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Uki Dele
Timaru District Council
Via email: Uki.dele@timarudc.govt.nz

Dear Uki

RE: CONTAMINANT TRANSPORT ASSESSMENT FOR GERALDINE STORMWATER CONSENT APPLICATION

1.0 Introduction

Pattle Delamore Partners Ltd have been engaged by Timaru District Council (TDC) to assess the potential for stormwater infiltration to affect the quality of shallow groundwater potentially used by downgradient supply bores to the southeast of Geraldine. TDC are currently applying to continue to discharge stormwater into land for the Geraldine Township urban catchment. There are many sources of stormwater discharge from impervious surfaces (roads, driveways and roofs) to stormwater infiltration systems (TDC sumps/soak pits and residential sumps/soak pits) within the stormwater management area (SMA), all of which may result in the transport/infiltration of microbial pathogens into the shallow groundwater system.

According to the ECan database, there appear to be four active (three of which are shallow, or possibly shallow in the absence of construction information) domestic supply bores within the east SMA or in the immediate vicinity (about 50 m) of the east SMA. These three bores are K38/1714 (10.5 m deep), K38/1283 (unknown depth), and K38/0232 (10 m deep) and are shown on Figure 1 (note bore K38/1284 is a stockwater bore next to domestic bore K38/1283). They are considered at risk of abstracting groundwater with microbial concentrations above the Maximum Acceptable Value for *E. coli* (<1 cfu/100ml) in the Drinking-water Standards for New Zealand 2005 (Revised 2018) due to their shallow construction and vulnerability to a number of microbial sources, one of which is the TDC/residential stormwater discharges to ground within the SMA in the immediate vicinity of the bores. Prior to this quantitative assessment of effects, a default estimated extent of 500 m was used to identify potentially affected bores (which is also shown on Figure 1).

Owners of the three shallow bores identified above should be contacted to confirm, that if they are in use, that they provide an appropriate level of treatment for microbial pathogens given the shallow nature of the bores and vulnerability to a number of sources, or to confirm that they utilise the nearby water supply network for their drinking water supply.

Active domestic supply bore BZ19/0205, also within the SMA, has a deeper top screened interval (33.5 m below ground level), however a level of risk from a number of sources is still expected, due to an absence of continuous confining strata, and potential for shallow groundwater ingress into/along the well casing, depending on the bore construction. We note that the listed owner of this bore also holds Resource consent CRC184264, which includes infiltration basins within 50 m of the bore (Ref Plan CRC184264B) with authorised discharges to ground with groundwater depths up to 200 mm below the base of the infiltration basin. The effects on this bore are deemed assessed under CRC184264, and it is expected that this consent will remain in place until the discharge is acceptable under TDC's SWMP requirements.

The risk of the use of other active non-domestic bores within/directly downgradient of the SMA for drinking water is considered low as their recorded use is for water level observation, geotechnical investigation or irrigation/stock for bores and the SMA is serviced by the TDC reticulated water supply network. Other active domestic bores at further downgradient distances from the discharges within the SMA are further addressed below.

The TDC/residential stormwater discharges within the SMA are located where groundwater appears to potentially be relatively shallow; between about 2 and 6 m below ground level (bgl) as indicated on Figure 2 and possibly shallower (within a metre of ground level) at times. This suggests that stormwater discharges to ground (both TDC and residential) within the SMA during heavy precipitation events may receive limited treatment in the vadose zone before reaching groundwater. This letter outlines the results of contaminant modelling carried out to assess the risk to drinking water supply bores abstracting shallow groundwater from *E. coli* in the stormwater reaching groundwater and provides recommendations regarding that risk. The results of the worst-case scenario modelling described in this letter suggest that it would be a conservative approach to contact owners of active domestic bores within the 500 m downgradient area previously identified (Figure 1) along with the other domestic bores noted above within the SMA.

2.0 Site Location and Hydrogeological Setting

2.1 Site Location

The TDC/residential stormwater discharge points are located within the Geraldine stormwater management zone, which covers the Geraldine township (Figure 1). The nearest major surface watercourse is the Waihi River, which divides the eastern and western SMA areas. The 1:50k scale topographic map indicates that there are also two minor surface water courses that flow through the western SMA and ultimately into the Waihi River (Figure 1). The locations of specific soak pits for road discharge are identified on Figure 1 and in addition to these, there are numerous discharge points to ground for roof and residential hardstand run-off on individual properties. All stormwater in the eastern SMA is discharged to ground, while by inspection, it is estimated that 50% of the stormwater from the western SMA discharges to the Waihi River.

2.2 Geology and Groundwater Information

Data from the ECAN GIS database indicates that soils immediately beneath the SMA range from imperfectly drained to moderately well drained soils, however TDC/residential stormwater discharge points may discharge beneath the soils to the underlying gravelly strata, depending on their depth/construction.

