64	0.92	11.1	1
	2	15.77	0.81	-2.5	1
	1	11.5	0.77	-32.4	2
Wagener Golf Club	1	4.46	0.28	-58.3	4
Fishing Club at Houhora	1	3.42	0.63	-67.1	5

The steady state model results, shown in **Figure 7**, were used to determine initial conditions for the transient model, and similarly steady state model parameters were used to provide an initial estimate, which were then refined in the process of calibrating the transient model. The RMSE of the steady state model was 1.9 m, representing 11% of the range of observations.

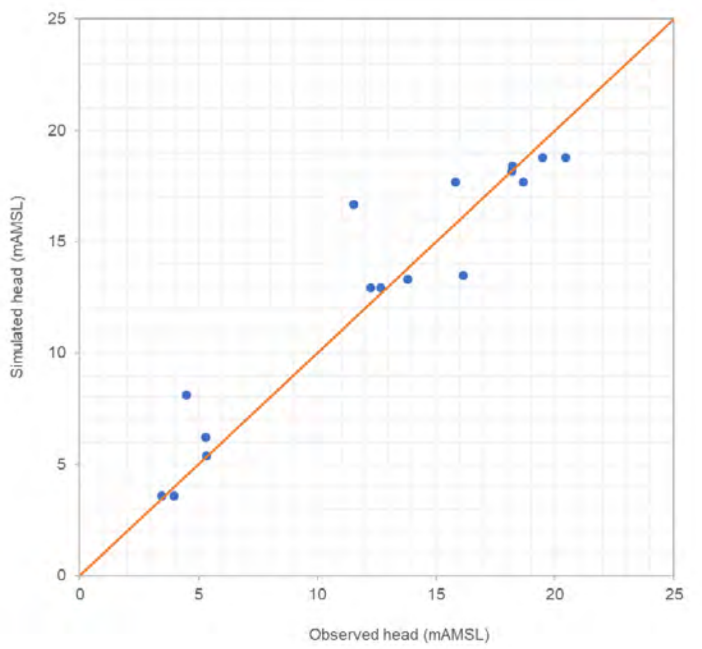


Figure 7. Simulated head versus observed head in steady state model

A transient model was developed using climate and groundwater pumping data for a period of approximately 58 years (1/1/1960 to 1/8/2018). The model was calibrated to the available data from the monitoring bores shown in **Figure 6**. Calibrated model parameters for all model zones and material types in the area relevant to Te Raite Station are presented in **Table 5**. **Appendix A** provides plots of simulated and observed data for each of the monitoring piezometers.

Table 5. Calibrated model hydraulic parameters.

Model Geological Units	Model Layer	K_x		Vertical Anisotropy	Sy	Ss
		(m/d)	(m/s)	(-)	(-)	(m-1)
L1-Peat_wetland-Motutangi	1	0.1	1.2E-06	15	0.05	-
L1-Coastal_sand-Motutangi	1	4.5	5.2E-05	70	0.30	-
L1-Coastal_sand-Waihopo	1	3.5	4.1E-05	10	0.30	-
L1-Coastal_sand-Motutangi	1	4.5	5.2E-05	70	0.30	-
L1-Inland_sand-Motutangi	1	3.0	3.5E-05	80	0.25	-
L1-Inland_sand-Waihopo	1	2.0	2.3E-05	20	0.25	-
L2-L3-Coastal_sand-Motutangi	2-3	4.0	4.6E-05	30	-	5.0E-04
L2-L3-Coastal_sand-Waihopo	2-3	3.5	4.1E-05	10	-	5.0E-04
L2-L3-Coastal_sand-Motutangi	2-3	4.0	4.6E-05	30	-	5.0E-04
L2-L3-Inland_sand-Motutangi	2-3	2.8	3.2E-05	90	-	5.0E-04
L2-L3-Inland_sand-Waihopo	2-3	2.0	2.3E-05	80	-	5.0E-04
Lower shell bed- Motutangi	4	22.0	2.5E-04	1	-	5.0E-04
Lower shell bed- Waihopo	4	30.0	3.5E-04	1	-	5.0E-04
Compact sand- Motutangi	5	6.0	6.9E-05	30	-	5.0E-04
Compact sand- Waihopo	5	1.0	1.2E-05	60	-	5.0E-04
Upper shell bed- Motutangi	6	35.0	4.1E-04	1	-	5.0E-04
Upper shell bed- Waihopo	6	30.0	3.5E-04	1	-	5.0E-04

The RMSE for the transient model is 2.03 m, which is equal to 9.9 % of the range of observed groundwater head for the observation bores in the Hukatere transect. The greatest errors in predicted groundwater head were at the Wagener Golf Club and at the Browne deep piezometer, which were also problematic in the models of LAT (2016) and WWA (2017). RMSE for all of the other monitoring locations was below 2 m.

The average daily water balance predicted by the transient model is presented in **Table 6**. The flux values are similar to those in the previous WWA models developed for the Motutangi-Waiharara and Waiharara-Paparore regions (WWA 2017; WWA 2018a).

Table 6. Average water budget for calibrated transient model (58-year simulation period).

Mass balance	Components	Baseline Model		Te Raite Station Analysis Area	
		Flow (m^3/d)	Percentage of Flow (%)	Flow (m^3/d)	Percentage of Flow (%)
Inflow	Storage	156,944	19.4	62,178	19.1
	CH	8	0.0	0	0.0
	Recharge	651,587	80.6	249,261	76.6
	Lakes	166	0.0	5	0.0
	Cross Boundary Flow	NA	NA	14,168	4.4
	Total inflow	**808,705**	**100**	**325,612**	**100**
Outflow	Storage	160,256	19.8	63,951	19.6
	Shallow Coastal Discharge (CH)	294,551	36.4	138,134	42.4
	Wells	10,179	1.3	1,392	0.4
	Drains/Wetlands (DC)	238,321	29.5	69,197	21.3
	Deep Coastal Discharge (GHB)	105,393	13.0	41,317	12.7
	Cross Boundary Flow	NA[1]	NA[1]	11,620	3.6
	Total outflow	**808,700**	**100**	**325,611**	**100**
Percentage discrepancy		0.0%		0.0%	

Note: CH = constant head; GHB = general head boundary; DC = drain cells.
[1]Cross boundary flow does not apply to the analysis for the full model area because there are no internal boundaries

To place the maximum proposed rate of take (10,400 m^3/day) under this consent application into context of the water budget for the area, it comprises 3.2% of the total water budget and 4.2% of groundwater recharge in the area. When combined with other groundwater takes in the area that are currently consented, the maximum total groundwater take is approximately 19,900 m^3/day, equating to 8.0% of groundwater recharge in the Te Raite Station area. It is important to note that this analysis is based on drainages within the Aupouri Aquifer Model rather than NRC groundwater allocation zones.

6. Model Scenarios

The numerical groundwater model was developed to assess the effect of various groundwater abstraction rates on the local aquifer. To facilitate this, a transient pumping dataset for each bore was developed using the simulated irrigation that included proposed groundwater extraction at Te Raite Station as well as proposed groundwater extraction in the Motutangi-Waiharara and Waiharara-Paparore areas.

Groundwater conditions were evaluated with and without the proposed extraction at Te Raite Station. This assessment was expanded to include a sensitivity analysis with significantly reduced connectivity between the surface conditions and the deep aquifer.

The sensitivity analysis was undertaken because the calibrated groundwater model errs on the side of over simulation of vertical leakage. This was deliberately built into the model in the absence of a single well defined low permeability horizon in the field, but rather a series of multi-layered and discontinuous iron pans and other low permeability horizons within the sedimentary sequence that in combination act as a flow barrier between the deeper groundwater system and the surface drains and wetlands. As a result, the model exaggerates the effects of the proposed abstraction on the groundwater levels in the shallow aquifer and at the surface. Conversely, the model under-predicts the local-scale drawdown in the deeper aquifer.

To investigate model uncertainty with regard to simulated drawdown in the deeper shellbed layer, permeability was reduced in Layer 2, the depth range where iron pans and peats layers prevail. The modified horizontal hydraulic conductivity of Layer 2 was $1x10^{-7}$ m/s in both the coastal sand and weathered sand regions, with vertical anisotropy remaining similar at a factor of 50. Boundary and source/sink conditions remained the same as in the baseline model. The model was not calibrated to the conditions applied in Scenarios 3, therefore Scenario 3 results are only referenced to illustrate relative (rather than absolute) changes in groundwater level and water budget.

Stress periods in the predictive scenarios were the same as in the transient calibration simulations. In effect, the climatic conditions of the last 58-years have been utilised to simulate conditions that may occur in the next 58 years.

The three predictive model scenarios can be summarized as follows:

- ***Scenario 1: Base Case*** – the calibration model which includes all currently consented groundwater takes at a total peak abstraction rate of 79,305 m^3/day as presented in **Appendix B**.
- ***Scenario 2: Proposed Extraction*** – includes current and proposed groundwater extraction totalling a combined peak rate of 89,016 m^3/day.
- ***Scenario 3: Low Permeability-Proposed Extraction*** – Groundwater extraction is the same as in Scenario 2 with horizontal hydraulic conductivity of Layer 2 was decreased to $1x10^{-7}$ m/s in both the coastal sands and weathered sand regions to simulate a hard pan extending over the model area.

7. Model Results

7.1 Mass Balance

The end of the 2010 irrigation season (30 April 2010) was selected for impact analysis as this date represents the end time of the driest period within the historical record, and the greatest simulated seasonal irrigation pumping requirement. Simulation results were evaluated for the drainages within and around Te Raite Station in order to assess potential effects from proposed pumping in the area most likely to be impacted. This area is referred to in this report as the Te Raite Station Assessment Area.

A comparison of the model flow budget during the peak pumping period within the 2009-2010 irrigation season for all three scenarios is provided in **Table 7**, which in the model corresponds to 24 December 2009. The peak pumping period in the model occurred at this date (as opposed to later in the season) due to the model stress period configuration. During the stress period ending 24 December irrigation occurred on 40 out of the proceeding 43 days, whereas during the following stress period (24 December to 30 April 2010) simulated pumping was cut-off after a further 69 days pumping due to the annual volume limit being reached, hence irrigation was required on only 114 out of 127 days in the later stress period. The pumping rates and irrigation demand requirements for these two model stress periods are exemplified in **Figure 8**.

Table 7. Simulated groundwater budget for peak pumping period in 2010 irrigation season.

Mass balance	Components	Scenario 1: Base Case		Scenario 2: Proposed GW Extraction	
		Flow (m^3/d)	Percentage of Flow (%)	Flow (m^3/d)	Percentage of Flow (%)
Inflow	Storage	152,373	56.9	160,371	58.2
	CH	0	0.0	0	0.0
	Recharge	100,886	37.7	100,886	36.6
	Lakes	5	0.0	5	0.0
	Cross Boundary	14,358	5.4	14,351	5.2
	Total inflow	267,622	100	275,614	100
Outflow	Storage	0	0.0	0	0.0
	Shallow Coastal Discharge (CH)	140,863	52.6	140,502	51.0
	Wells	8,845	3.3	18,812	6.8
	Drains/Wetlands (DC)	64,004	23.9	62,930	22.8
	Deep Coastal Discharge (GHB)	42,295	15.8	41,841	15.2
	Cross Boundary	11,600	4.3	11,510	4.2
	Total outflow	267,607	100	275,595	100
Percentage discrepancy		0.01%		0.01%	

Note: CH = constant head; GHB = general head boundary; DC = drain cells. Changes in storage are due to the difference in climatic and hence water table conditions between the start and the end of the model run.

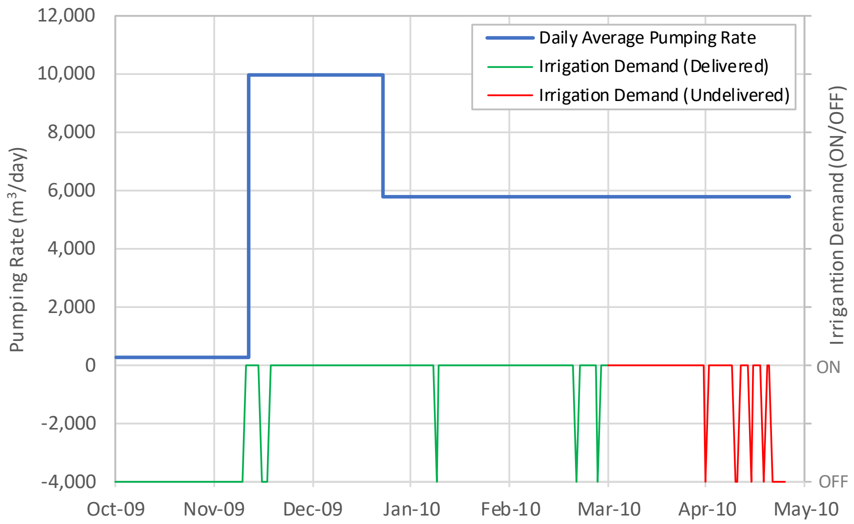


Figure 8. Model pumping rates during the 2009-2010 irrigation season.

Comparison between Scenario 1 and Scenario 2 from an environmental impact perspective of key water budget components in **Table 7** indicates the following:

- Groundwater extraction in the Base Case scenario is predicted to be approximately 3.3% of the water budget in the Te Raite Station analysis area for this time period. The additional pumping proposed for Te Raite Station, approximately 10,000 m³/day, is predicted to increase to groundwater extraction to 6.8% of the groundwater budget for the area.
- Groundwater discharge to surface water, primarily occurring as drain flows in the Te Raite area, are predicted to decline by 1.1 % in the total groundwater budget.
- Shallow coastal discharge adjacent to Te Raite Station is predicted to decline by 1.6%.
- Deeper coastal discharge adjacent to Te Raite Station is predicted to decline by 0.6%.
- During the peak irrigation season, the majority of groundwater pumping demand is drawn from aquifer storage. With the increased groundwater take at Te Raite Station this is predicted to increase by 1.3% of the groundwater budget (approximately 8,000 m³/day).

