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Groundwater protection zone delineation of Matamata supply wells

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EXECUTIVE SUMMARY

Protection zones (PZs) were delineated for the two Matamata groundwater supply wells located near Tawari Street, Matamata, in the Waikato Region. The two groundwater supply wells are identified as 64_511 and 72_4434. An existing resource consent allows for a combined take of 120 m³/hr of groundwater from these wells.

Matamata is located on the Hinuera Formation (part of the Taranga Group), which is composed of cross-bedded pumice sand, silt, and gravel with interbedded peat. The average annual rainfall in the study area is 1,340 mm/year. Matamata is situated between two surface water basins that flow northwards along the Hauraki Plains: the Waitoa River and Waihekau Stream on the western side, and Waihou River and other minor streams on the eastern basin. The wells are located near stormwater discharge outlets from the central business district, which includes a normally dry stormwater retention pond.

The groundwater supply wells are screened in a relatively shallow (16 m to 22 m depth) leaky-confined aquifer. Aquifer test interpretations based on constant-rate pump tests show a low storativity value (0.0002), and transmissivity of about 1,000 m²/day. Recharge for the region is estimated to be about 420 mm/year, which is about 32% of the average annual rainfall. Surface water elevations were approximated from LiDAR data, and surface elevation profiles show a regional slope of 0.0028 m/m dipping northwards.

Groundwater quality is routinely monitored at both supply wells, and is incorporated into the National Groundwater Monitoring Programme and in Waikato Regional Council's monitoring network. Groundwater chemistry at both wells indicates oxic conditions. Nitrate concentrations in well 64_511 were initially around 9 mg/L in 1993, but have decreased with time, and were measured as 3 to 4 mg/L since 2006.

The Analytic Element Method (AEM) approach was used to simulate steady-state 2D groundwater flow for the delineation of capture and groundwater PZs. The software GFLOW was used to simulate rivers, streams, and drains using line-sink elements. The model was as calibrated by adjusting recharge, hydraulic conductivity, aquifer base elevation and thickness. Additional inhomogeneity zones were included for variable urban recharge rates. A Base case model was calibrated using PEST software and manual methods with observed hydraulic heads from 50 boreholes. The respective calibrated groundwater recharge and hydraulic conductivity for this model is 400 mm/year and 40 m/d.

Wells were implemented analytically using a 3D partially penetrating function defined by the elevations of the well screen interval with pump rates distributed to 60 m³/hr for each well. Capture zones were delineated around the pair of supply wells, and well PZs were delineated at 1-, 5-, 10-, and 20-year isochrones. A model sensitivity analysis was conducted by adjusting parameters by ±25%. The predicted capture zones are elongated towards the southwest of the wells, with the median 20-year PZ covering an area of 1.93 km², a width 0.94 km and length 3.00 km. The groundwater source for the wells is a combination of rainfall recharge and horizontal groundwater flow in the aquifer from Waitoa River.

The zones can be used to inform policy in several ways. For instance, the 1 year PZ polygon can be used to define microbial PZ. A risk-based approach can use the results of the sensitivity results to use the maximum PZs for high-risk activities, and the median PZs for lower impact activities.

1.0 INTRODUCTION

Waikato Regional Council (WRC) commissioned GNS Science to delineate capture zones for the Matamata groundwater supply wells. Matamata–Piako District Council (MPDC) currently use two groundwater wells located near Tawari Street for public drinking water supply to Matamata (Figure 1). These groundwater wells are used for municipal water supply, and are identified as 64_511 and 72_4434. The existing resource consent allows for a combined take of 120 m^3/hr of groundwater from these wells (AUTH119179.01.01, WRC, 2014a).

Mapping of well-head capture zones for municipal supply wells is common practice worldwide to help protect the quality of municipal groundwater supplies (US EPA, 1987; 1994). A capture zone consists of the up-gradient and down-gradient areas that will drain into a pumping well (Fetter, 1994). For management purposes, the mapped capture zone is often defined on the basis of groundwater time of travel (TOT), i.e., the time that it takes for groundwater to move from the land surface, through the unsaturated zone, to groundwater and subsequently to the pumping well. The zone is then referred to as a protection zone (PZ). For example, concentric PZs can be mapped for a single well based on one year, five year and ten year TOT. PZs are either coincident or contained within a capture zone boundary. PZs are usually contaminant specific as the TOT threshold may vary between contaminant types. A review of capture zone guidelines for New Zealand can be found in Moreau *et al*., 2014a.

2.0 REGIONAL SETTINGS

2.1 GEOLOGY

The town of Matamata is situated (Figure 2) on Hinuera Formation sediments (part of the Taranga Group), which are Late Pleistocene (Quaternary) river deposits consisting of cross-bedded pumice sand, silt, and gravel with interbedded peat (Leonard *et al*., 2010). The Kaimai Range, located 9 km to the east, consists of Pliocene-aged igneous rocks from the Coromandel Volcanic Zone, and hills 5 km to the west consist of Early Pleistocene igneous rocks from the Mangakino Volcanic Centre. Holocene-aged gravel, sand and silt deposits are located along several of the rivers and streams, including Waitoa River, Waihou River, and Mangawhero Stream.

The Kerepehi Fault is an active normal fault that runs along the length of the Hauraki Plains, and a 10 m vertical throw is visible on the surface topography 2 km northeast of Matamata. Other known faults in the area are inactive.

2.2 HYDROLOGY

Climatic normals are calculated from 30-years periods of metrological data at a single weather station, and can be used to quantify a relatively stable measurement of annual rainfall due to their long averaging period. Average annual rainfall for the Matamata region is about 1,340 mm/year. This calculation was based on the median of 14 calculated normals from five rainfall gauges from the Matamata region for the period 1951 to 2010 (Figure 3, Table 1).

Matamata is situated between two drainage basins that flow northwards along the Hauraki Plains to the Firth of Thames. The Waitoa River and Waihekau Stream are located in the western basin, and eventually flow into the Piako River. The drainage basin on the east side of Matamata is Waihou River, which includes numerous streams, such as Mangawhara, Mangawhero, and Karengorengo. The approximate land area of the drainage basins upstream of Matamata is 120 km² for the western basin, and 800 km² for the eastern basin.

WRC measured surface water flows at five locations in the vicinity of Matamata (Figure 3, Table 2), each location have between 1 and 25 flow observations. Matamata has three stormwater discharge outlets, including one near Tawari Street which discharges water from the central business district, including near-continuous flows from the swimming pool complex (R. Utting 2014, pers. comm.). At the Tawari Street facility, high-peak stormwater flows into a 4 m deep stormwater retention pond beside the reservoir (AUTH108780.01.01, WRC, 2014a). This retention pond is normally dry with grass and other vegetation growing at the base, but fills with stormwater several times a year. The stormwater and retention pond near Tawari Street discharges northwards into an artificially straightened tributary stream of the Waihekau Stream.

Surface water elevations, labelled in Figure 3, were estimated using LiDAR data obtained using airborne laser scanning between 22 November 2007 and 5 February 2008 (WRC, 2014b). While laser strikes have been processed into *ground* and *non-ground*, the definition of *ground* under trees and other vegetation is likely to be less accurate. The 1 m gridded data was aggregated to 10 m grids using the minimum value (e.g., of the 100 values in each 10 m × 10 m area, the minimum value was used to represent the elevation of each 10 m grid cell). This method promotes the lowest-elevation data to best represent low-lying areas where surface water may be present.

Table 1 Calculated normal rainfall for climate stations in the vicinity of Matamata (National Climate Database, 2014), locations of Agent Numbers are in Figure 3.

Agent Number	Network Number	Name	Year range	Average rain mm/year
1584	B75771	Waharoa	1951 – 1980	1336
1586	B75781	Matamata, Okauia	1941 – 1970	1518
			1951 – 1980	1492
			1961 – 1990	1430
			1971 – 2000	1386.8
			1981 – 2010	1307.3
1592	B75871	Matamata	1941 – 1970	1329
			1951 – 1980	1343
1593	B75872	Matamata, Calder's Fm	1941 – 1970	1324
			1951 – 1980	1361
1594	B75873	Matamata, Smith St	1951 – 1980	1341
			1961 – 1990	1321
			1971 – 2000	1304.6
			1981 – 2010	1249.8

Table 2 Summary of stream flow measurements (D. Stewart, 2014, pers. comm.), locations of IDs are in Figure 3.

ID	Location	Name	Number of obs.	Median flow m^3/s
490_9	T14:572-715	Mangawhero Stm (Matamata) @ Tauranga Rd Br	24	0.768
521_2	T14:546-738	Matamata Stormwater Drain @ U/S Recorder	12	0.362
1113_1	T14:528-752	Waihekau Stm @ Buckleys Matamata	1	0.066
1249_23	T14:515-746	Waitoa River @ Peria Rd Matamata	4	0.108
1249_32	T14:517-721	Waitoa River @ Station Rd Matamata	25	0.084
1859_1	T14:513-728	Waitoa R Trib (Matamata) @ Upstm Waitoa R Confluence	1	0.022

2.3 HYDROGEOLOGY

Groundwater flows northward along the Hauraki Plains through Tauranga Group sediments that have been described as a "large leaky hydraulic system comprising numerous lensoidal aquifers" (Hadfield, 2001). As described in Section 2.1, the Hinuera Formation beneath Matamata contains a wide range of fluvial sediments, including pumice sand, silt, and gravel with interbedded peat (Leonard *et al*., 2010). The borehole logs near the production wells at Tawari Street show similar lithology descriptions to depths over 120 m below ground level (BGL) (Zemansky and Wall, 2007).

The Matamata community water-supply wells near Tawari Street are relatively shallow compared to other wells in the region. The uppermost water-bearing zone located at depths generally between 16 m to 22 m BGL, consists of very coarse sand and gravel (Appendix 1). This aquifer which is penetrated by the production wells, is confined above by layers of moderately sorted silt and sand, and confined below with sandy loam to very fine sand and pumice sediments. Deeper water-bearing zones have also been identified at depths of 41 m to 47 m BGL (Zemansky and Wall, 2007).

Aquifer test interpretations from constant-rate pump tests from both boreholes (Table 3) indicate the aquifer is leaky-confined (Cameron, 2006; Zemansky and Meilhac, 2007). The aquifer is regarded to be *confined*, because it has a low storativity value (0.0002). However, the aquifer is also regarded as *leaky* as there is either a recharge boundary or leaky aquifer after 220 minutes of a constant rate pump test (Zemansky and Meilhac, 2007). While data from the June 2007 24-hour pump test cannot be used to distinguish between leaky aquifer or recharge boundary, the approximate radial distance to a recharge boundary, if present, would be about 1 km from well 72_4434 (Zemansky and Meilhac, 2007).

Estimates of rainfall recharge for the Hauraki Plains are about 420 mm/year (Hadfield, 2001), which is 32% of the average annual rainfall for the region. Over the residential area of Matamata (approximately 3.7 km²), recharge rates are expected to be reduced due to runoff diversion to stormwater drainage from paved surfaces.

Streams north of Matamata, including tributaries of the Waihekau Stream near Tawari Street flow northwards, and have been artificially straightened and their beds are silt-lined (R. Utting, 2014, pers. comm.).

Table 3 Summary of aquifer hydraulic properties from previous studies, where T is transmissivity, K is hydraulic conductivity, S is storativity, and b is thickness.

Test details	T [m²/d]	K [m/d]	S	Assumption	Reference
September 2005, 2-hr pump test in 64_511 at 53.5 m³/hr, determined using two observation bores.	950	150	0.001	b=6.4 m	Cameron, 2006
April 2007, short-term pump tests in shallow and deep observation bores at 2 L/s.	50 – 100	10 – 20	-	b=5 m, from screen length	Zemansky and Wall, 2007
April 2007, slug tests in shallow and deep observation wells.	60	12	-	b=5 m, from screen length	Zemansky and Wall, 2007
June 2007, 24-hour pump test on 72_4434 at 33 m³/hr; determined using two observation bores.	1000		0.0002		Zemansky and Meilhac, 2007

A north–south elevation profile across the region was constructed using the LiDAR data, and indicates the topography dips northwards with an average slope of 0.0028 m/m. In absence of any other hydrogeologic data, this value could be used to approximate a hydraulic gradient in the shallow aquifer near Tawari Street.

2.4 GROUNDWATER CHEMISTRY

Groundwater quality in the Hauraki Plains exhibits large spatial trends, with more reduced conditions observed towards the north. This translates mainly in nitrogen found in nitrate form towards Matamata and as ammonia north of Te Aroha (Hadfield, 1993). Groundwater quality data collected at well 64_511 (June 2005 to June 2007) and well 72_4434 (14/06/2014) were provided by WRC for this study (L. Prince, 2014, pers. comm.). Well 64_511 has also been sampled quarterly since 1992 as part of the National Groundwater Monitoring Programme (GGW site ID 16, GNS Science, 2014) and is included in WRC's monitoring network for community supply (Hadfield, 2011).

Available groundwater analyses at both wells reveal median conductivities of 124 µS/cm and 232 µS/cm at wells 64_511 and 72_4434, respectively (Appendix 1). Chemical analyses at well 64_511 (GNS Science, 2014) indicate oxic groundwater conditions with a median iron concentration of 0.03 mg/L (detection limit of 0.02 mg/L, 24% results were non-detects over the 1992 – 2014 period); and a median manganese concentration below detection limit of 0.005 mg/L (97% results were non-detects for the same time period). The analyses available for 72_4434 (GNS Science 2014) indicated an iron concentration below the detection limit (0.02 mg/L) and a manganese concentration of 0.0006 mg/L.

Initial nitrate concentrations at well 64_511 in 1993 were measured around 9 mg/L, which was close to Drinking-water Standards for New Zealand (Ministry of Health, 2008) maximum acceptable values (MAV) of 11.3 mg/L. However, nitrate-nitrogen concentration has decreased over time (Figure 4) to around 3 to 4 mg/L (GNS Science, 2014). Prior to 2005, trace metals such as aluminium, arsenic, copper, antimony, and zinc were measured well below the NZDWS: 2000 MAV and guideline values (GV) (Appendix 1).

3.0 CAPTURE ZONE DELINEATION

3.1 ANALYTIC ELEMENT METHOD

3.1.1 GFLOW Model

Guidelines for New Zealand (Moreau *et al*. 2014a) summarise a range of methods that may be used to delineate capture zones for groundwater wells. An analytic element method (AEM) approach was selected as the appropriate method for the Matamata community supply wells, because of the relatively small size of the region and limited availability of hydrogeologic data. GFLOW is groundwater software based on the AEM, which solves steady-state groundwater flow in a single aquifer (Haitjema, 1995; 2007). With this technique, analytic elements formed as analytical groundwater flow equations are digitised on a map. Streams and pumping wells are represented as line-sink and point-sink analytic elements (analytic solutions to boundary value problems; Strack, 1989), and their contributing flow discharge potentials are combined using the principle of superposition to evaluate groundwater flow for the aquifer. With the AEM approach, streams and rivers are represented using line-sink elements, which have a specified river stage elevation, and resistance terms that are related to the connections of groundwater–surface water interactions. Abstraction wells are represented with discharge-specified point-sink elements. Lastly, line doublet elements are used to define inhomogeneity zones which are used to specify areas with different aquifer base, saturated thickness, hydraulic conductivity, or recharge rates.

The GFLOW model for Matamata is shown in Figure 5. All linear elements appear jagged compared to their 1:50,000 mapped equivalents, because each segment is an individual analytical element that is used to determine the groundwater flow. Adding complexity by detailing the mapped geometry of each feature does not necessarily improve the model ability to simulate groundwater flow. The model was constructed by first identifying significant surface-water features within the vicinity of the study region that may have a hydrologic influence to the Matamata community supply wells. Secondly, the elevations were obtained from high-resolution LiDAR data (Table 4; Figure 5) and used to specify the elevations of starting and ending heads for each uniquely named line-sink group. Tributary streams were designated as drain elements, which do not allow any contribution of surface water flow to the aquifer, but may receive groundwater where the potentiometric surface is above the specified head of the line-sink elements. All other line-sink elements allow flow of water between the aquifer and surface water. Routing line-sink elements are used where stormwater discharge is specified at the upstream segments that start near the perimeter of Matamata, and any cumulative discharge is routed downstream (northwards). Line-sink properties are shown in Table 5.

The outermost inhomogeneity zone is used to apply recharge to the region, which covers the extent of line-sinks in the model. An inhomogeneity zone for the residential area of Matamata is used to reduce recharge rates based on different land use. The Mangawhero inhomogeneity zone was used to help calibrate water levels from around a topographic feature, and is used to vary the hydraulic conductivity for this region.

The two pumping wells near Tawari Street (Table 5) were implemented in the model as point-sinks, using a 3D partially penetrating function defined by the elevations of the well screen interval. Pumping rates used to delineate capture zones were distributed to 60 m^3/hr for each well, as the combined consent for the Tawari Street well field is 120 m^3/hr.

Global model settings define the aquifer base and saturated thickness for the 2D model. An elevation of 19.3 m BGL was used for the aquifer base, which is deeper than the primary aquifer where the production wells are screened in (see Table 5). The deeper base elevation was required to accommodate the specified head elevations from line-sinks used for streams at the north part, which have a minimum elevation of 22.4 m. A saturated thickness of 30 m was used as it allows the well screens to fit vertically within the saturated portion of the model, from an elevation range from the base of the aquifer to an elevation of 49.7 m. A conjunctive surface water-groundwater solution was enabled, and 6 inner loop iterations were used to solve drain and flow-routing model complexities.

3.1.2 Model Calibration

The GFLOW model for Matamata was calibrated using groundwater elevation observations from 60 boreholes from the region, obtained from drilling records maintained by WRC (L. Prince 2014, pers. comm.). Ground elevations for each bore were derived from LiDAR surface elevations using coordinate data, and groundwater elevations were calculated using the depth to groundwater level. Many of these groundwater levels may not actually represent ambient groundwater flow in the aquifer, because they may have been measured immediately after drilling, influenced by nearby pumping wells, obtained from a separate/deeper aquifer, or have an uncertainty with the coordinates and elevation. Of the 60 groundwater elevation data points, 10 were removed prior to calibration as they had inconsistent values compared to neighbouring trends and values, and/or were interpreted as to be from a deeper aquifer.

To achieve a suitable calibration, groundwater recharge rates and hydraulic conductivity values were adjusted to minimise the residuals between simulated and observed groundwater levels. This process was completed first using PEST (Doherty, 2004). Additional manual calibration adjustments to model parameters were also made to the resistance terms for line-sink elements representing surface water features. The calibration was completed without any pumping, as the measured groundwater levels from the Matamata wells represent static groundwater levels prior to aquifer testing.

The estimated values characterizing calibration conditions are as follows: recharge of 0.00011 m/d or 400 mm/year, and hydraulic conductivity of 40 m/d. The calibrated recharge is close to the expected effective rainfall for the Hauraki Plains (Hadfield, 2001). Within Matamata, a recharge of 0.00027 m/d (100 mm/year) was removed, and resulting in a value of 300 mm/year. With a saturated thickness of 30 m, the aquifer transmissivity is 1200 m^2/d, which is within an order of magnitude of the estimates from aquifer pump testing in Table 3. Groundwater elevation contours from the calibrated Base model are shown in Figure 6, and calibration statistics and a scatter plot of observed versus simulated heads in Figure 7.

A conductivity of 1 m/d was used for the Mangawhero inhomogeneity zone, although this zone is relatively insensitive to groundwater flow simulation near the Matamata community supply wells.

Table 4 Properties of line-sinks used represent surface water features in the model. Drains have zero depth. For elements with routing enabled, in-flow rate or ending properties are specified.

Label	Specified head [m]		Resistance [d]	Width [m]	Depth [m]	Routing
	Start	End				
Waitoa1	70.13	56.42	2	3	1	No
Waitoa2	56.42	54.6	1	3	1	No
Waitoa3	54.6	48.23	0.5	3	1	No
Waitoa4	48.23	44.04	0.5	3	1	No
Waihekau3	56.23	50.98	20	1	1	Yes, 31276.8 m^3/d
Waihekau4	54.03	51.4	1	1	1	Yes
Waihekau5	51.4	50.98	1	1	1	Yes
Waihekau6	50.98	46.06	0.05	1	1	Yes, end
Waihekau7	62.27	56.77	5	1	1	Yes, 5702.4 m^3/d
Waihekau8	62.07	56.77	0.1	1	drain	Yes
Waihekau9	56.77	51.94	5	1	1	Yes
Waihekau10	51.94	49.1	10	1	1	Yes, end
Karengorengo	58.4	49.07	1	1	drain	No
Okauia	50	26.11	0.05	1	drain	No
StationRd	66.24	54.9	1	1	drain	No
Mangawhara	76.27	56.1	0.1	1	1	No
Mangawhero1	70.3	56.1	0.01	2	1	No
Mangawhero2	56.1	40.3	1	2	1	No
Mangawhero3	40.3	27.8	1	2	1	No
Waihou1	50	43.62	1	5	1	No
Waihou2	43.62	34.3	1	5	1	No
Waihou3	34.3	27.8	1	5	1	No
Waihou4	27.8	26.11	1	5	1	No
Waihou5	26.11	22.4	1	5	1	No

Table 5 Tawari Street pump well data. Ground elevations are obtained from LiDAR data.