7.2 Drain Flows

An analysis of the impact on flows including discharge to both farm drains and wetlands was undertaken for low-flow situations. The annual minima in daily flow was obtained from the global flow budget for all drain boundary cells combined for each time step exported from the model. Annual recurrence intervals were calculated from this table of data for each scenario, and the resulting data is presented in

Table 8 and **Figure 9.**

A comparison of the proposed groundwater extraction (Scenario 2) against the Base Case scenario indicates that the reduction in mean annual (1-year) low flow as a result of Te Raite Station increasing groundwater pumping is likely to be under 2%. However, as stated earlier, we consider the model to exaggerate groundwater level reduction in the shallow aquifer and at the surface because of the lack of hard pans in the model. In this regard, these values can be considered conservative estimates.

These results indicate that the variation in annual minimum discharge from groundwater to surface water over a range of drought severities (i.e. annual to 100-year recurrence interval) is likely to be in the range of a 2% reduction with the proposed groundwater extraction, with the relative reduction increasing slightly for the more infrequent events. In the event of a 100-year drought the annual low flow with proposed groundwater extraction is likely to be under 2.4% less than under the conditions applied in the Base Case scenario. In summary, the effect of the proposed pumping on surface flows is <u>less than minor</u> based on this analysis.

Scenario 3 was not considered in the analysis of drain flow impacts because the scenario represents an uncalibrated version of the Aupouri Aquifer model.

Table 8. Low-flow analysis of surface discharge and percentage reduction in flow from Baseline scenario

Recurrence Interval	Scenario 1: Base Case	Scenario 2: Proposed GW Extraction	Relative Difference
(years)	**(L/s)**	**(L/s)**	**(%)**
1	813	800	-1.6%
2	595	584	-2.0%
5	507	497	-2.1%
10	473	464	-2.0%
25	433	423	-2.3%
50	415	405	-2.4%
100	399	389	-2.4%

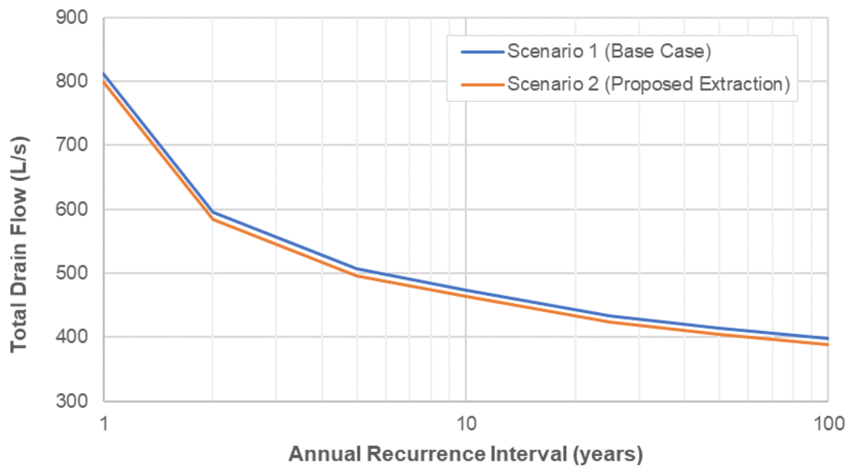


Figure 9. Surface drainage low flow analysis for model predictive scenarios.

7.3 Drawdown Effects

The simulated end of 2010 irrigation season groundwater level for Scenario 2 and Scenario 3 was subtracted from the head simulated at the corresponding time from the Baseline Model in the case of Scenario 2, and a revised version of the Baseline model with low permeability in Layer 2 for Scenario 3, to produce regional drawdown maps (**Figure 10** and **Figure 11**). The resulting drawdown predictions are used to evaluate the potential impact of proposed pumping on both the shallow and deep aquifers in the Te Raite Station groundwater investigation area for both scenario conditions.

Deep aquifer

In Scenario 2 the maximum drawdown was 2.2 m at the proposed Cropping Avocado bore location (labelled in **Figure 5**) and the maximum extent of drawdown (taken as the 0.6 m drawdown contour) was approximately 1.0 km from the Pivot A bores, as shown in **Figure 10**. Drawdown in this area was more widespread than around the Cropping Avocado bores because of the cumulative impact of multiple bores.

In Scenario 3 the low permeability of model Layer 2 limited leakage from the overlying layers thereby magnifying the impact of pumping on groundwater levels. The maximum drawdown predicted in Scenario 3 was 5.1 m at the pumping locations while the 0.6 m drawdown contour extended approximately 4 km toward the west coast, though only 2 km toward the south where the majority of other groundwater users are located (**Figure 11**).

Figure 10. Simulated drawdown of deep aquifer (Scenario 2) (see A3 attachment at rear).

Figure 11. Simulated drawdown of deep aquifer (Scenario 3) (see A3 attachment at rear).

Shallow aquifer

The shallow aquifer is less effected by the proposed pumping relative to the deep aquifer, however, there is drawdown simulated for the proposed extraction scenario (Scenario 2). The maximum predicted drawdown in the shallow aquifer is 1.0 m occurring around the proposed bores at Pivots A and B (**Figure 12**). The extent of impact in the shallow aquifer was approximately 1.0 km, with a similar profile to the deep aquifer though extending somewhat further to the south. Shallow aquifer drawdown due to increased groundwater pumping in Scenario 3 was negligible because of the disconnection of the upper and lower portions of the aquifer.

Figure 12. Simulated drawdown of shallow aquifer (Scenario 2) (see A3 attachment at rear).

Existing bores

The proposed bores at Te Raite Station are shown in **Figure 13** along with 57 other bores located within, or adjacent to, the Te Raite Station groundwater investigation area.

Figure 13. Proposed Te Raite Station bore location and neighbouring bores (see A3 attachment at rear).

The drawdown induced by the groundwater take utilised in each scenario was calculated and plotted similarly at 57 existing bores as a boxplot, with the maximum and minimum drawdown shown in **Figure 14**.

The drawdown at the existing bores predicted in Scenario 2 is largely affected by their distance to the proposed new groundwater take locations. At the driest condition (30/04/2010), the simulated drawdown in neighbouring bores in Scenario 2 ranges between 0.01 m to 0.65 m. The maximum predicted drawdown that can be attributed to the proposed extraction at Te Raite Station was at the Fullam bore (labelled as number 4 in **Figure 13**) approximately 500 m northeast of the proposed Pivot A-South bore. With the proposed groundwater extraction at Te Raite Station, 79% of the bores had predicted drawdown of under 0.1 m in the Base case scenario.

For the same date in Scenario 3 simulated drawdown ranged from 0.07 m to 2.04 m with drawdown centred around the proposed takes at both Te Raite Station and at the proposed bore locations south of the Te Raite Station area. The increased drawdown in Scenario 3 is due to the cumulative influence of additional pumping combined with lack of shallow aquifer leakage.

In Scenario 3 the cone of depression from the northern and southern groups of Te Raite Station bores merges, causing the maximum predicted drawdown to be at the L & P Trust bore located within Te Raite Station boundary, while the Fullam bore had the greatest predicted drawdown among bores outside of Te Raite Station at 1.92 m. Given the available drawdown in the Aupouri aquifer, typically 70 to 100 m in most shellbed bores, the interference effects on existing groundwater users is considered less than minor.

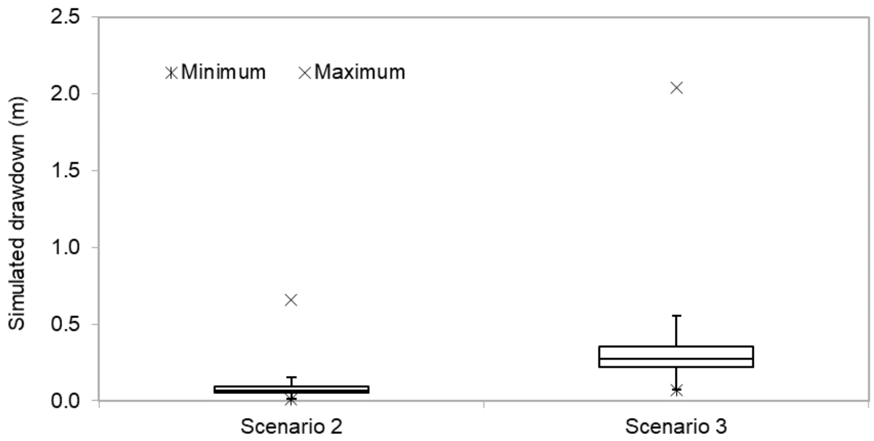


Figure 14. Range of predicted drawdown at existing bores for each scenario.

7.4 Saltwater Intrusion

Saltwater intrusion under the hydrogeological conditions in the Te Raite Station area, and specifically into the shellbed aquifer has been evaluated using the method of *Lateral Migration Analysis*. Lateral migration along the aquifer/bedrock interface considers the material under the aquifer impermeable where inland migration of salinity occurs via the permeable sediments along the lower boundary of the aquifer. This mechanism assumes that the pressure at the coastal margin is relevant to maintaining an offshore position of the saline interface.

The shellbed aquifer in the Te Raite Station groundwater investigation area is underlain by relatively impermeable basement rock and is well represented by this conceptual approach.

Lateral Migration Analysis

Based on the estimated depth to the basement rock at the coastal margins, the Ghyben-Herzberg relation was used to back-calculate the minimum hydraulic head required to maintain the saline interface below the shellbed aquifer (i.e. the lateral migration “Trigger Level”). This calculation was performed approximately 500 m intervals along the coastal margins on the east and west model boundaries, respectively. The simulated groundwater levels for Layer 6 from each scenario were extracted for these points.

Saltwater intrusion is not an instantaneous response to the lowered water table - it is a gradual process requiring prolonged reduction in groundwater level below a critical level to initiate the landward migration of the saline interface. A 90-day rolling average (RA) was calculated from the simulated groundwater level to reflect this slow process. The simulated groundwater levels were then compared against the Trigger Level at the model time 27/07/1994, which corresponds to the lowest groundwater level over the simulation period.

The location of the points is shown in **Figure 15.** The points were selected to provide a representative coverage in the area where reduced groundwater levels due to pumping at Te Raite Station could induce saline intrusion at or near the coast. It was determined that a 500 m spacing provided adequate coverage to make this determination.

Figure 15. Location of the selected points for lateral migration analysis (see A3 attachment at rear).

The hydraulic heads in the deep shellbed at the selected time step (27/07/1994) in both Scenario 2 and Scenario 3 are on average approximately 1.4 m greater than the pressure required to maintain the saline interface below the shellbed aquifer at the selected points.

The greatest difference between the two scenarios is predicted to occur at sampling point 23, adjacent to the proposed Te Raite Station bores, with similar drawdown predicted at points 22 and 24. The predicted groundwater level at these locations is 2 to 4 m above the head required to prevent saline intrusion at the point of minimum groundwater elevation over the 58-year simulation. Based on this result the predicted drawdown resulting from proposed extraction at Te Raite Station is not a risk to induce saline intrusion along the east coast (**Figure 16**).

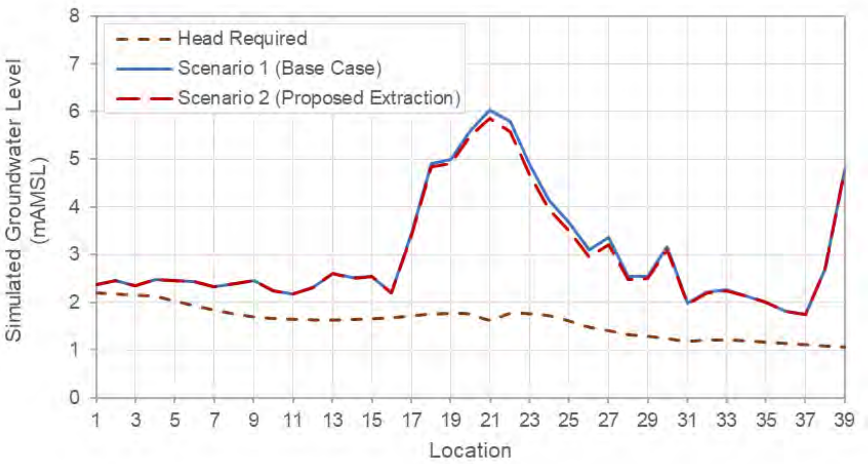


Figure 16. Simulated minimum shell bed groundwater level at select points along east coast relative to head required to prevent saline intrusion.

Simulated drawdown was not predicted to extend to the west coast. This is evident in **Figure 17** which shows that predicted groundwater levels are the same with proposed extraction as with the Base Case simulation.

Sampling locations 65, 73, and 79, had simulated groundwater elevation below the head required to prevent saline intrusion in the Calibrated Model simulation. This indicates that localised saline intrusion may occur in this location under natural conditions when groundwater levels are low.

The Calibrated Model shows that these locations are not impacted by pumping from bores at Te Raite Station or groundwater extraction in the Motutangi area. The areas impacted are used for forestry and are not susceptible to impacts from periodic saline intrusion.

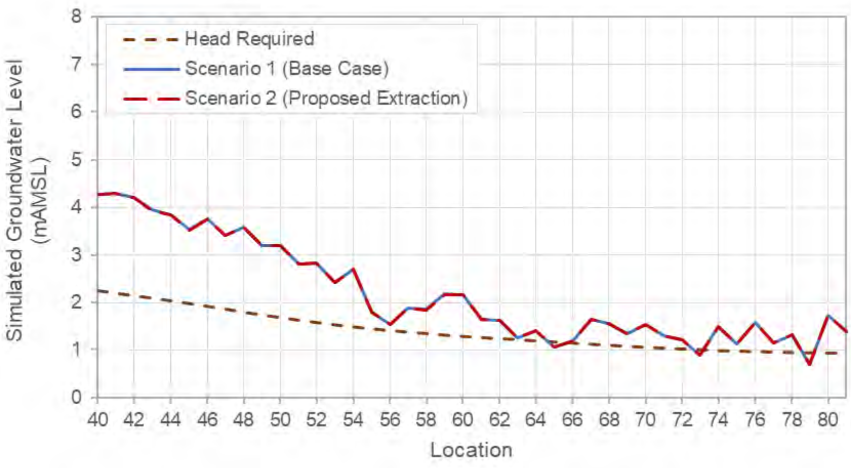


Figure 17. Simulated minimum shell bed groundwater level at select points along west coast relative to head required to prevent saline intrusion.