Label	Coordinate NZTM		Ground elev. [m]	Screen depth [m]		Screen elevation [m]	
	Easting	Northing		Top	Bottom	Top	Bottom
72_4434	1844684	5812723	58.86	14.50	20.50	44.36	38.36
64_511	1844481	5812637	59.47	15.69	21.77	43.78	37.70

3.1.3 Sensitivity Analysis

Several parameters were identified as sensitive parameters to the capture zone delineation. These parameters were varied to produce alternative maps for capture zones to complete a sensitivity analysis. Parameters were either increased and/or decreased to yield larger capture zones than the calibrated Base case. The sensitivity analysis scenarios are summarised in Table 6. The K+ case increased the hydraulic conductivity by 25%, while the

R- and R+ cases varied the recharge rate by 25%. The rationale for the 25% adjustment to parameter values is provided by Moreau *et al*., (2014b). The TB case adjusts the aquifer bottom and thicknesses to their practical limits to contain the range of specified head elevations of all the line-sinks, and contain the well screen elevation intervals. Note that parameters for other inhomogeneity zones were not included in the selectivity analysis as flow to the Tawari Street wells was less sensitive.

Table 6 Sensitivity analysis scenarios. Dashes indicate no change from "Base" condition.

Case name	Hydraulic conductivity [m/d]	Recharge [m/d]	Bottom elev. [m]	Thickness [m]
Base	40.0	0.0011	19.3	30.0
K+	50.0	-	-	-
R-	-	0.000825	-	-
R+	-	0.001375	-	-
TB	-	-	22.0	22.0

3.1.4 Protection Zone Mapping

Protection zones (PZs) can be delineated using a particle tracking technique, which is a type of transport model (Haitjema, 1995). Effective porosity is considered only for particle tracking time, and does not change the groundwater flow solution. An effective porosity of 0.2 is assumed for the aquifer. This value is lower than the estimate for the aquifer materials, which allows for a larger and thus more conservative PZ size.

The particle-tracking technique uses rings of reverse-tracking particles placed near the bottom of the pump well screen. Each particle pathline has a travel time, which is used to delineate the areas for 1-, 5-, 10-, and 20-year isochrones. This process is illustrated in Figure 8, showing pathlines for 10-year of groundwater travel time. PZs were also delineated for each sensitivity analysis scenario, and isochrones are shown in Figure 9. Median PZs are spatially determined where 3 of 5 polygons overlap, and maximum PZs are determined by the outer spatial extent of all sensitivity analysis PZs.

Dimensions of the PZs are summarised in Table 7. The zones are elongated toward the southwest, with a grid azimuth 240°. The 10-year PZs are beneath the northern part of Matamata and SH27, and the 20-year PZs extend to Station Road. Longer travel times (not shown) eventually reach Waitoa River, 4.2 km distance from the wells. The model indicates that the source of groundwater for the capture zone to the wells is a combination of surface water–groundwater interaction with Waitoa River and from rainfall recharge.

Table 7 Dimensions of PZs from the Base-calibrated model and statistically-derived median and maximum PZs from sensitivity analysis model runs.

PZ [yr]	Area [km²]			Width [km]			Length [km]		
	Base	median	max	Base	median	max	Base	median	max
1	0.18	0.19	0.25	0.36	0.37	0.44	0.61	0.63	0.69
5	0.75	0.75	1.05	0.77	0.78	0.95	1.28	1.28	1.49
10	1.30	1.29	1.90	0.86	0.85	1.13	1.95	1.95	2.28
20	1.99	1.93	3.14	0.93	0.94	1.19	3.08	3.00	3.66

4.0 DISCUSSION

Groundwater source for the Matamata supply wells is interpreted from the model to be a combination of rainfall recharge from the areas delineated by the PZs (Figure 8 and Figure 9), and from horizontal groundwater flow in the aquifer from Waitoa River. Decreasing trends in nitrate concentrations shown in Figure 4 suggest that the quality of groundwater has improved with time. One interpretation is that change of land use within the capture zone since 1993 has resulted in a decrease in observed nitrate levels. Another interpretation is that before the pump wells were installed, a build-up of nitrate had infiltrated and accumulated in the aquifer, which was later diluted with fresher water from Waitoa River after the wells started pumping.

The connectivity of the aquifer to nearby streams near the Tawari Street facility is unknown. Concurrent flow gauging measurements along the constant-flowing tributary of the Waihekau Stream could help identify if there is any flow loss to groundwater near the wells.

The PZs delineated in this report can be used to inform policy in several ways, as suggested in the capture zone guidelines for New Zealand (Moreau, 2014a). For instance, the 1 year PZ can be used for a microbial PZ to prevent pathogens with a lifespan of less than 1 year from entering the drinking water supply. The maximum extent zone, covering all sensitivity analyses, can be used to define zones for higher-risk land activities that have a potential of creating groundwater contaminants.

Limitations of the findings and data derived in this report include all of the assumptions behind the AEM (Strack, 1989) implemented in the software (Haitjema, 1995), such as assuming that groundwater flow is horizontal in a single aquifer, and that boundary conditions (such as stream levels and pump rates) are steady state. Furthermore, the calibration of the numerical model is influenced on the availability of data, such as hydraulic heads from wells.

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FIGURES

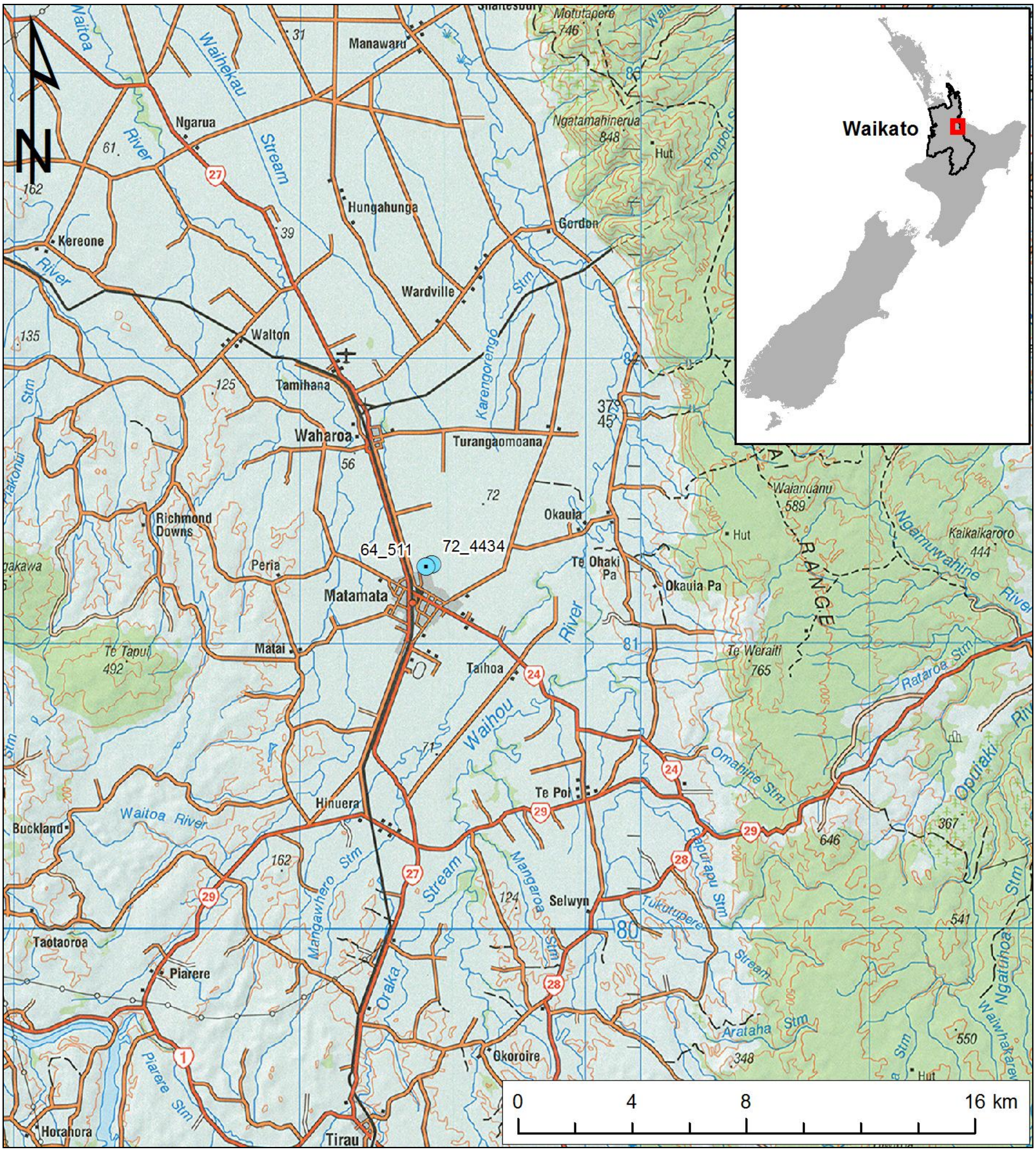


Figure 1 Matamata township and surrounding eastern Waikato region, including the location of the two municipal supply wells located near Tawari Street.