It can be concluded that saltwater inland migration along the basement contact is unlikely to increase in response to the proposed groundwater extraction at Te Raite Station and the predicted impact on any wells that are currently operating is less than minor.

7.5 Land Settlement

Land subsidence due to groundwater extraction was calculated using the Bouwer (1977)[1] equation:

$$S_u = (P_{i2} - P_{i1})\frac{Z_1}{E}$$

where S_u = vertical subsidence (m)
$P_{i2} - P_{i1}$ = Increase in intergranular pressure due to drop of the water table
Z_1 = layer thickness
E = modulus of elasticity of the soil

The following characteristics were assumed for the aquifer:

- Porosity = 0.30
- Unsaturated water content = 0.08
- Specific weight of aquifer material (consolidated silty sand) = 20 kN/m^3 (Silty sand density ranges between 1,410 kg/m^3 and 2,275 kg/m^3 (http://structx.com/Soil_Properties_002.html), corresponding to specific weight of 14 kN/m^3 and 22 kN/m^3)

- Specific weight of water = 9.81 kN/m^3.

The deep shellbed material is denser and less compressible compared to the mixture of sand, silt and peat overlying above. The subsidence analysis was conducted using three separate layers representing the conceptual hydrogeological units of the sub-surface environment, and the parameter values used were based on Bouwer (1977).

The potential maximum ground settlement was estimated at the proposed Te Raite bores based on the maximum simulated drawdown in the Base Case Scenario, as summarised in **Section 0**. The results are presented in **Table 9**.

Predicted settlement at the 10 bores ranges from 0.02 to 0.04 m with the maximum settlement predicted to occur at Pivot B. In a rural setting, settlement effects of this magnitude are less than minor for the following reasons:

- there is no sensitive urban infrastructure such as water or wastewater mains or high-rise buildings to rupture or crack; and
- the changes in land surface due to farm machinery (e.g. rotary hoeing) would likely mask impacts of this magnitude (<0.1 m) if materialised.

Table 9. Predicted subsidence at proposed Te Raite Station bores

Bore ID	Subsidence (m)
Pivot A-centre	0.036
Pivot A-N	0.042
Pivot A-S	0.034
Pivot B	0.044
Pivot C-E	0.040
Pivot C-W	0.039
Salvation road	0.038
Waihopo-Kimberly	0.020
Waihopo-Trig	0.015
Cropping Avocados	0.043

8. Conclusion

To address hydrogeological aspects of a RMA s92 request made by Northland Regional Council in the matter of a proposed groundwater take at Te Raite Station, Williamson Water & Land Advisory (WWLA) has carried out two aquifer pumping tests on the property along with associated data analysis. In addition, a numerical groundwater model was developed and calibrated to simulate conditions in the Te Raite Station area, using in part, information derived from the pumping tests and from other recently completed models.

The groundwater flow model was used to determine the potential impact from the proposed groundwater abstraction on the regional aquifer system and the hydrological condition of relevant surface water. In particular, the model was used to inform an assessment of effects with regard to seasonal pumping on the aquifer system water budget, aquifer groundwater levels, surface water drain flows, saline intrusion, and land settlement.

A baseline model was calibrated to current conditions. This model was used to develop a Base Case Scenario where groundwater takes in the Motutangi area that are currently under consideration are included, and a Proposed Extraction Scenario where the proposed groundwater takes at Te Raite Station were also included. An alternate version of these scenarios was also run with reduced connection between the surface and the deep shell bed aquifer to test model sensitivity to variable conditions as may occur in areas where hard pans layers are present in the relatively shallow subsurface.

Water Budget

The proposed groundwater extraction, 10,400 m³/day accounts for 4.2% of average daily recharge in the Te Raite Station area over the simulation period, or 8.0% of average daily recharge when combined with all other consented groundwater takes in the area.

At the time of peak irrigation, total groundwater abstraction under Base Case conditions accounts for 3.3% of the groundwater budget in the area around Te Raite Station, increasing to 6.8% of the water budget with the proposed groundwater takes, an increase of 3.5%. The increase in groundwater abstraction is balanced by change in aquifer storage, decreasing coastal discharges and a slight reduction in drain discharges.

Drain Flows

The impact of proposed groundwater extraction at Te Raite Station has potential to lower groundwater levels in the shallow aquifer and intern reduce discharge to drains and streams. However, the simulated impact on drain flows with a leaky aquifer model configuration (conservative scenario) was negligible, with the predicted impact on annual low flows being a reduction of approximately 2%.

Drawdown from Pumping

The proposed abstraction has potential to change groundwater levels in both the deep and the shallow aquifer, particularly during dry times, but the aquifers respond quickly to wetter climate following the irrigation season.

Predicted drawdown at existing bores was primarily governed by their distance to the proposed groundwater takes. At the driest time (27/07/1997), the maximum simulated drawdown in the deep aquifer at a neighbouring bore was 0.65 m with the new groundwater takes applied to the simulation and the majority of bores were predicted to see drawdown of less than 0.1 m.

With Scenario 3 (low leakage model configuration) the maximum drawdown predicted for a bore on a neighbouring property was 1.9 m while the majority of nearby bore were expected to see drawdown of less than 0.35 m.

In the shallow aquifer the drawdown at neighbouring bores in the Bae Case Scenario was predicted to be a maximum of 0.5 m in one case and less than 0.1 m for the majority of bores. No drawdown was predicted in the shallow aquifer in the Scenario 3 due to the disconnection between the shallow aquifer and the deeper pumping layer.

Saline Interface

Groundwater depressurisation at the coast margin has the potential to induce the landward migration of saline groundwater. The model was used to assess potential saline intrusion by the process of lateral migration of the saline/fresh water interface. Simulation results showed that there is not likely to be any saline intrusion along the East Coast adjacent to Te Raite Station. Along the West Coast there may be isolated areas where natural saline intrusion occurs, but this is well out of the area effected by drawdown from the proposed groundwater extraction at Te

Raite Station and therefore the pumping had no impact on the salt water interface along the West Coast.

Land Settlement

Potential land subsidence as a result of proposed groundwater extraction at Te Raite Station was assessed based on predicted drawdown at the proposed pumping bores. Results indicated that settlement was likely to be less than 0.05 m, a negligible value that would not impact anything in the rural area where the settlement would likely occur.

9. References

Bouwer, H., 1977. Land Subsidence and Cracking Due to Ground-Water Depletion. Ground Water 15, 358–364. doi:10.1111/j.1745-6584.1977.tb03180.

HydroGeo Solutions, 2000. Aupouri Aquifer Sustainable Yield Groundwater Modelling Study. Consultancy report prepared for Northland Regional Council.

Lincoln Agritech, 2015. Aupouri Aquifer Review. Consultancy report prepared for Northland Regional Council.

SKM, 2007a. King Avocado Orchard Groundwater Take Consent Application (AEE Final). Consultancy report prepared for King Avocado Limited.

SKM, 2007b. Awanui Artesian Aquifer Numerical Modelling. Consultancy report prepared for Northland Regional Council.

SKM, 2010. Sweetwater Station Water Take Hearing - Response to Section 92 request. Consultancy report prepared for Landcorp Farming Limited and Te Runanga O Te Rarawa.

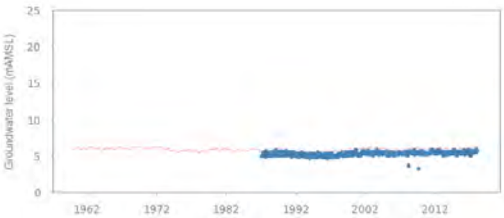
Williamson Water Advisory (2017). Motutangi-Waiharara Groundwater Model Factual Technical Report. Consultancy report prepared for Motutangi-Waiharara Water User Group.

Williamson Water Advisory (2018a). Waiharara-Paparore Groundwater Model Factual Technical Report. Consultancy Report prepared for Valic NZ LTD, Tiri Avocados LTD, and Wataview Orchard.

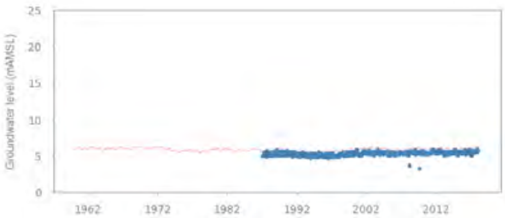
Williamson Water Advisory (2018b). Irrigation Water Take Consent. Resource Consent and Assessment of Environmental Effects. Consultancy Report prepared for NE Evans Trust.

Appendix A. Calibrated Model Hydrographs.

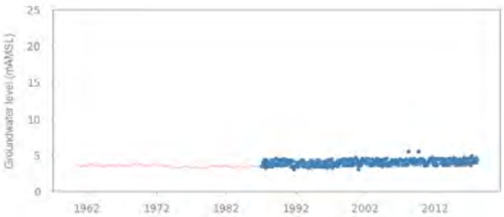
Waterfront Piezometer 1



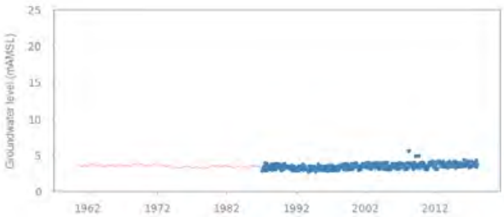
Waterfront Piezometer 2



Waterfront Piezometer 3



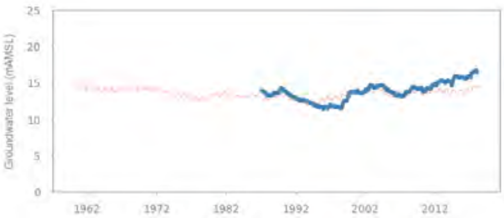
Waterfront Piezometer 4



Hukatere Piezometer 1

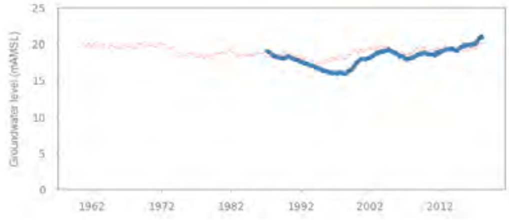
Hukatere Piezometer 2

Hukatere Piezometer 3

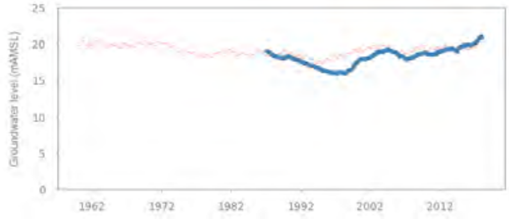


Wagener

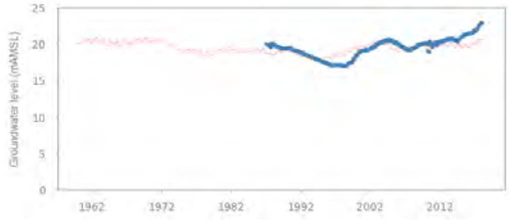
Forest Piezometer 1



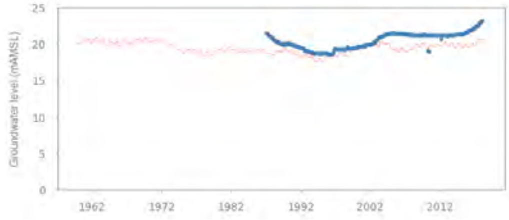
Forest Piezometer 2



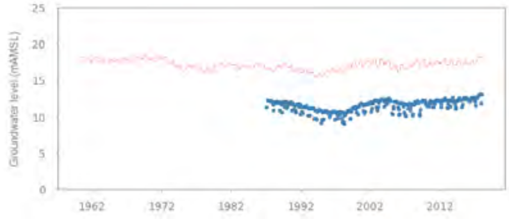
Forest Piezometer 3



Forest Piezometer 4

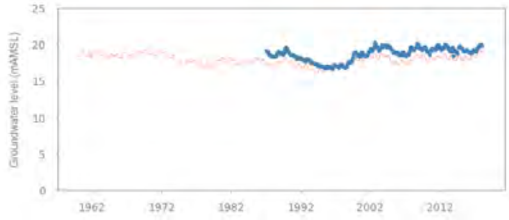


Browne Piezometer 1

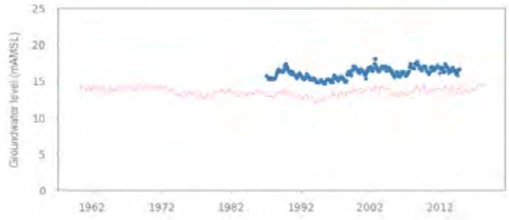


Browne Piezometer 2

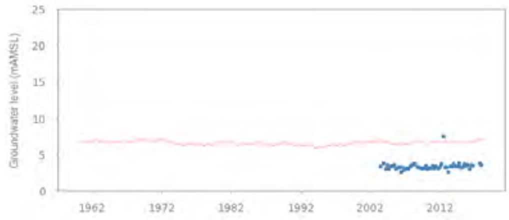
Browne Piezometer 3



Burnage Piezometer 4



Fishing Club



Appendix B. Consented Groundwater Users

Table B1 lists all current and expired consents and proposed groundwater takes included in the Aupouri Aquifer Model.