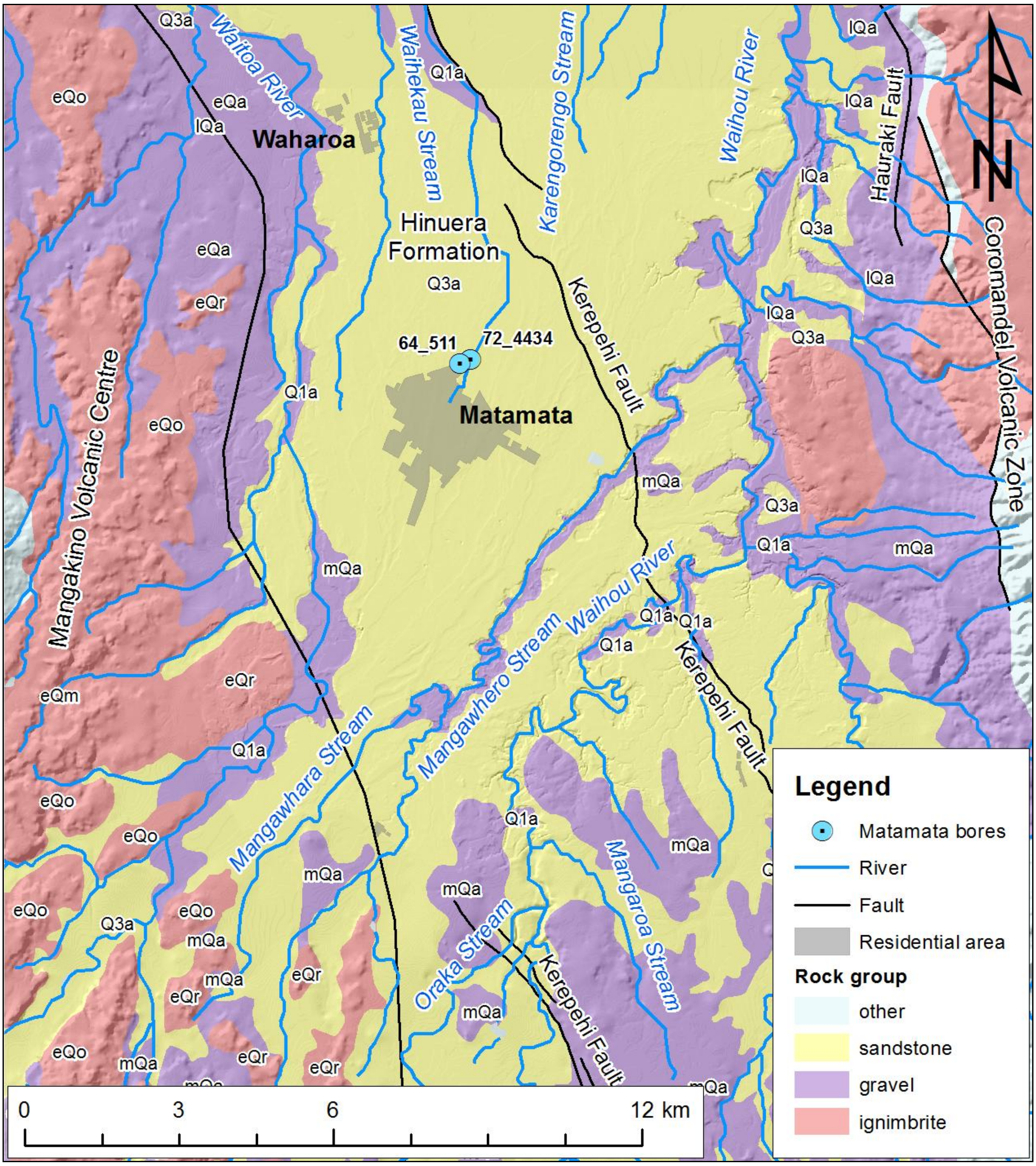


Figure 2 Geological map of the Matamata area (Leonard *et al.*, 2010), showing Matamata township and rivers from the 1:250,000 topographic map series (LINZ, 2012).

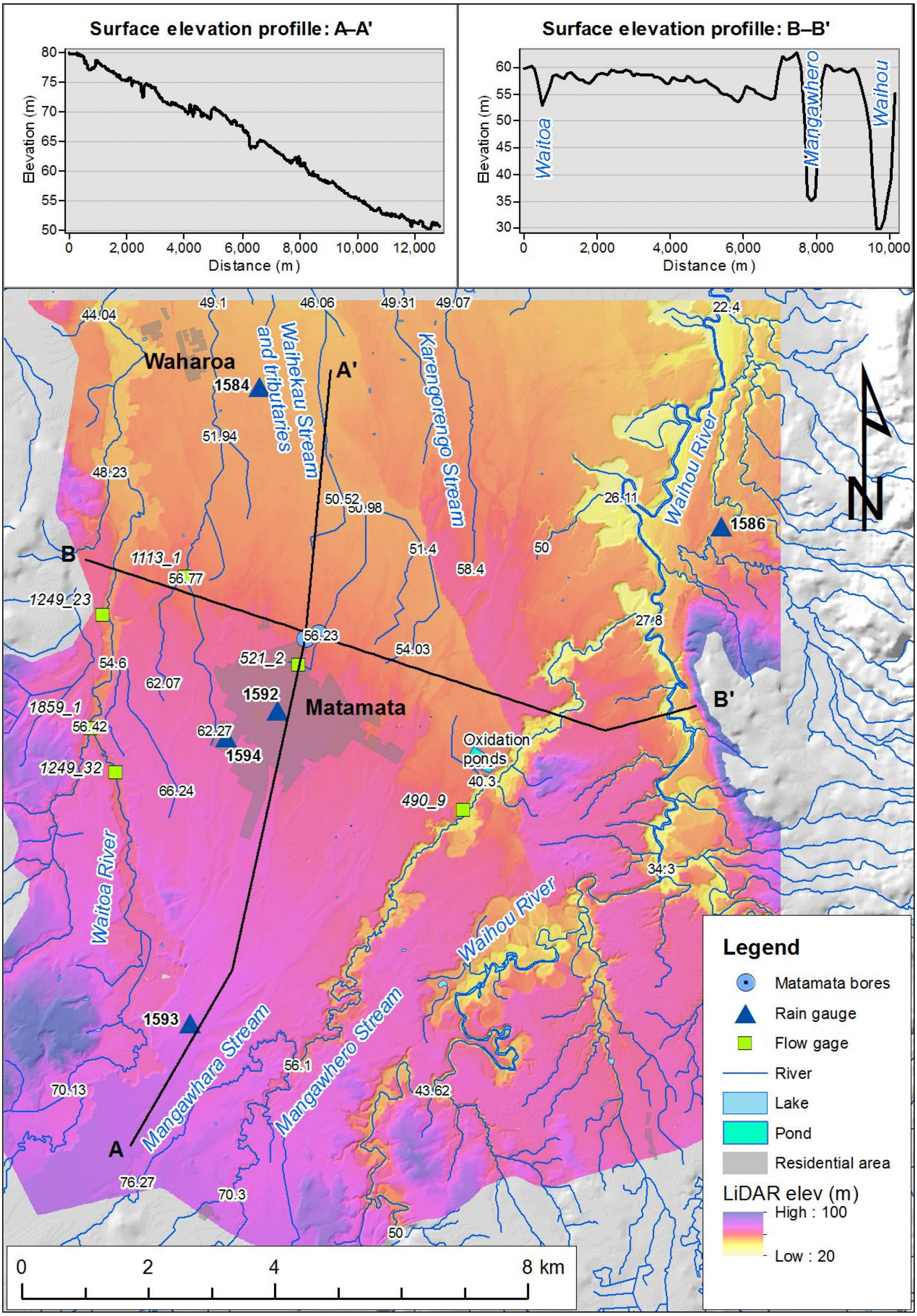


Figure 3 Map of hydrology and surface elevation from LiDAR and two elevation profiles which intersect the Matamata supply wells. Elevations of surface water features from LiDAR data are labelled. Bold labels are climate station agent numbers (Table 1), and italics labels are flow gauge identifiers (Table 2).

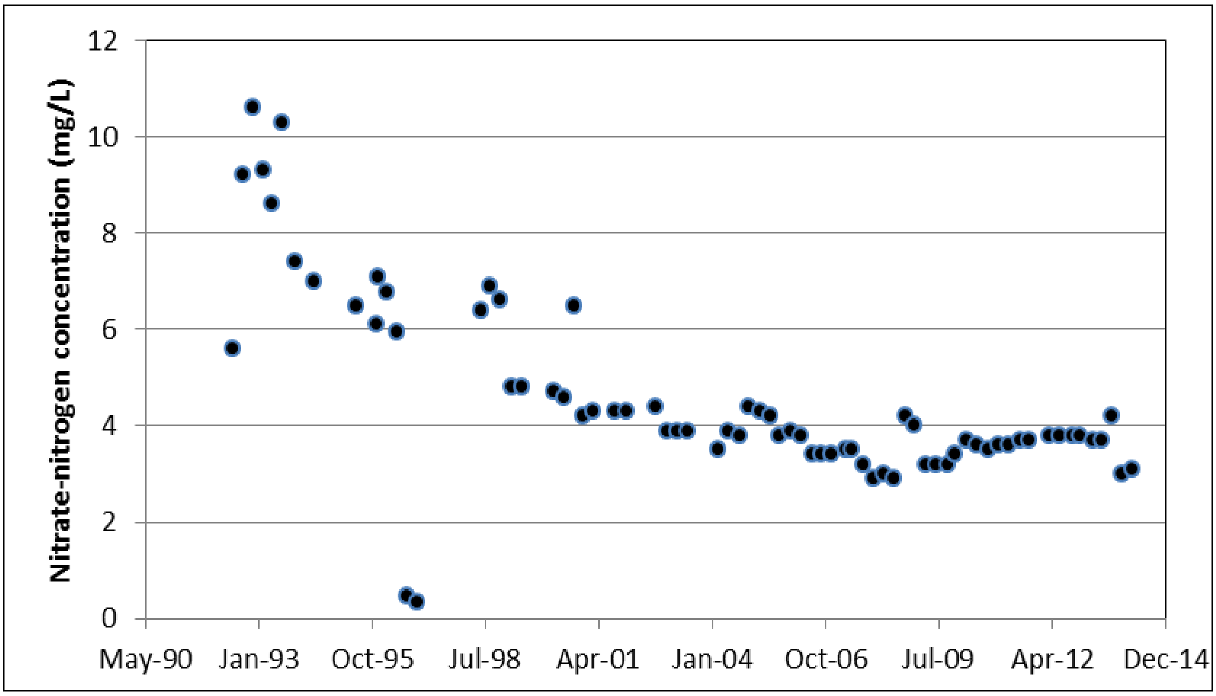


Figure 4 Nitrate–nitrogen concentrations at well 64_511 (GNS Science, 2014).