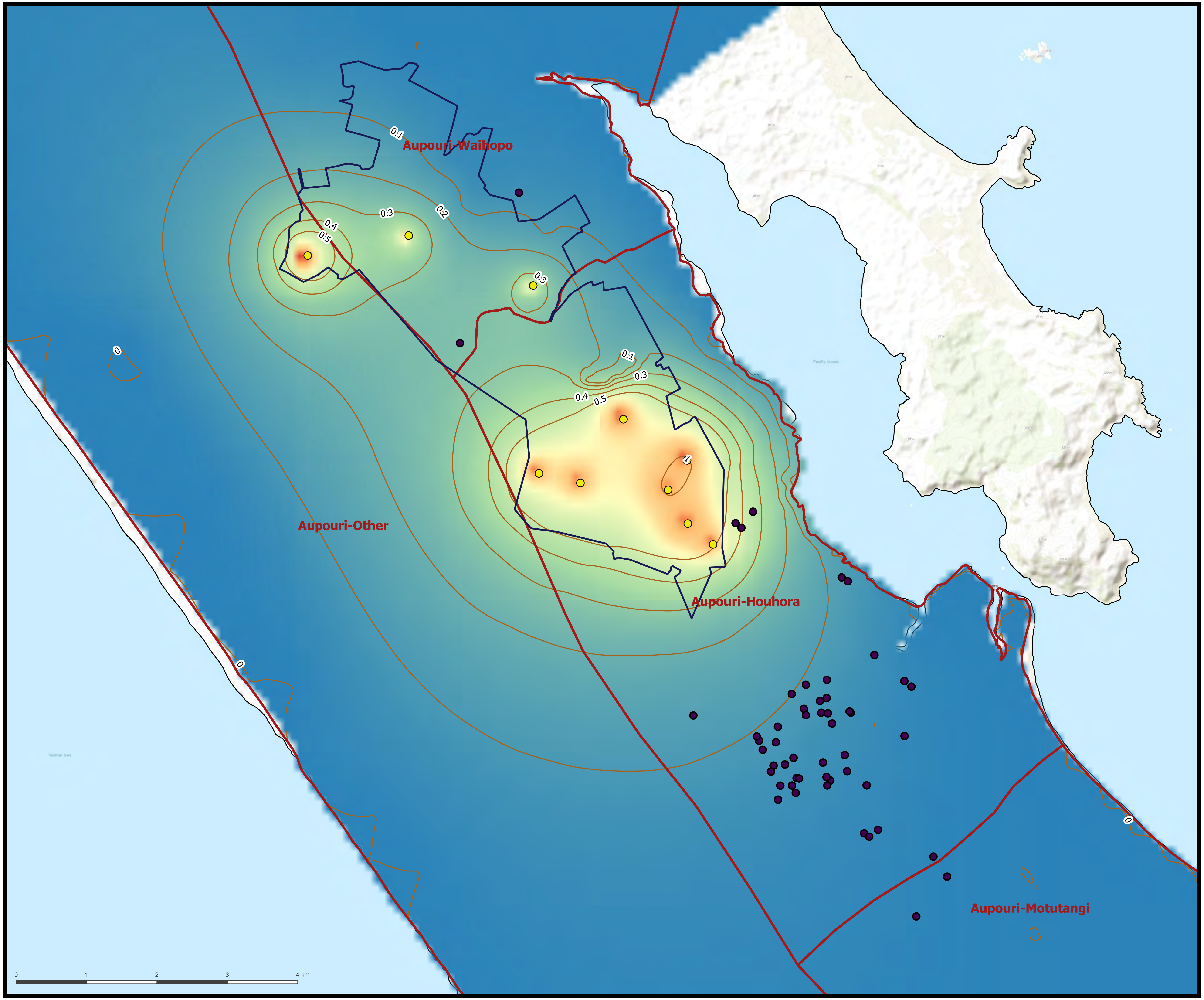
Table B1. Groundwater takes included in the Aupouri Aquifer Model.

Bore Owner	Reference ID	Annual Allocation (m^3/year)	Status	Notes
Alligator Pear Partnership	AUT.026611.01.01	49,752	Current	
Avocado Investments Ltd	AUT.002459.01.03	18,600	Current	
B C Smith	AUT.009808.01.02	51,200	Current	
Bell	AUT.038402.01.01	35,000	Current	
Broadhurst	AUT.038339.01.01	50,000	Current	
DC & MA Olsen	AUT.004571.01.03	45,000	Current	
De Bede	AUT.038379.01.01	70,000	Current	
DG & HA Inglis	AUT.003968.01.03	25,000	Current	
E J Williams	AUT.020726.02.02	33,000	Current	
EJ Wagener	AUT.008586.02.01	30,000	Current	
Far North Avos Limited	AUT.028511.01.02	32,000	Current	
Far North Farms Ltd	AUT.004564.01.04	80,000	Current	
Far North Holiday Park-Non irrigation		10,920	Current	
FNDC: GW take for Kaitaia		1,460,000	Current	
Fullam GW take	AUT.037292.01.01	14,000	Current	
G J & D J Price	AUT.029091.01.01	7,500	Current	
Hayward	AUT.004350.01.03	24,000	Current	
Hine & Associates current	AUT.003726.01.02	74,400	Current	
Honeytree Farms Ltd	AUT.020727.02.02	33,000	Current	
I M Fulton-1	AUT.029109.01.01	20,000	Current	
I M Fulton-2	AUT.016914.02.01	40,000	Current	
IJ & BM Broadhurst	AUT.017559.02.01	105,000	Current	
J A Trussler		148,800	Current	
J Jones	AUT.028476.01.01	60,000	Current	
J P Broadhurst	AUT.029171.01.01	24,000	Current	
Javo	AUT.003788.01.03	18,600	Current	
JB & GM Clark	AUT.008177.01.02	24,000	Current	
JR Avocados Ltd	AUT.028834.01.01	20,000	Current	
KJ & FG King : GW for Awanui Straight		278,262	Current	
KSL Ltd	AUT.008647.01.03	52,800	Current	
L & P Trust	AUT.003768.01.04	6,000	Current	

Bore Owner	Reference ID	Annual Allocation (m^3/year)	Status	Notes
Landcorp Farming Limited		200,000	Current	
LL & DF Rasmussen	AUT.002890.01.02	43,200	Current	
Longbeach Trust	AUT.003883.01.03	26,400	Current	
Luca Vista	AUT.020533.02.01	24,200	Current	
Matalaka Trust	AUT.007108.01.02	16,740	Current	
McQuarrie	AUT.038075.01.01	12,000	Current	
Millpara1	AUT.014520.02.01	91,960	Current	
Millpara2	AUT.014520.01.02	91,960	Current	
NG Rouse	AUT.003798.01.04	16,500	Current	
Ongare Trust-1	AUT.012472.01.01	17,856	Current	
Ongare Trust-2	AUT.008203.01.02	37,200	Current	
RA & LS Huddart	AUT.008589.01.02	11,040	Current	
Rangaunu	AUT.003580.01.03	35,000	Current	
RB Freeman-1	AUT.003888.01.02	34,560	Current	
RB Freeman-2	AUT.003372.01.02	25,920	Current	
RF & MH Barber-Tudorwood Orchard		23,760	Current	
S127 GW take	AUT.007735.01.04	66,000	Current	
Shirttail Orchards	AUT.008340.01.03	158,520	Current	
Soltysik-Freeman Family Trust	AUT.036910.01.02	135,000	Current	
Stanisich-1	AUT.027391.01.01	120,000	Current	
Stanisich-2	AUT.036868.01.01	60,000	Current	
Subritzky	AUT.003964.01.03	67,106	Current	
Sweetwater PB2		1,158,500	Current	
Sweetwater PB6		1,158,500	Current	
Te Urungi O Ngati Kuri LTD		18,250	Current	
Tomo Orchard Ltd	AUT.003841.01.02	14,800	Current	
Trebcombe Limited-1	AUT.008605.01.02	52,080	Current	
Trebcombe Limited-2	AUT.003527.01.02	26,040	Current	
Valic-1	AUT.017045.01.02	186,000	Current	
Valic-2	AUT.017045.01.02	186,000	Current	
Valic-3	AUT.017045.01.02	186,000	Current	
Wagener Houhora Heads Properties Ltd	AUT.004543.01.03	45,000	Current	
Whalers Rd Houhora	AUT.037274.01.01	74,500	Current	
Whispering Pines Ltd	AUT.023557.01.02	46,000	Current	
B C Aitken	AUT.009808.01.01	45,000	Expired	
Beedy J	AUT.007735.01.01	120,000	Expired	

Bore Owner	Reference ID	Annual Allocation (m³/year)	Status	Notes
Colville WF	AUT.003527.01.01	30,000	Expired	
Courtenay PA-1	AUT.003513.01.01	3,750	Expired	
Courtenay PA-2	AUT.007115.01.01	3,750	Expired	
Doody M P	AUT.002839.01.01	60,000	Expired	
Freeman RB	AUT.003888.01.01	25,500	Expired	
Freeman RB	AUT.003372.01.01	25,500	Expired	
Gunn GA & DK	AUT.008203.01.01	37,500	Expired	
Hickey JB	AUT.003870.01.01	18,750	Expired	
Hine & Associates exp	AUT.003726.01.01	90,000	Expired	
Kwan Holdings LTD	AUT.008306.01.01	40,500	Expired	
Lo-Giacco PL & R	AUT.007524.01.01	10,500	Expired	
McChesney RJW	AUT.004320.01.01	6,000	Expired	
Northern Experience Limited	AUT.003883.01.02	18,750	Expired	
Rasmussen LL & DF	AUT.002890.01.01	24,000	Expired	
RJ & D Bryant-Jones	AUT.003841.01.01	13,500	Expired	
Ronald AJ & JM	AUT.003883.01.01	18,750	Expired	
Sole & Colville	AUT.008340.01.01	90,000	Expired	
Subritzky	AUT.003964.01.01	18,750	Expired	
Wagener E J	AUT.008586.01.01	45,000	Expired	
Wagener Holdings LTD-1	AUT.004543.01.01	9,000	Expired	
Wagener Holdings LTD-2	AUT.004543.01.02	30,000	Expired	
Wallace RC & K-1	AUT.004903.01.01	30,000	Expired	
Wallace RC & K-2	AUT.008605.01.01	24,000	Expired	
Wedding PH & MB	AUT.008647.01.01	14,400	Expired	
Brien Lamb	APP.039381.01.01	14,900	proposed	MWWUG
Candy Corn Ltd	APP.039332.01.01	78,400	proposed	MWWUG
Cypress Hills Ltd	APP.038591.01.01	35,280	proposed	MWWUG
Elbury Holdings-King	APP.038454.01.01	113,700	proposed	MWWUG
GT & MT Covich	APP.038410.01.01	223,500	proposed	MWWUG
Hewitt	APP.038650.01.01	39,200	proposed	MWWUG
Holloway	APP.038380.01.01	14,900	proposed	MWWUG
Honeytree	APP.038471.01.01	346,425	proposed	MWWUG
KB & SD Shine	APP.038328.01.01	39,200	proposed	MWWUG
Kelvin Thomas	APP.039244.01.01	59,600	proposed	MWWUG
Mapua Avocados	APP.038610.01.01	418,000	proposed	MWWUG
Matijevich	APP.038420.01.01	193,700	proposed	MWWUG
McLarnon-Ongare trust	APP.039345.01.01	23,520	proposed	MWWUG
Ngai Takakto	APP.038513.01.01	193,700	proposed	MWWUG

Bore Owner	Reference ID	Annual Allocation (m^3/year)	Status	Notes
Stanisich-proposed	APP.027391.01.02	64,070	proposed	MWWUG
Thompson	APP.038589.01.01	35,280	proposed	MWWUG
Valadares	APP.038732.01.01	22,350	proposed	MWWUG
Cropping Avocados		175,000	proposed	Te Raite Station
Pivot A-centre		100,000	proposed	Te Raite Station
Pivot A-N		100,000	proposed	Te Raite Station
Pivot A-S		100,000	proposed	Te Raite Station
Pivot B		180,000	proposed	Te Raite Station
Pivot C-E		110,000	proposed	Te Raite Station
Pivot C-W		110,000	proposed	Te Raite Station
Salvation Rd		175,000	proposed	Te Raite Station
Waihopo-Kimberly		60,000	proposed	Te Raite Station
Waihopo-Trig		60,000	proposed	Te Raite Station
Tiri-1		290,625	proposed	Waiharara-Paparore
Tiri-2		290,625	proposed	Waiharara-Paparore
Valic-4		173,700	proposed	Waiharara-Paparore
Wataview		33,750	proposed	Waiharara-Paparore



Map Title:
Simulated drawdown in shallow aquifer (scenario 2)

Project:
Te Raite Station Groundwater Investigations

Client:
WSP-Opus

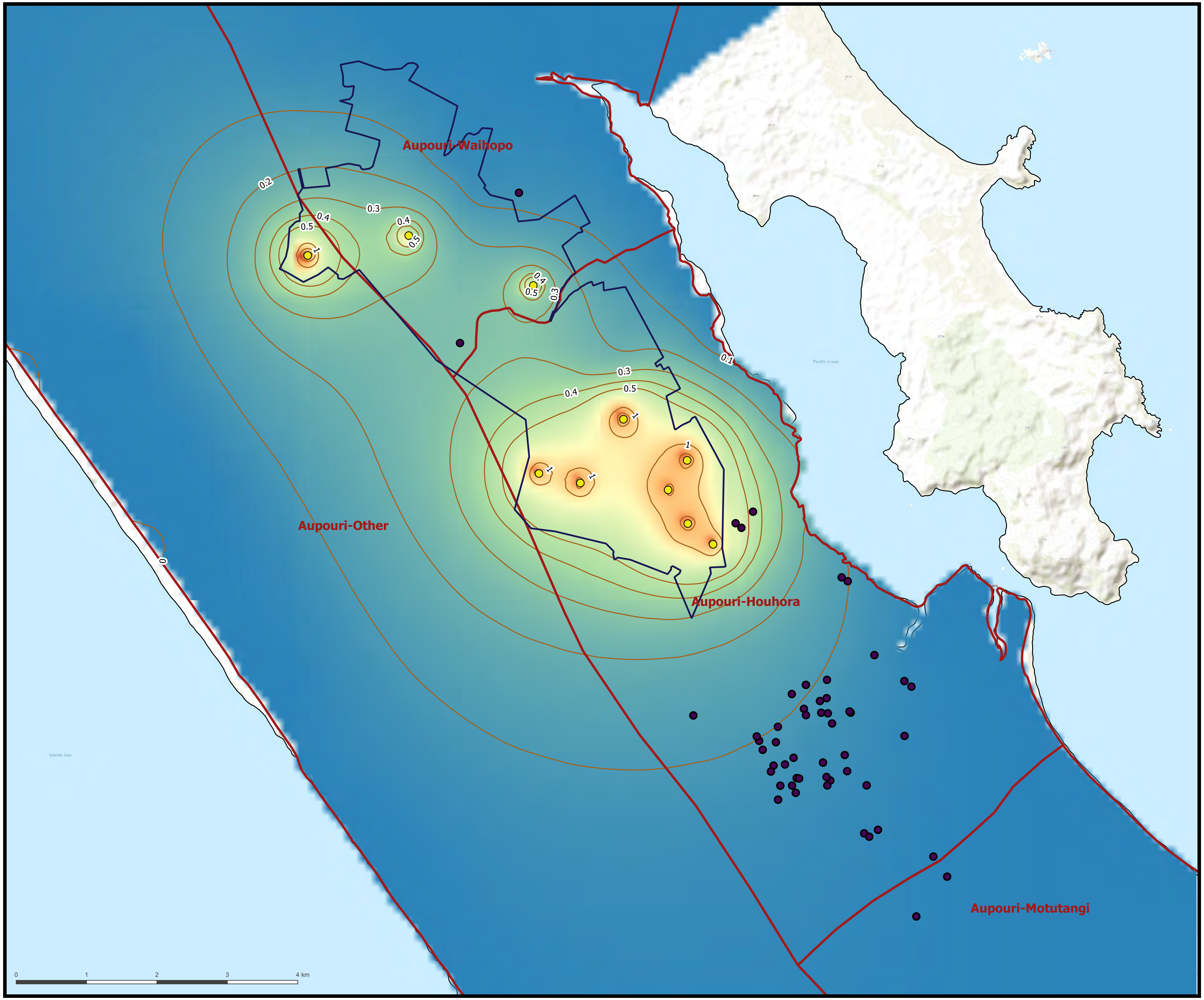
New groundwater take
Consented bores
Drawdown contour (m)
Groundwater Allocation Zone
Te Raite Station boundary

Drawdown (m)
0
0.2
0.4
0.6
0.8
1
1.5
2
2.5

Data Provenance
Topographic Data derived from Land Information New Zealand
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008.
Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved

QGIS by:
WWLA

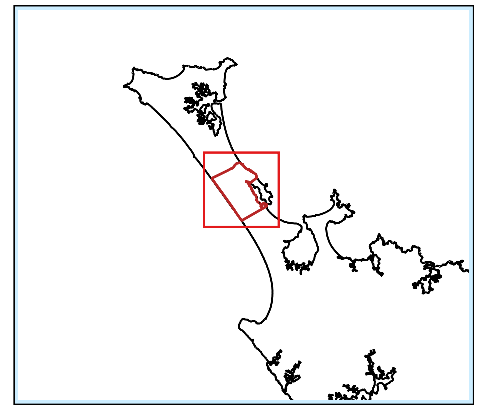
Figure 12.



Map Title:
Simulated drawdown in deep aquifer (scenario 2)

Project:
Te Raite Station Groundwater Investigations

Client:
WSP-Opus

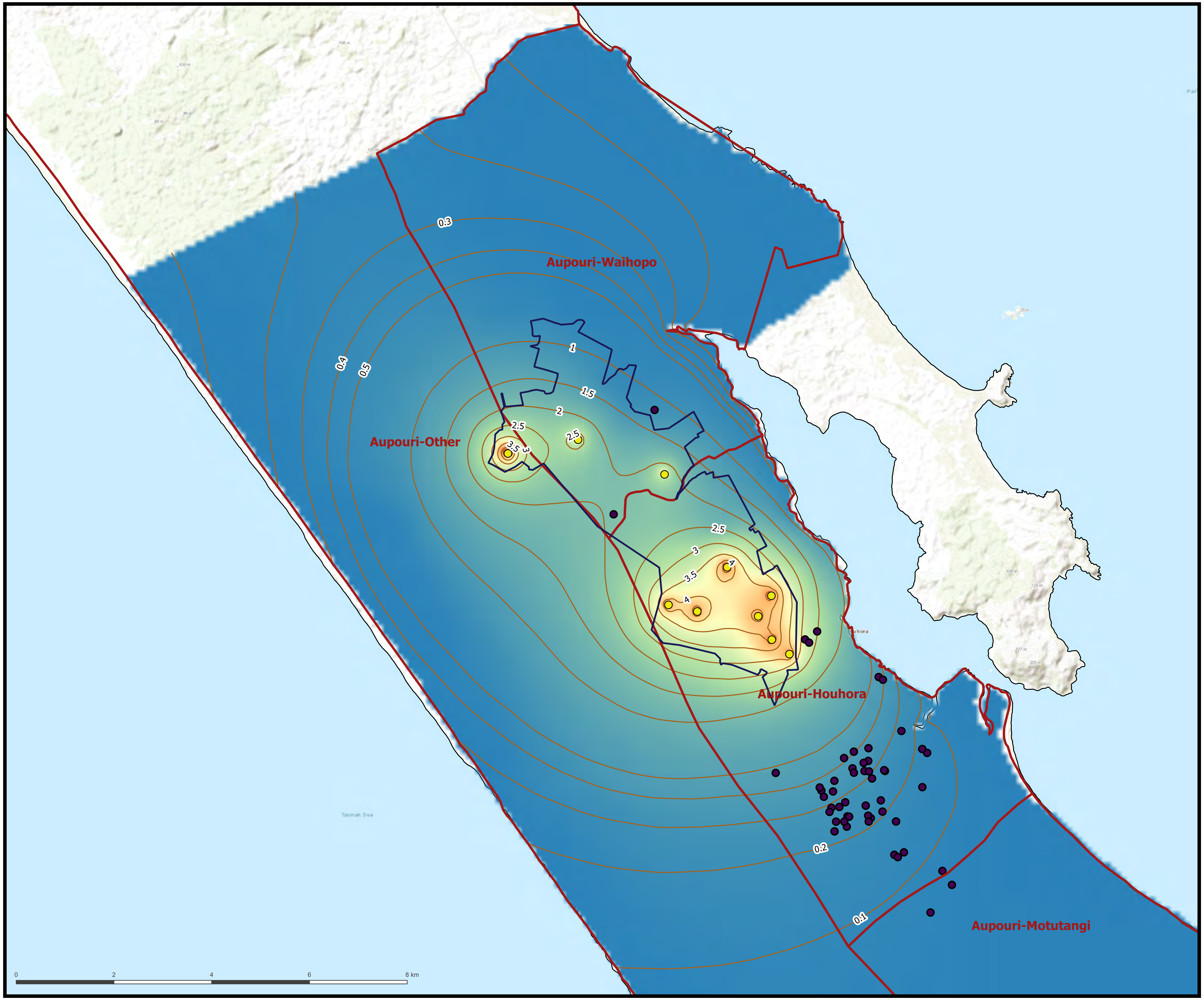


New groundwater take
Consented bores
Drawdown contour (m)
Groundwater allocation zone
Te Raite Station boundary

Drawdown (m)
0
0.2
0.4
0.6
0.8
1
1.5
2
2.5

QGIS by:
WWLA

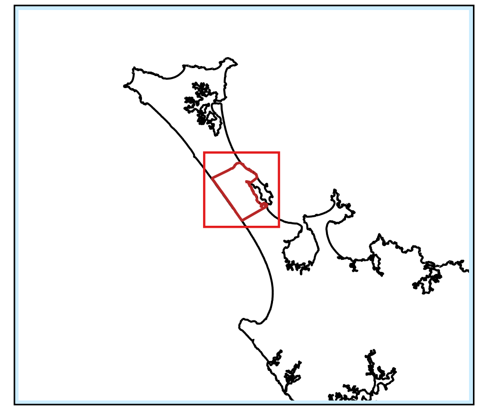
Figure 10.



Map Title:
Simulated drawdown in deep aquifer (scenario 3)

Project:
Te Raite Station Groundwater Investigations

Client:
WSP-Opus



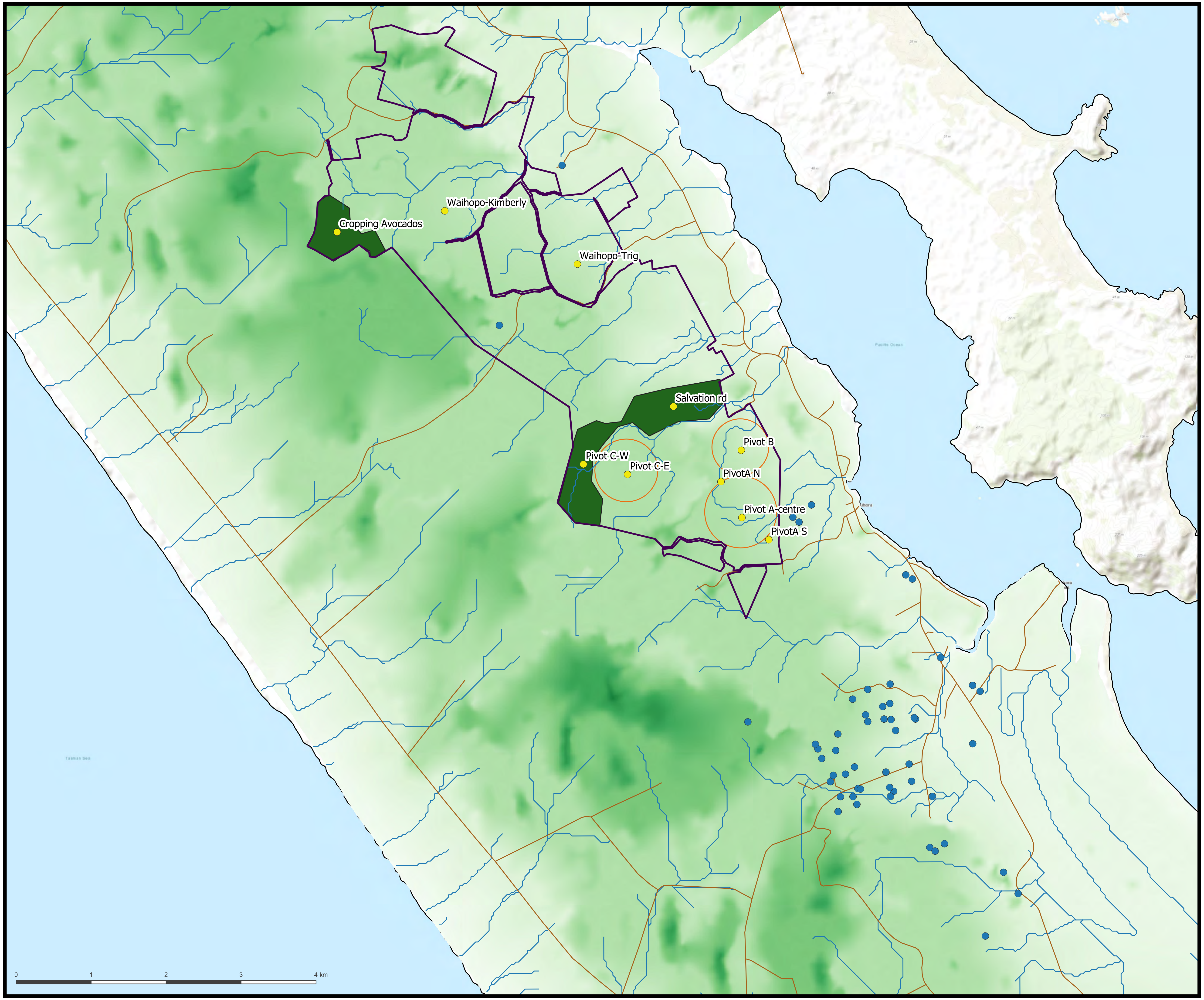
New groundwater take
Consented bores
Drawdown contour (m)
Groundwater Allocation Zone
Te Raite Station boundary

Drawdown (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Data Provenance
Topographic Data derived from Land Information New Zealand
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008. Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved

QGIS by:

Figure 11.



Map Title:

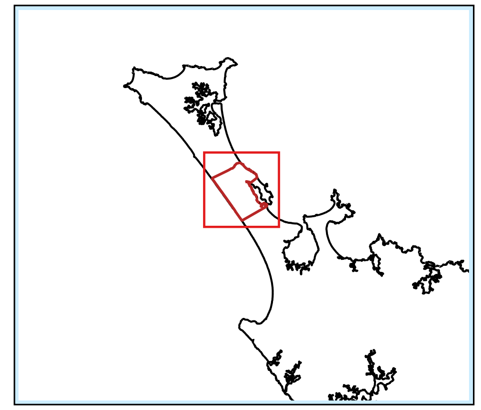
Te Raite Station groundwater investigation area detail

Project:

Te Raite Station Groundwater Investigations

Client:

WSP-Opus



Te Raite Station

Model boundary

- **New groundwater take**
- **Existing groundwater take**
- **Horticulture area**
- **Centre pivot irrigation areas**
- **Drains**
- **Roads**

Topography (mAMSL)

- **0**
- **20**
- **40**
- **60**
- **80**
- **100**
- **120**

Data Provenance

Topographic Data derived from Land Information New Zealand

Crown Copyright Reserved

Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008. Contour Data Licensed under CC BY 3.0 NZ.