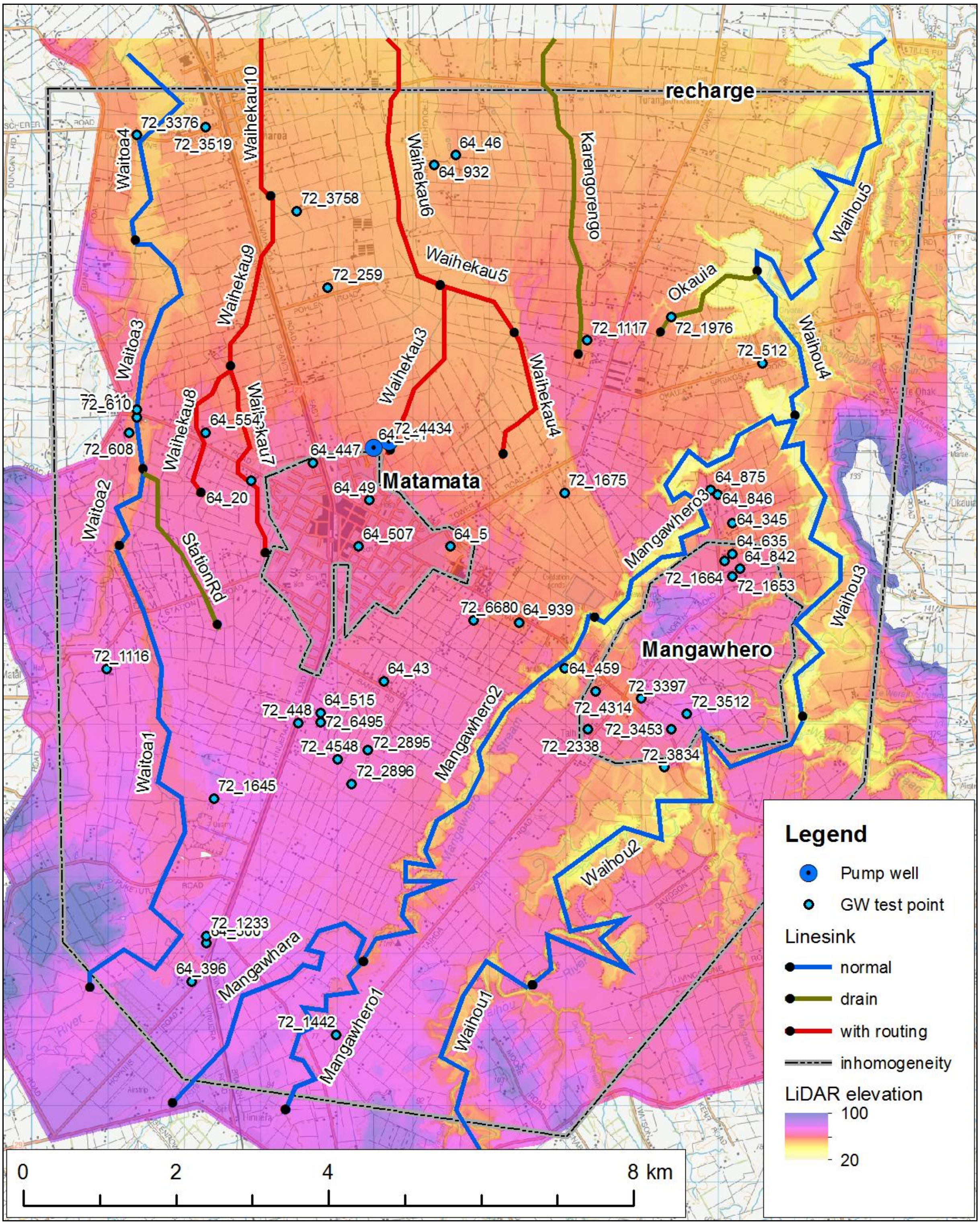


Figure 5 GFLOW model for the Matamata region, showing different labelled analytic elements. The starting locations for each line-sink are shown with a black dot, and have properties listed in Table 4. Three inhomogeneity zones for recharge, Matamata residential area, and Mangawhero, are shown. Labelled GW test points show boreholes that have groundwater elevations, and were used for the calibration process.

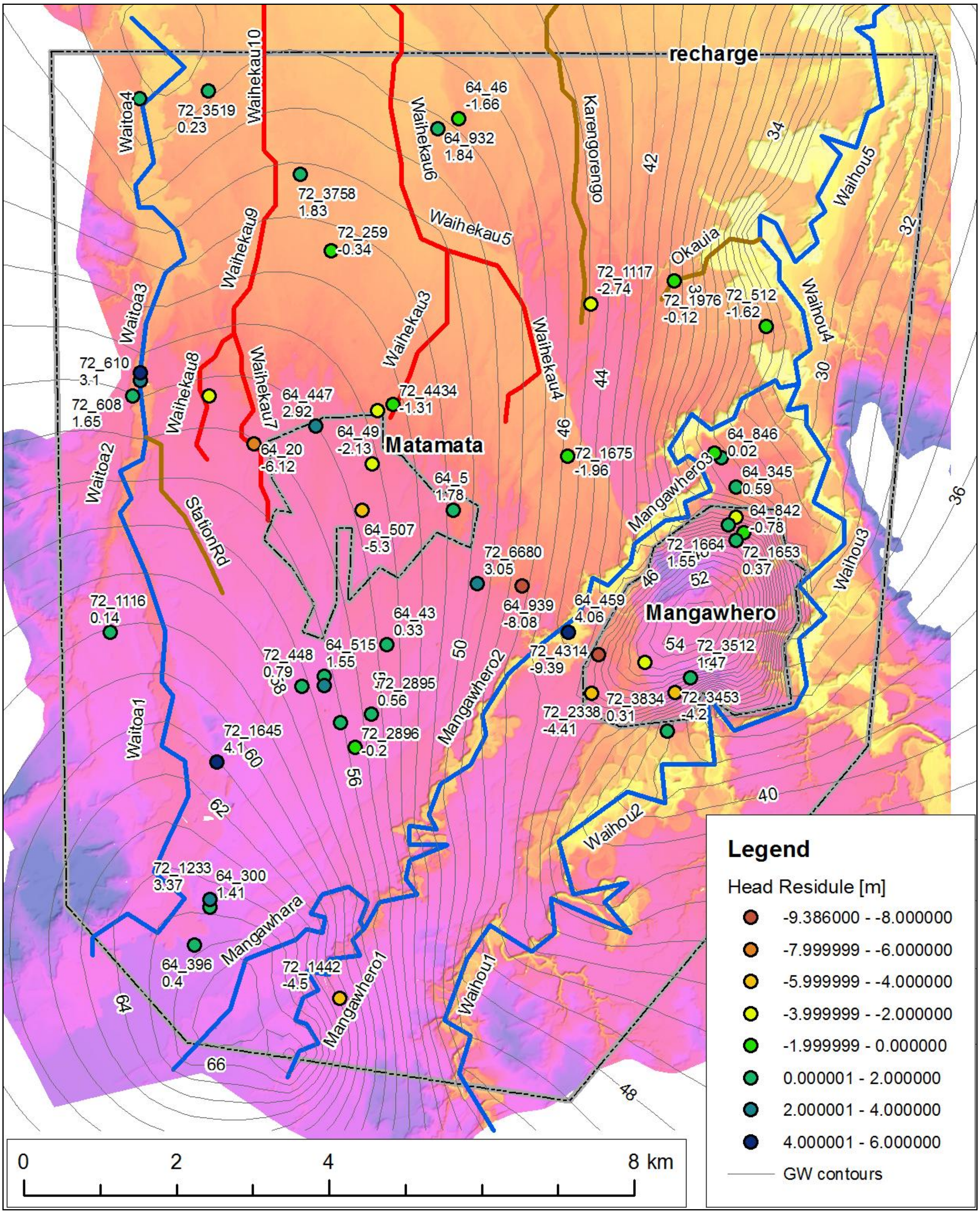


Figure 6 Base scenario calibration without pumping, showing groundwater head contours and head residuals between observed and simulated values.

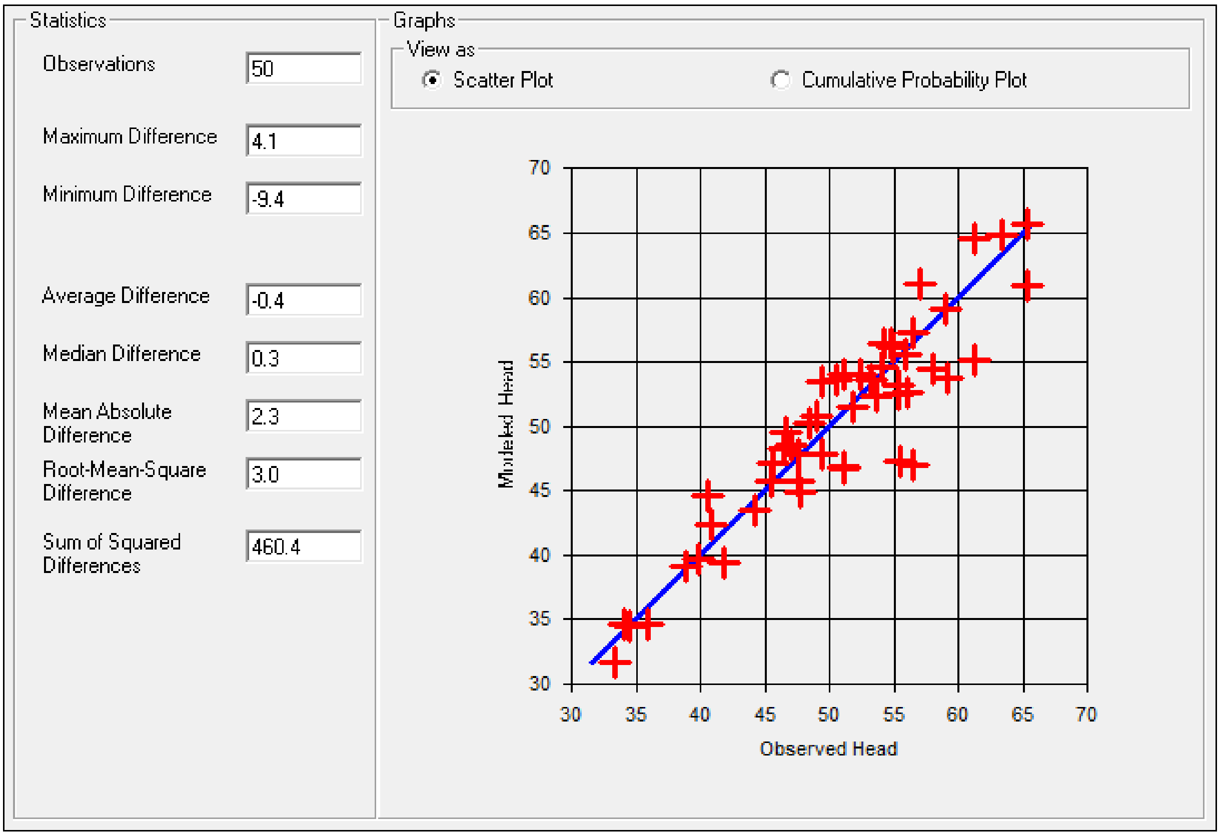


Figure 7 Base scenario calibration statistics and scatter plot of observed and simulated heads. Scatter of residules along the one-to-one line reveals that the calibration is unbaised, with a near constant variance.