Crown Copyright Reserved

Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.

Crown Copyright Reserved

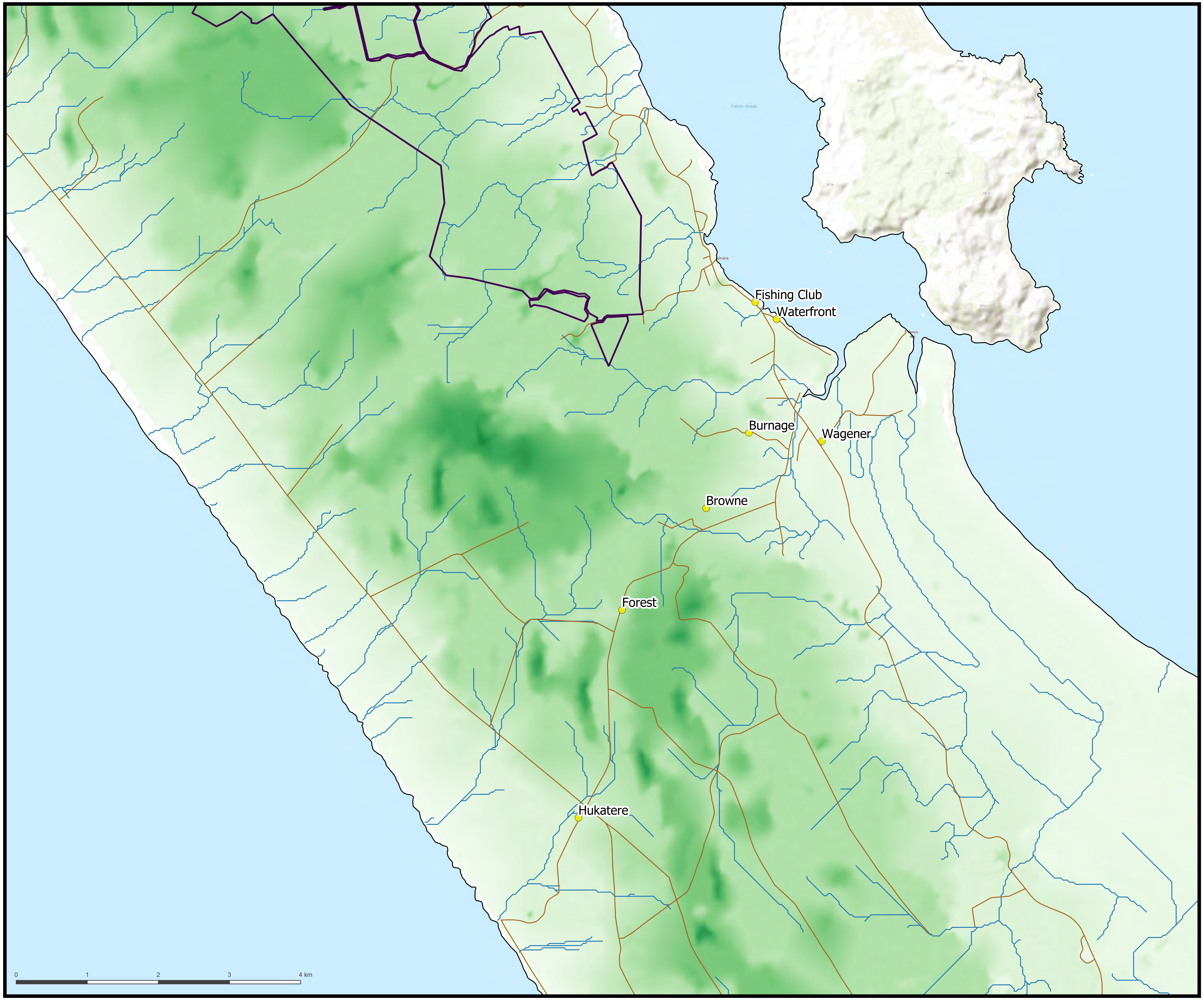
QGIS by:

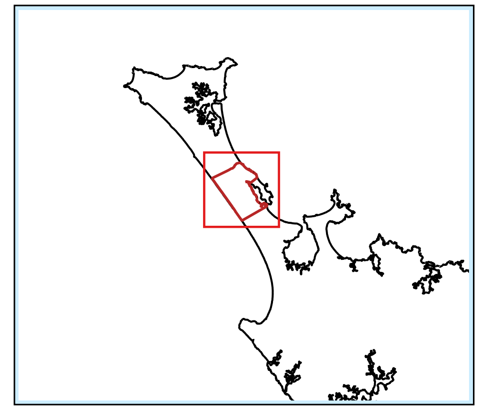
Figure 5.

Map Title:
NRC monitoring piezometer locations

Project:
Te Raite Station Groundwater Investigations

Client:
WSP-Opus

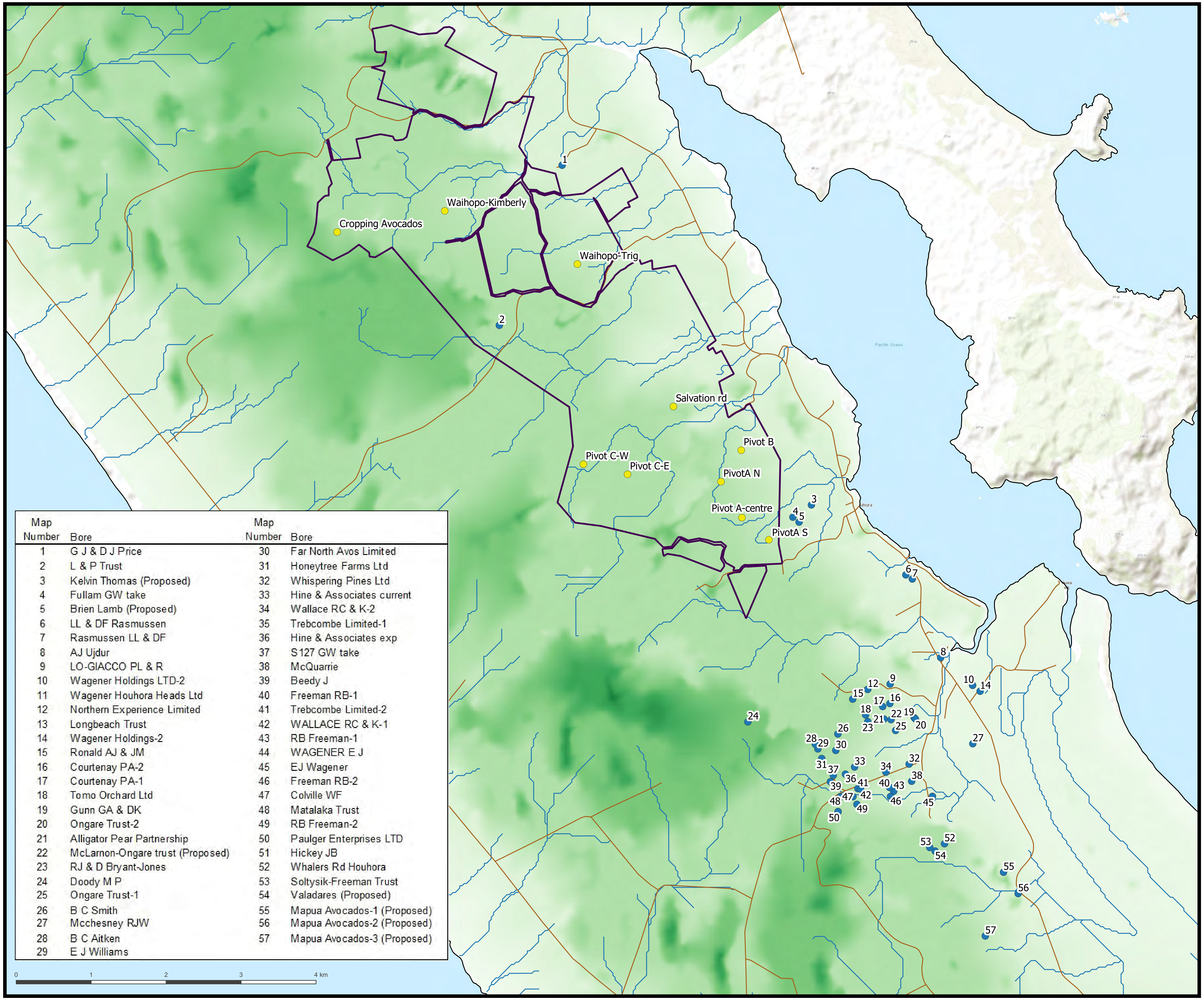




NRC Piezometers
Te Raite parcels
Drains
Roads
Model boundary
Topography (m AMSL)
0
20
40
60
80
100
120

QGIS by:

Figure 6.



Map Number	Bore	Map Number	Bore
1	G J & D J Price	30	Far North Avos Limited
2	L & P Trust	31	Honeytree Farms Ltd
3	Kelvin Thomas (Proposed)	32	Whispering Pines Ltd
4	Fullam GW take	33	Hine & Associates current
5	Brien Lamb (Proposed)	34	Wallace RC & K-2
6	LL & DF Rasmussen	35	Trebcombe Limited-1
7	Rasmussen LL & DF	36	Hine & Associates exp
8	AJ Ujdur	37	S127 GW take
9	LO-GIACCO PL & R	38	McQuarrie
10	Wagener Holdings LTD-2	39	Beedy J
11	Wagener Houhora Heads Ltd	40	Freeman RB-1
12	Northern Experience Limited	41	Trebcombe Limited-2
13	Longbeach Trust	42	WALLACE RC & K-1
14	Wagener Holdings-2	43	RB Freeman-1
15	Ronald AJ & JM	44	WAGENER E J
16	Courtenay PA-2	45	EJ Wagener
17	Courtenay PA-1	46	Freeman RB-2
18	Tomo Orchard Ltd	47	Colville WF
19	Gunn GA & DK	48	Matalaka Trust
20	Ongare Trust-2	49	RB Freeman-2
21	Alligator Pear Partnership	50	Paulger Enterprises LTD
22	McLarnon-Ongare trust (Proposed)	51	Hickey JB
23	RJ & D Bryant-Jones	52	Whalers Rd Houhora
24	Doody M P	53	Soltysik-Freeman Trust
25	Ongare Trust-1	54	Valadares (Proposed)
26	B C Smith	55	Mapua Avocados-1 (Proposed)
27	Mcchesney RJW	56	Mapua Avocados-2 (Proposed)
28	B C Aitken	57	Mapua Avocados-3 (Proposed)
29	E J Williams		

Map Title:
Neighboring bore locations

Project:
Te Raite Station Groundwater Investigations

Client:
WSP-Opus

Te Raite parcels
New groundwater take
Existing groundwater take
Drains
Roads
Topography (m AMSL)
0
20
40
60
80
100
120

Data Provenance
Topographic Data derived from Land Information New Zealand
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008.
Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved

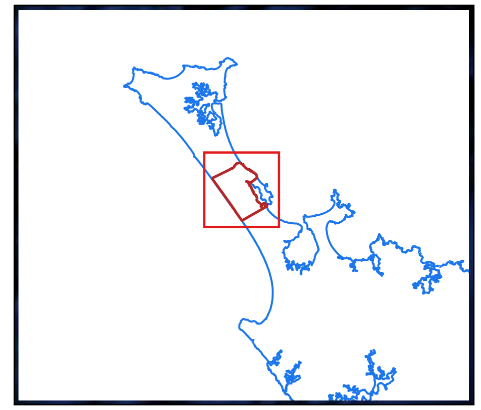
QGIS by:
WWLA

Figure 12.

Map Title:
Lateral intrusion analysis points

Project:
Te Raite Station Groundwater Investigations

Client:
WSP-Opus



Lateral intrusion analysis points
Te Raite Station
New groundwater take
Drains
Roads

Data Provenance
Topographic Data derived from Land Information New Zealand

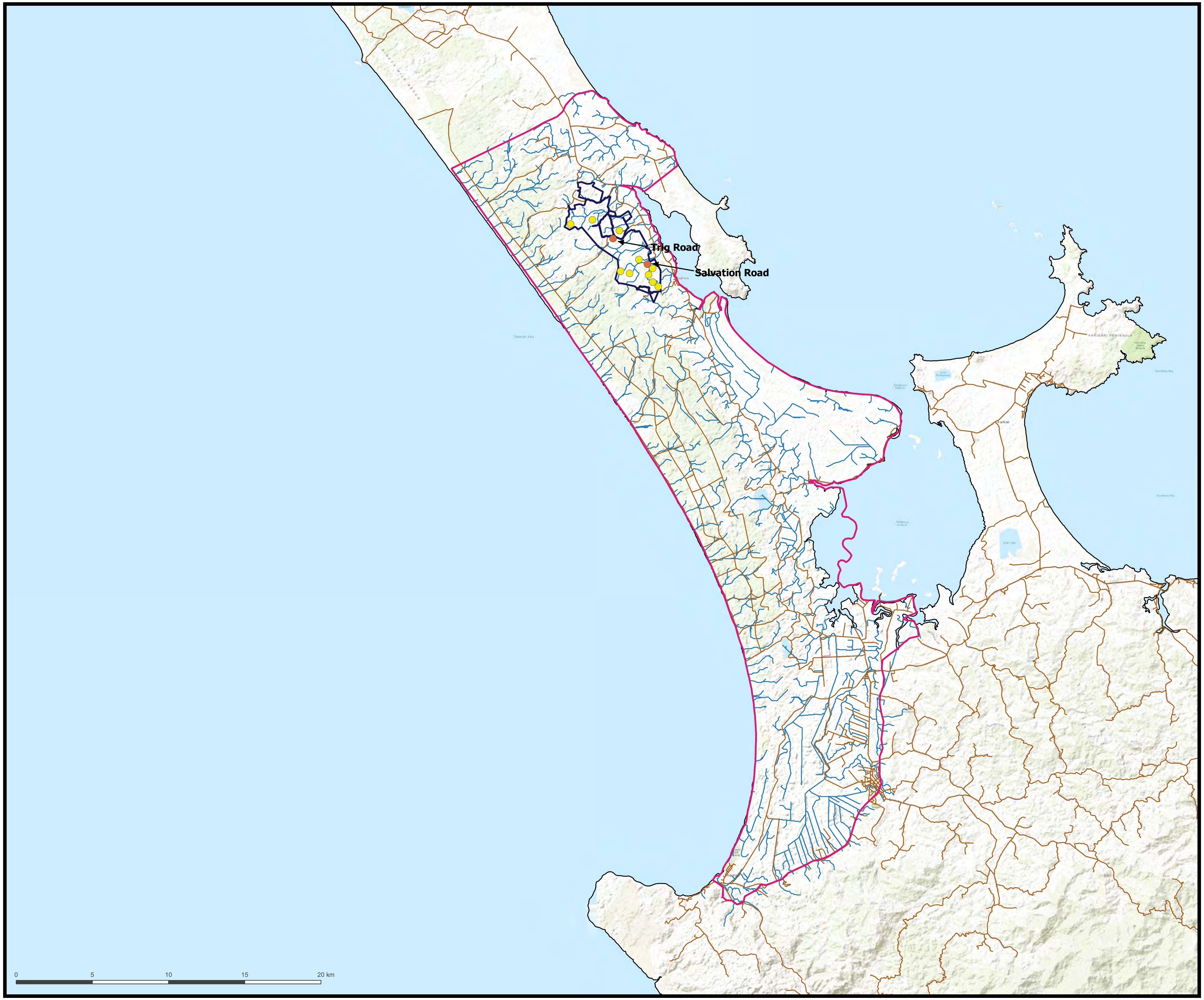
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008.
Contour Data Licensed under CC BY 3.0 NZ.

Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.

QGIS by:

WWLA

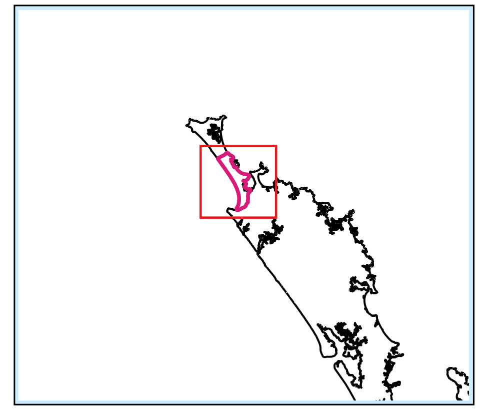
Figure 14.



Map Title:
Far North model area overview

Project:
Te Raite Station Groundwater Investigations

Client:
WSP-Opus



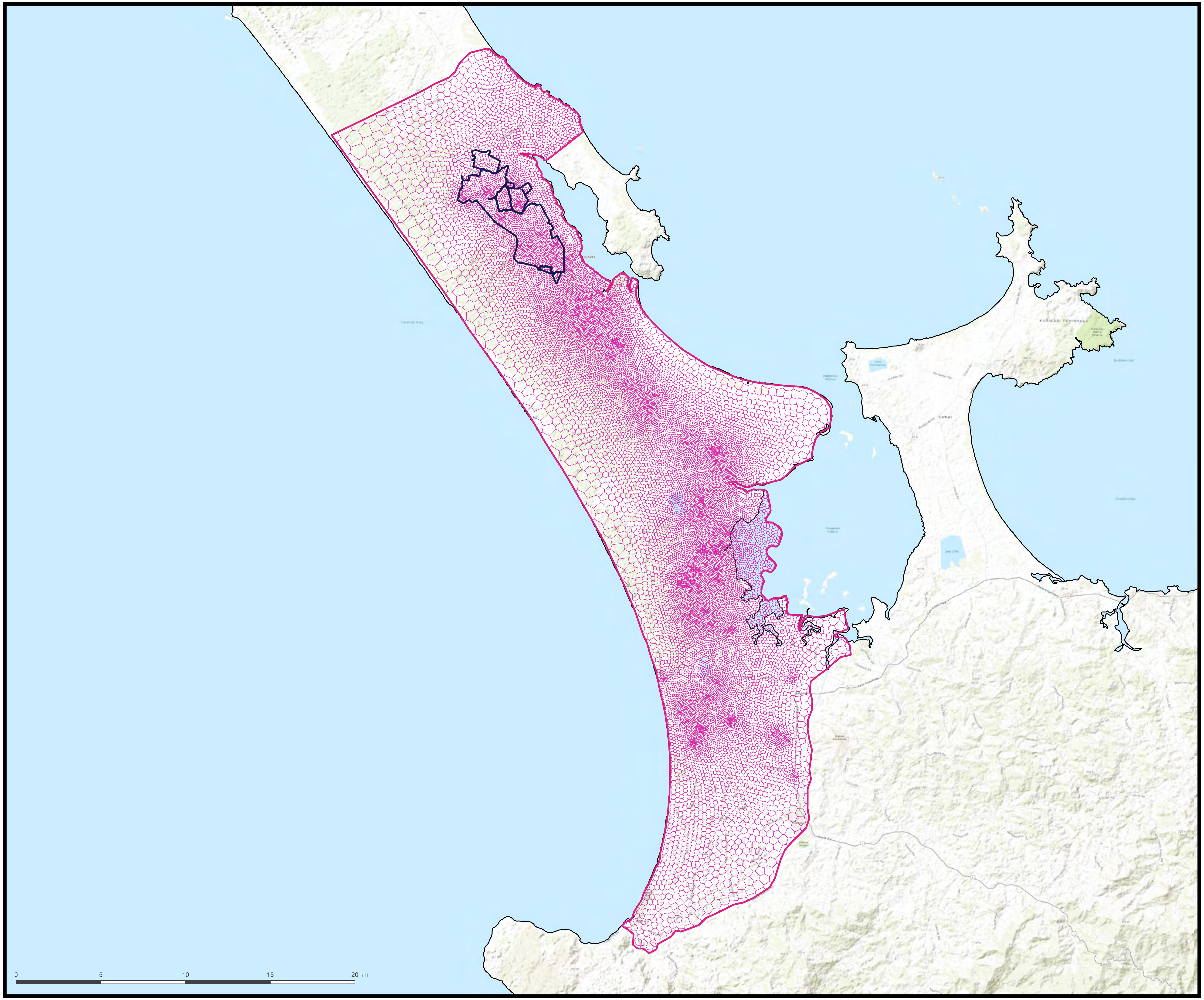
Te Raite parcels
Pump test locations
New groundwater take
Drains
Roads
Model boundary
Toopography (m AMSL)
0
20
40
60
80
100
120

Data Provenance
Topographic Data derived from Land Information New Zealand
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008.
Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved

QGIS by:

WWLA

Figure 1.



Map Title:

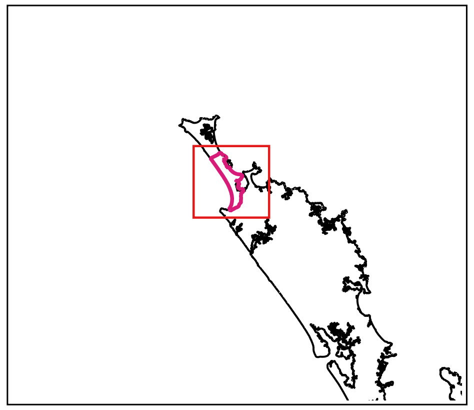
Aupori aquifer model grid

Project:

Te Raite Station Groundwater Investigations

Client:

WSP-Opus



Te Raite parcels

Model grid

Model Boundary

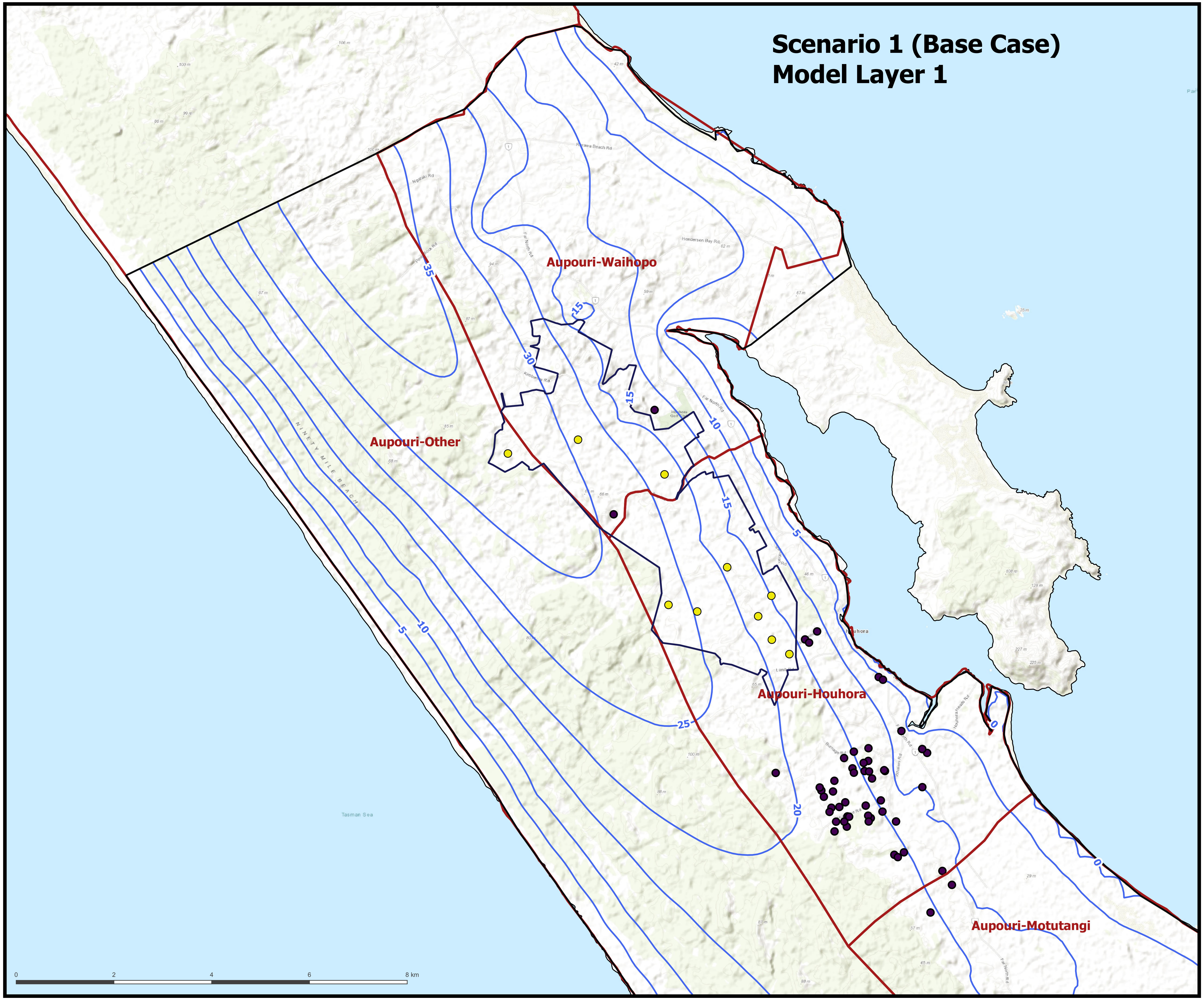
Data Provenance

Topographic Data derived from Land Information New Zealand
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008.
Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved

QGIS by:

WWLA

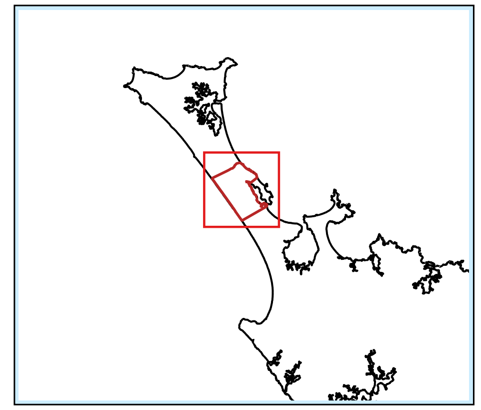
Figure 4.