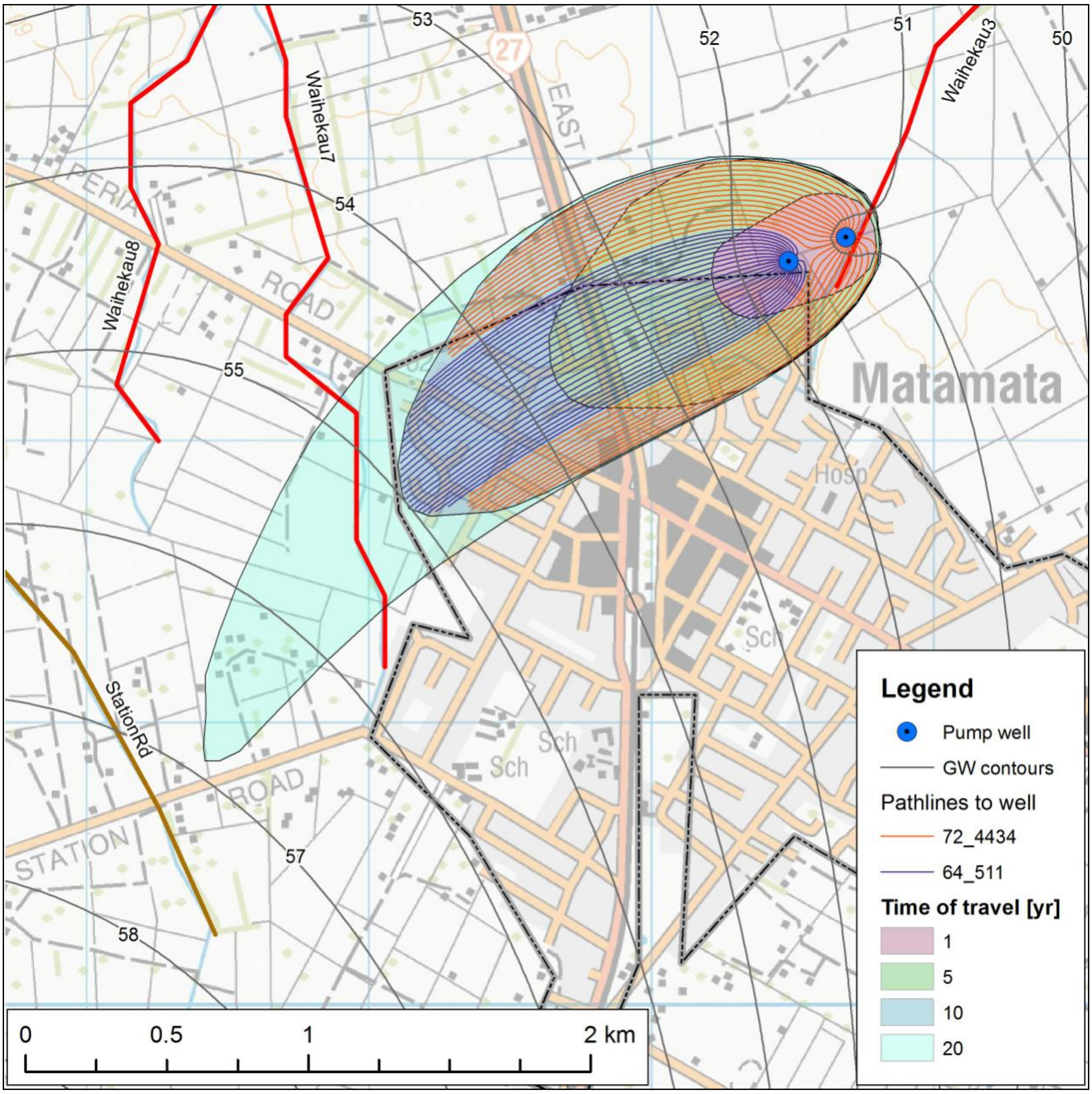


Figure 8 Flow pathlines with 10-year travel time to Tawari Street groundwater wells, based on a pumping rate of 60 m³/hr (total 120 m³/hr). PZ delineations are shown for 1-, 5-, 10-, and 20-year isochrones. This model is the calibrated Base scenario.

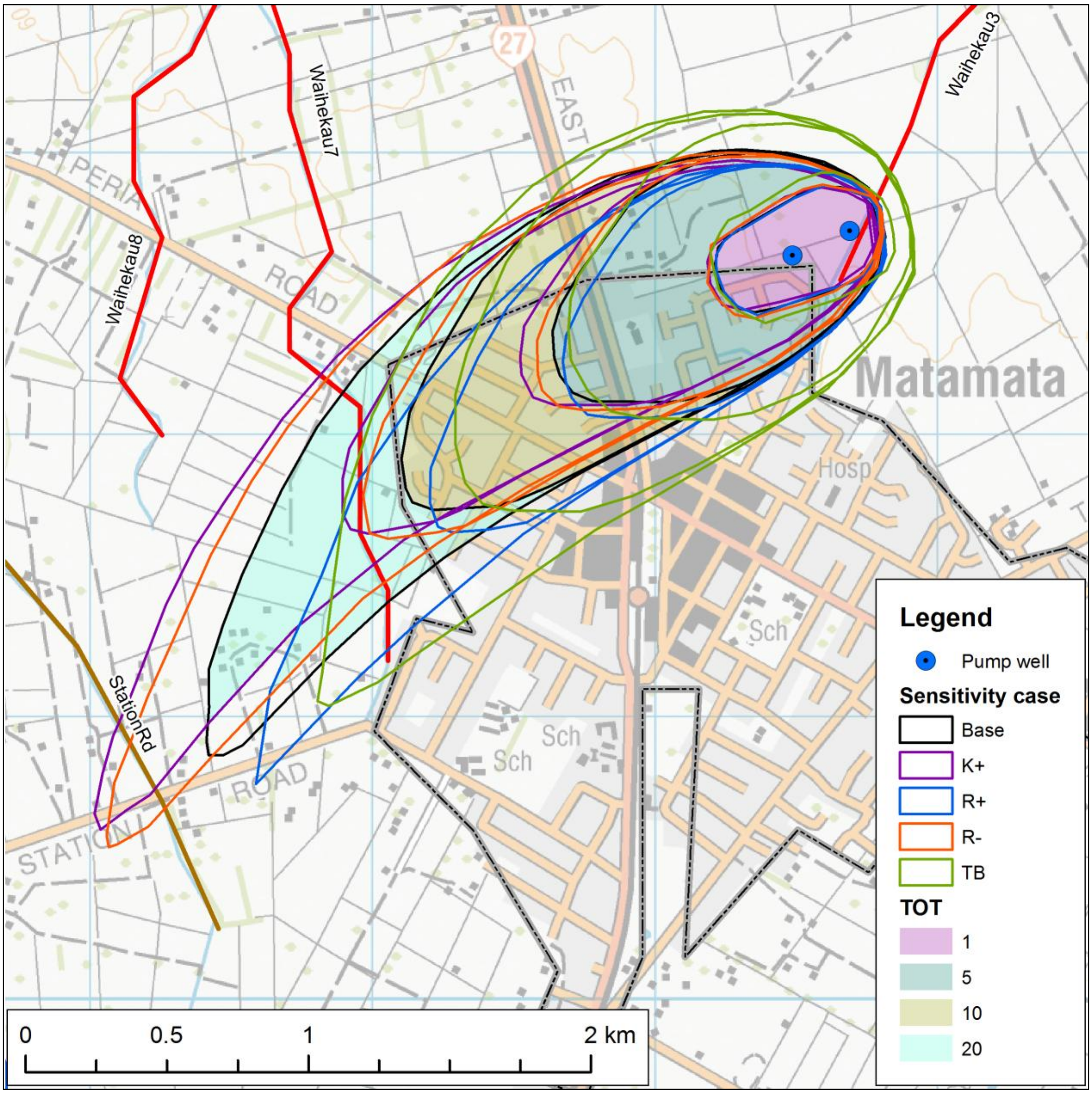
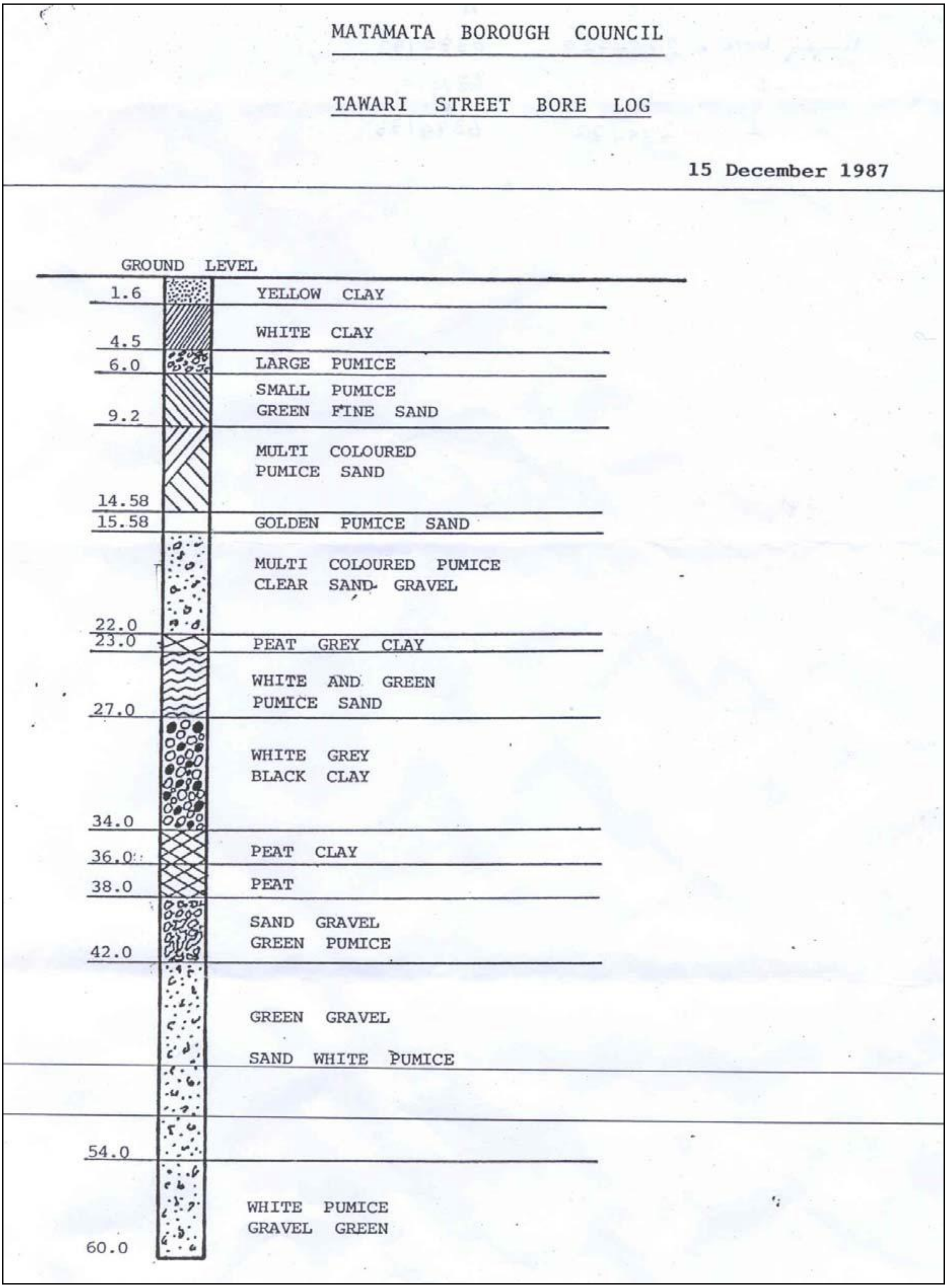


Figure 9 Capture zone delineations for all sensitivity analysis scenarios (Table 6), each showing 1-, 5-,10-, and 20-year isochrones. The filled polygons show the median PZs.

APPENDICES

APPENDIX 1: BOREHOLE LOGS FOR PRODUCTION WELLS

Well 64_511 (from Cameron, 2006)



MATAMATA BOROUGH COUNCIL

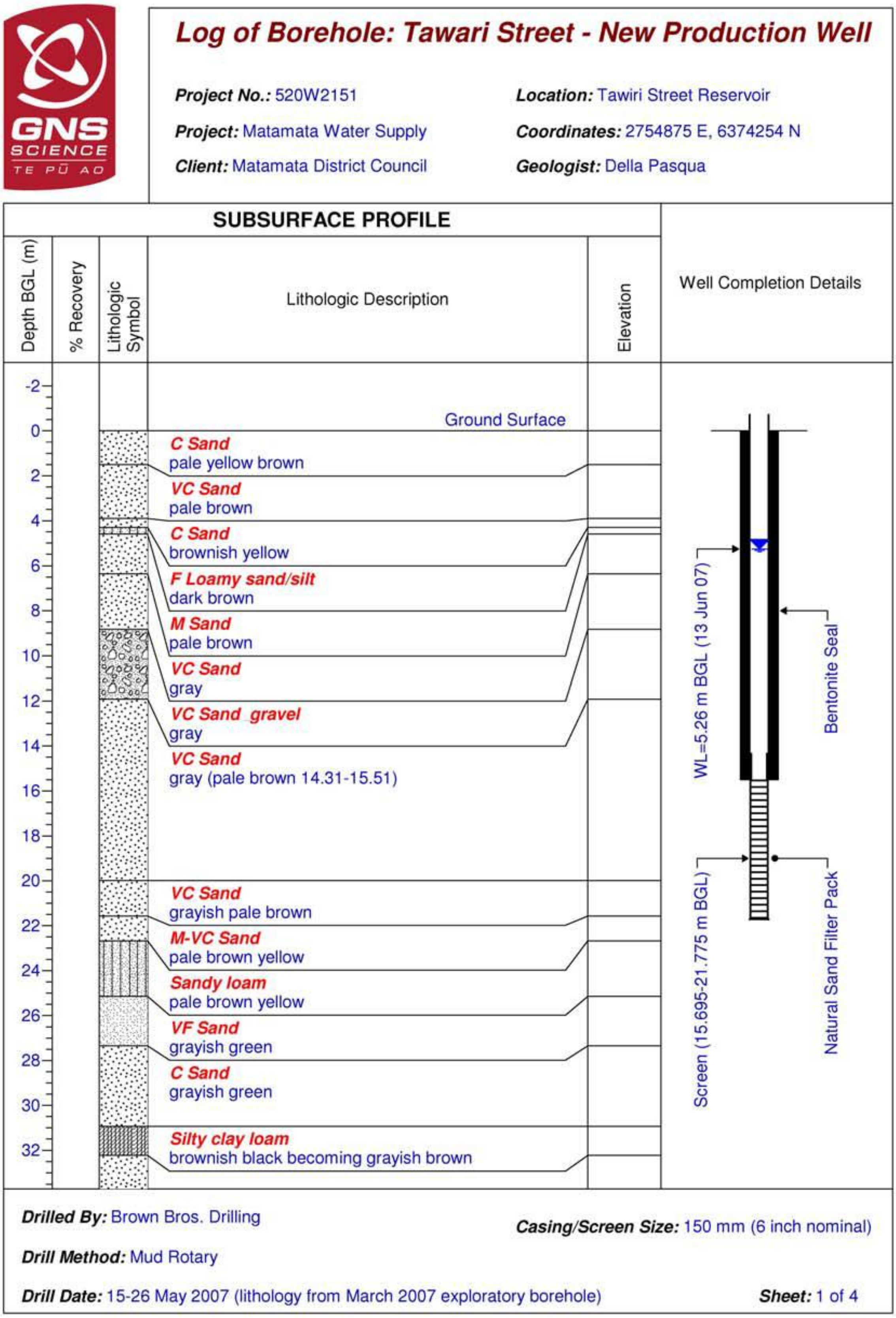
TAWARI STREET BORE LOG

15 December 1987

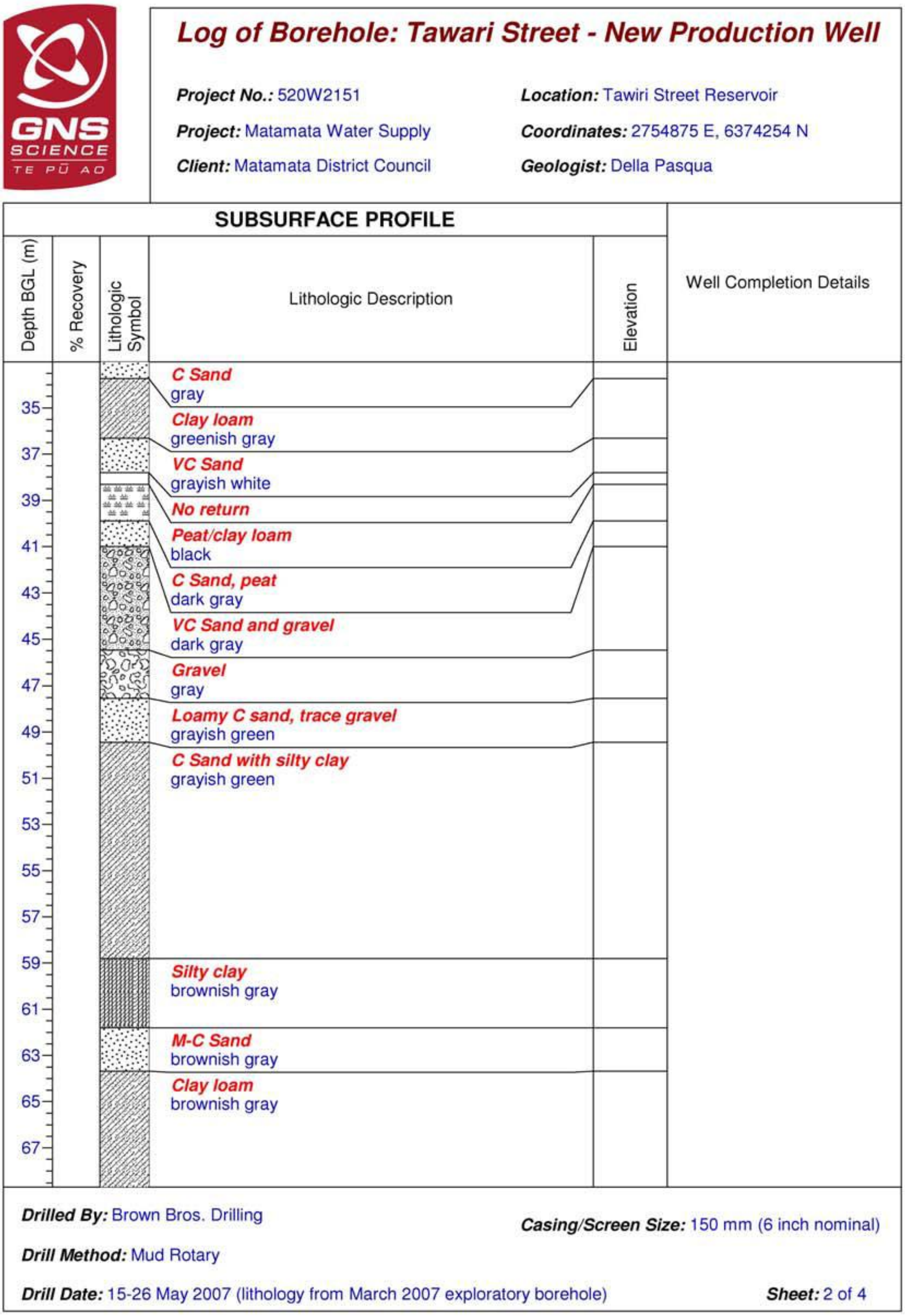
GROUND LEVEL

1.6	YELLOW CLAY
4.5	WHITE CLAY
6.0	LARGE PUMICE
9.2	SMALL PUMICE GREEN FINE SAND
14.58	MULTI COLOURED PUMICE SAND
15.58	GOLDEN PUMICE SAND
22.0	MULTI COLOURED PUMICE CLEAR SAND GRAVEL
23.0	PEAT GREY CLAY
27.0	WHITE AND GREEN PUMICE SAND
34.0	WHITE GREY BLACK CLAY
36.0	PEAT CLAY
38.0	PEAT
42.0	SAND GRAVEL GREEN PUMICE
54.0	GREEN GRAVEL SAND WHITE PUMICE
60.0	WHITE PUMICE GRAVEL GREEN