Map Title:
Simulated groundwater level for end of 2010 irrigation season (mAMSL)

Project:
Te Raite Station Groundwater Investigations

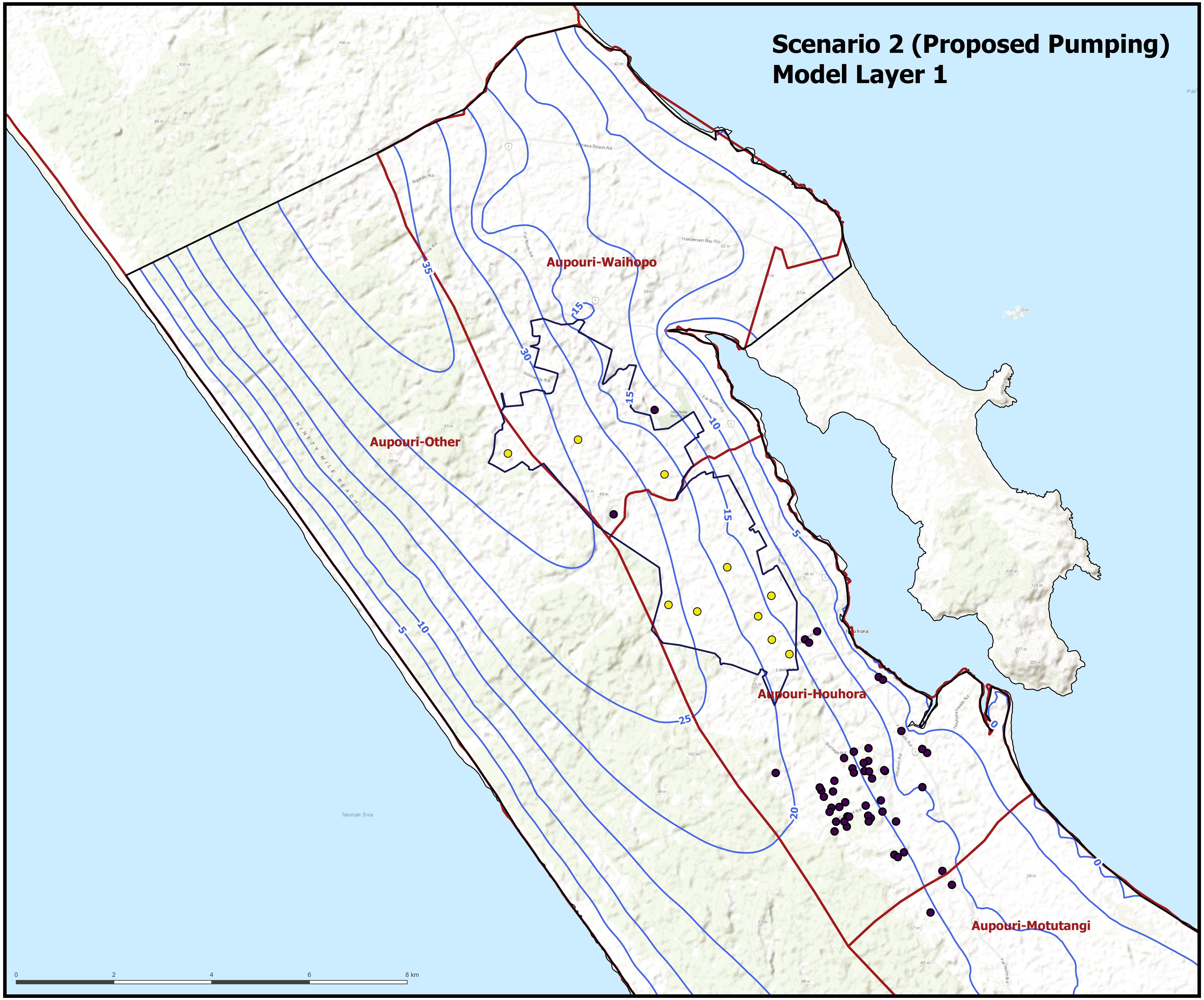
Client:
WSP-Opus



- **New groundwater take**
- **Consented bores**
- **Model Boundary**
- **Groundwater Allocation Zone**
- **Te Raite Station boundary**
- **Simulated groundwater level (mAMSL)**

Data Provenance
Topographic Data derived from Land Information New Zealand
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008.
Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved

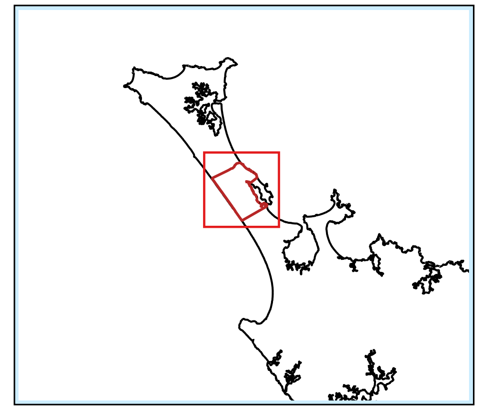
QGIS by:
WWLA



Map Title:
Simulated groundwater level for end of 2010 irrigation season (mAMSL)

Project:
Te Raite Station Groundwater Investigations

Client:
WSP-Opus



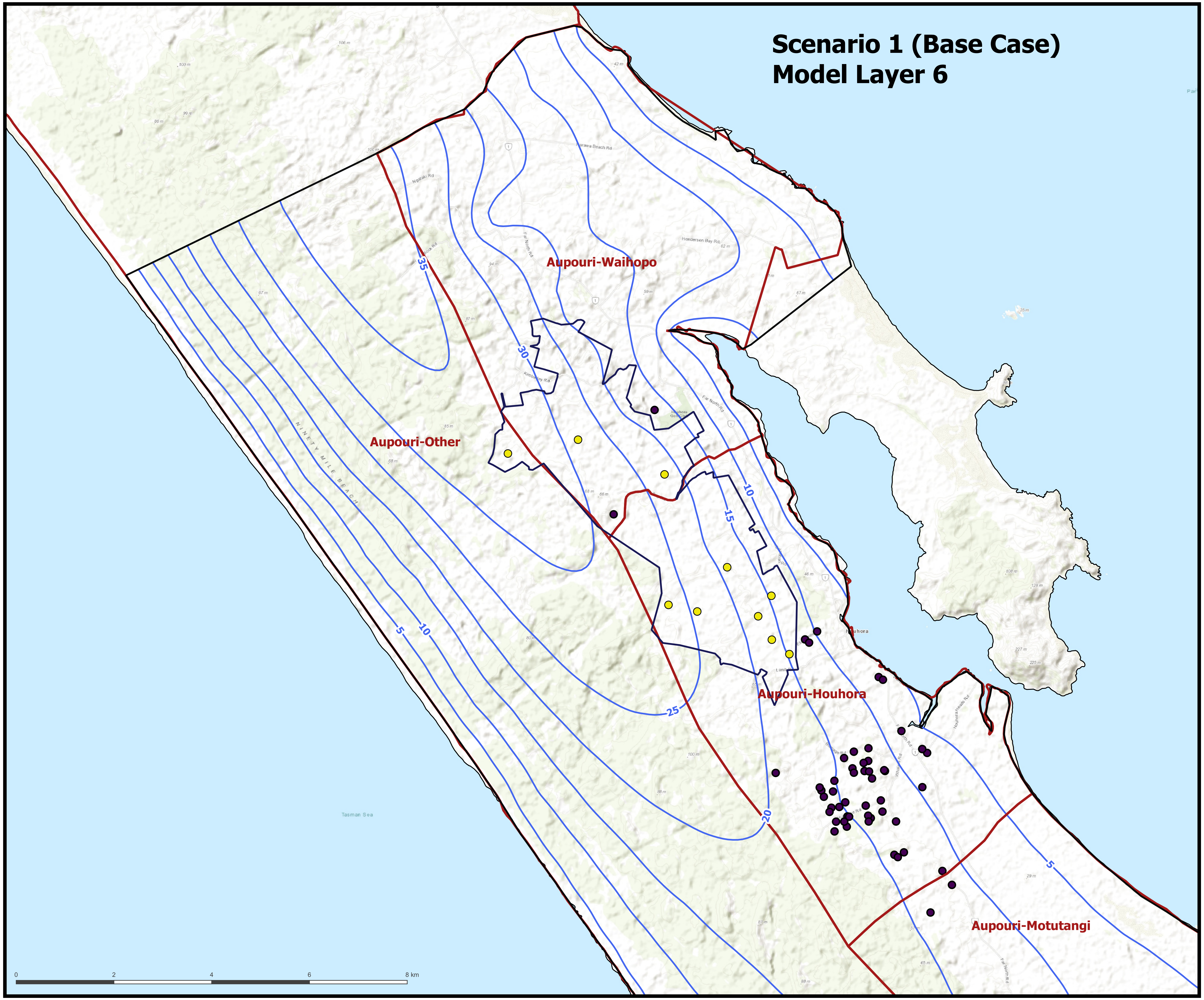
- **New groundwater take**
- **Consented bores**
- **Model Boundary**
- **Groundwater Allocation Zone**
- **Te Raite Station boundary**
- **Simulated groundwater level (mAMSL)**

Data Provenance

Topographic Data derived from Land Information New Zealand
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008.
Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved

QGIS by:

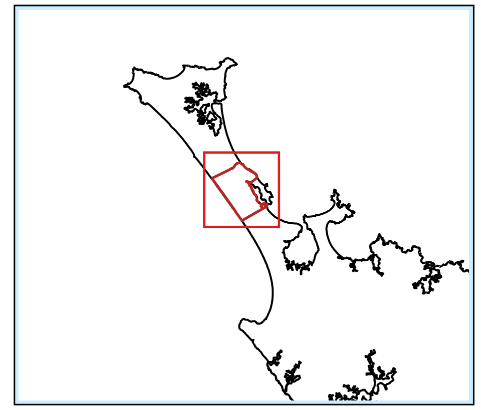
WWLA



Map Title:
Simulated groundwater level for end of 2010 irrigation season (mAMSL)

Project:
Te Raite Station Groundwater Investigations

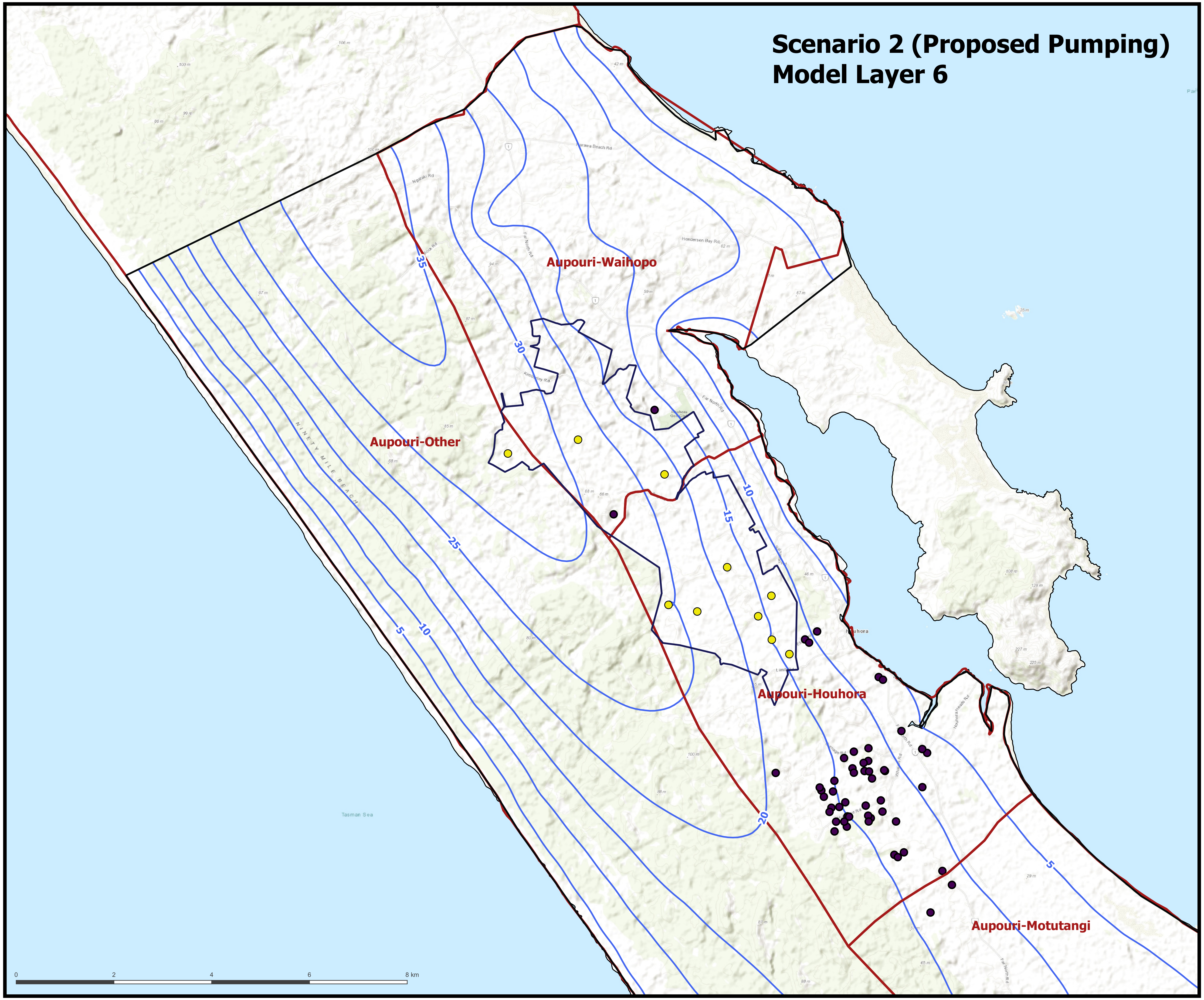
Client:
WSP-Opus

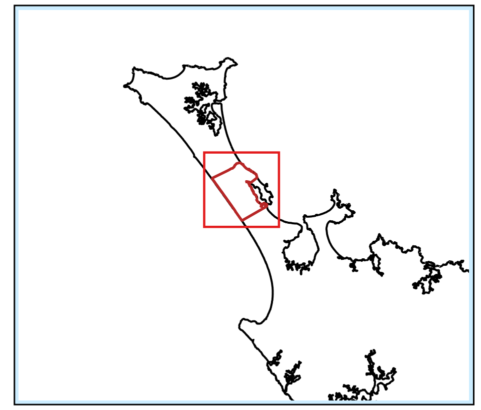


- **New groundwater take**
- **Consented bores**
- **Model Boundary**
- **Groundwater Allocation Zone**
- **Te Raite Station boundary**
- **Simulated groundwater level (mAMSL)**

Data Provenance
Topographic Data derived from Land Information New Zealand
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council 2007 - 2008.
Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved
Light Detection and Ranging (LiDAR) 2007/2008. Waikato Regional Council & NZ Aerial Mapping Ltd 2010 - 2011. Contour Data Licensed under CC BY 3.0 NZ.
Crown Copyright Reserved

QGIS by:
WWLA





Map Title:

Simulated groundwater level for end of 2010 irrigation season (mAMSL)

Project:

Te Raite Station Groundwater Investigations

Client:

WSP-Opus

- **New groundwater take**
- **Consented bores**
- **Model Boundary**
- **Groundwater Allocation Zone**
- **Te Raite Station boundary**
- **Simulated groundwater level (mAMSL)**

Data Provenance

QGIS by:

WWLA