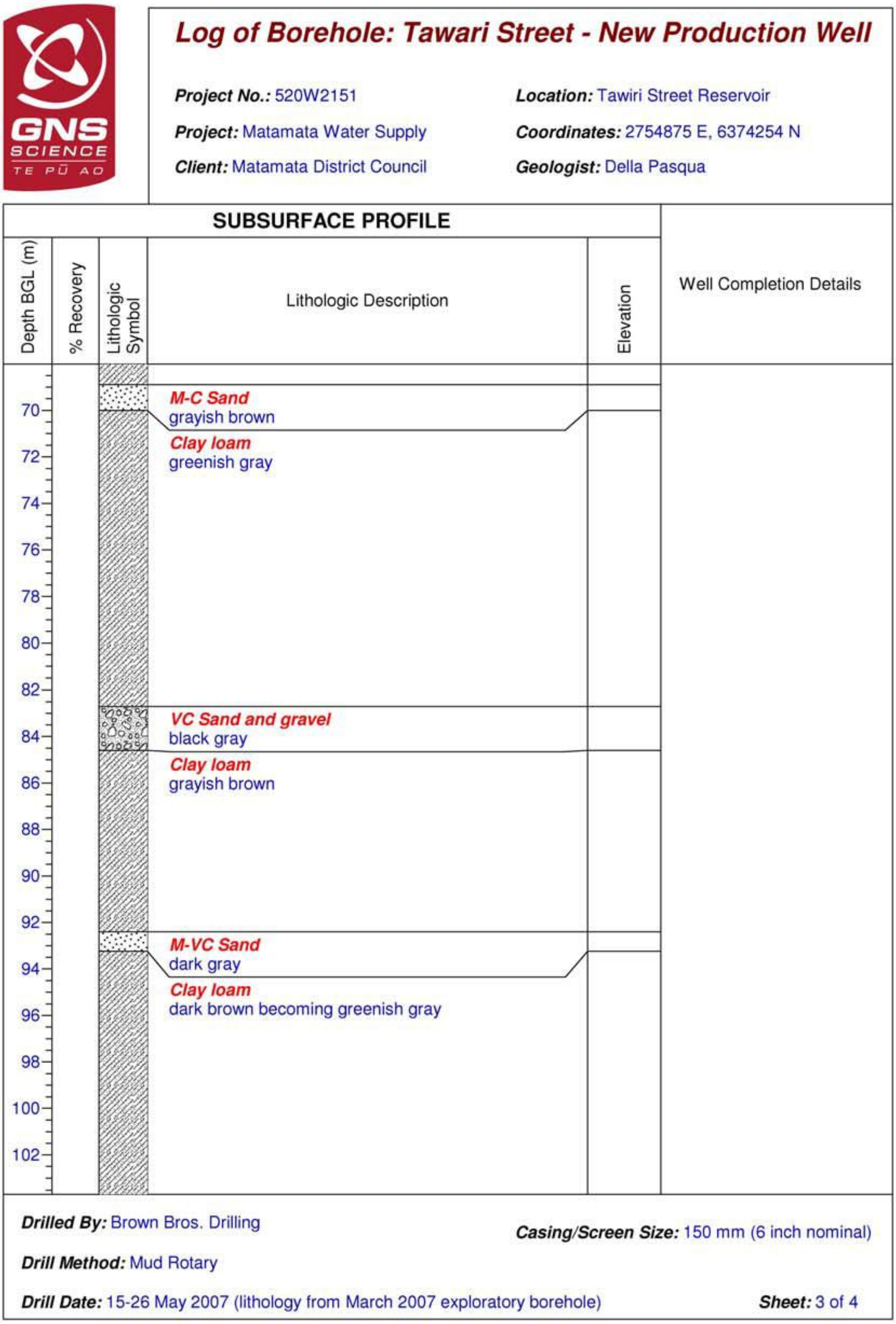
Well 72_4434 (from Zemansky and Meilhac, 2007; 1 of 4)



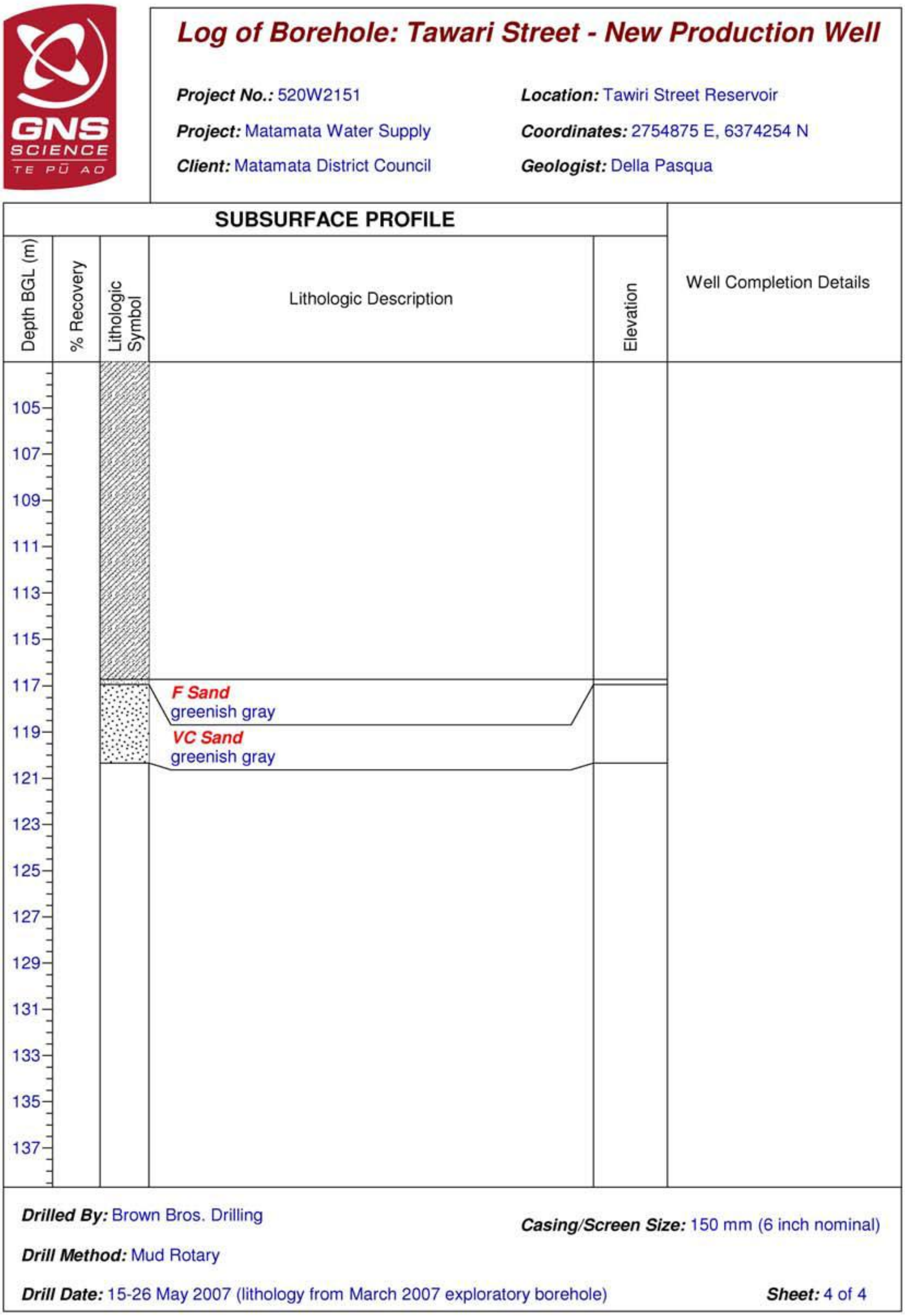
Well 72_4434 (2 of 4)



Well 72_4434 (3 of 4)



Well 72_4434 (4 of 4)



APPENDIX 2: GROUNDWATER CHEMISTRY AT MATAMATA SUPPLY WELLS

Table A2.1: Groundwater median concentrations for major ions, nutrients, and dissolved metals. Source: Waikato Regional Council database 2014, GNS Science 2014, Ministry of Health 2008 Drinking-Water Standards for New Zealand 2005 (Revised 2008).

			64_511						72_4434	
	Period		**Jun 2005 – Mar 2007**			**Jun 1992 – Mar 2014**			**17 Jun 2007**	
	Parameter	**Units**	**# results**	**# non-detect**	**median**	**# results**	**# non-detect**	**median**	**result**	**NZDWS MAV/GV**
Field	Conductivity	uS/cm	28	0	123.5	27	0	123		-
	DO	mg/L	7	0	8.7	9	0	8.38		-
	pH	-	36	0	6.6	0	0	ND*	7	7.0 – 8.5 (GV)
	Turbidity	NTU							0.08	2.5 (GV)
Major ions	Calcium	mg/L	15	0	6.1	69	0	6.3*	13.5*	Hardness
	Sodium	mg/L	15	0	11.8	70	0	12.1*	14.9*	200 (GV)
	Potassium	mg/L	15	0	5.1	70	0	5.2*	7.51*	-
	Magnesium	mg/L	15	0	3	70	0	3.1*	5.8	Hardness
	Bicarbonate	mg/L as HCO_3	0	0	35.38	70	0	37*	36	-
	Chloride	mg/L	15.0	0	7.6*	70	0	7.8*	15.9*	250 (GV)
	Sulphate	mg/L	6	0	7.5*	71	0	8.9*	16.1*	250 (GV)
Nutrients	Nitrate-Nitrogen	mg/L	15	0	3.6	71	0	3.8*		11.3
	Nitrate-Nitrogen	mg/L	13	0	3.3				9.91	11.3
	Total Organic Caron (TOC)	mg/L							< 0.5	-
	DOC	mg/L	1	1	< 0.3					-
	Ammonia-Nitrogen	mg/L	36	34	0.0215	60	43	< 0.01*	< 0.01	1.5 (GV)
	Nitrite-Nitrogen	mg/L	14	13	0.003	8	5	0.002*	< 0.002	0.2 and 3
	Total Kjeldahl Nitrogen	mg/L						*	< 0.1	-
	Total Nitrogen	mg/L						*	9.9	-
	Total Oxidized Nitrogen	mg/L	14	0	3.35			*	9.91	-
	Total Phosphorus	mg/L				26	7	0.048*R	0.052	-
Metals	Aluminium	mg/L							< 0.003*	0.1 (GV)
	Arsenic	mg/L	4	0	0.00125*				< 0.001*	0.01
	Arsenic	mg/L	8	0	0.0013R					0.01
	Boron	mg/L	15	0	0.069R	70	0		0.045*	1.4
	Cd	mg/L	5	5	< 0.00005*					0.004
	Cd	mg/L	6	6	< 0.000053R					0.004
	Copper	mg/L	15	6	0.00092R				< 0.0005*	2
	Copper	mg/L								2
	F	mg/L	6	6	< 0.05	55	13	0.03*		1.5
	Iron	mg/L	15	14	0.057R	70	58	0.01*	< 0.02*	0.2 (GV)
	Manganese	mg/L	9	8	0.00078*	65	63	< 0.005*	0.0006*	0.04 (GV)
	Manganese	mg/L	15	13	0.00079R					0.04 (GV)
	Sb	mg/L	1	1	< 0.00021					0.02
	Si	mg/L as SiO_2	3	0	36*	69	0.0	80.1*		-
	Si	mg/L as SiO_2	1	0	82					-
	Zinc	mg/L	4	2	0.0015*				0.012*	1.5
	Zinc	mg/L	10	3	0.0017					1.5
	Zinc	mg/L	5	2	0.002R					1.5

* dissolved
R reactive