The 1:250k scale geological map of the area indicates the strata beneath the soils consists primarily of late last glacial alluvium comprised of mainly gravel with some sand, silt, and clay (Q2a, Figure 3) across both the eastern and western SMAs. The upgradient area (northwest side) of the western SMA is underlain by basalt rock while the southern area of the western SMA is in an area of young terrace/plain alluvium comprised of mainly gravel with some sand, silt, and clay. Borelogs listed on the ECan database for bores within 2 km of the management zone are consistent with the geological map, indicating that gravels extend to depth beneath the stormwater management zone and within a 2 km radius of the site (aside from the areas of basalt rock described above). The borelogs also indicate that there is some stratification within the gravels, with some layers described as claybound gravels and others as gravels and/or loose gravels. The thickness of these layers varies and it is difficult to correlate these layers between boreholes, which implies that the variations may represent more permeable gravelly lenses within the overall sequence of claybound or less permeable gravelly strata.

Piezometric contours provided on the ECan GIS database indicate that the overall groundwater flow direction is southeast, although minor, local scale variations are likely. The contours available for the area represent a number of monthly surveys (Orari water table surveys) conducted between 2006 and 2007 with relatively consistent results (Figure 1) with relatively deeper groundwater levels in October 2006 and shallower conditions in December 2006.

Depth to groundwater below the ground surface estimated from the October 2006 groundwater elevation contours relative to a 2014 LiDAR digital elevation model (Figure 2) suggests that groundwater may be between 2 and 6 m below ground level (bgl) throughout most of the eastern and western SMAs. This appears to be somewhat similar to initial water levels recorded at wells (Figure 2), however, December 2006 groundwater elevation contours (also part of the Orari water table surveys 2006 to 2007, ECan) suggest groundwater may rise to shallower depth throughout most of the SMA. The limited groundwater level data available suggests shallow groundwater may only rise within about 1.5 m bgl, but it should be noted that the water level data from any particular bore within/around the SMA does not appear to exceed a count of 5 measurements, so it is possible that the highest shallow groundwater conditions have not been fully captured within the ECan database. The Orari water table surveys 2006 to 2007 suggest that, within the downgradient area of both the west and east SMA, the lateral hydraulic gradient is about 0.009 (Figure 1).

Some connectivity is expected with the Waihi River and response of groundwater levels to rainfall is expected. No groundwater level information appears to be available for periods when the Waihi River is in flood or during and after heavy rainfall.

A resource consent has recently been issued by Environment Canterbury for infiltration basins at Mckenzie Lifestyle Villas permitting a seperation to groundwater of 200 mm. It is understood that this consent was revised following a wetter than average year in 2017 with groundwater levels close to surface level.

The stormwater management plan is addressing these limitations in information on groundwater with continuous groundwater level monitoring for a minimum of three years to establish better estimates of the maximum groundwater levels in the SMA.

3.0 Potential Receptors

3.1 Domestic Water Supply Bores

Figure 1 shows the location of active domestic supply wells that lie within the SMA and/or within the 500 m downgradient area of the SMA. These wells are potential receptors to microbial pathogens that may be transported in groundwater as a result of the stormwater discharges to ground within the SMA. At present, it is unknown if owners of these bores currently utilise the bores for their drinking water supply and/or utilise the reticulated water supply network and/or provide an appropriate level of treatment to the groundwater abstracted from the bores. It is acknowledged that these bores, particularly shallow bores, will be vulnerable to microbial pathogens from a number of other sources, such as wastewater discharges, agricultural land use and river water recharge and should be receiving appropriate treatment if they are in use.

3.2 Commercial/Industrial Water Supply Bores

There are no commercial/industrial bores within the SMA or 500 m downgradient area, however there is the shallow TDC bore K38/2304 about 650 m downgradient of the west SMA. According to the ECan database, this bore is only used for sewer water dilution.

3.3 Irrigation and Stockwater Water Supply Bores

Two active bores with irrigation recorded as the only/primary use are located about 110 m downgradient of the western SMA (J38/0855 and J38/0246, Figure 1). They are relatively shallow (22 and 8 m bgl respectively). Similarly, stockwater/irrigation bore BZ19/0100 is noted as active/shallow and is within about 40 m of the west SMA. The next closest active stockwater/irrigation bores appear to be 300 to 380 m cross-gradient (east) of the east SMA (shallow irrigation bores K38/0481 and K38/1311, Figure 1). These irrigation/stockwater bores are not listed as for drinking water, so are not considered potential receptors for this assessment of effects on drinking water.

3.4 Public Drinking Water Supply Sources

With regard to public supply wells in the area, Figure 4 indicates that the Temuka community supply bore K38/0487 protection zone overlaps a small section of the western SMA. This well is a very shallow infiltration gallery (2 m deep) next to a stream (a first order tributary of the Raukapuka Stream that flows out of the eastern SMA) and about 2.5 km downgradient (in terms of December 2006 groundwater elevation contours) from the western SMA. TDC have confirmed that this community supply is not being used previously during this consenting process.

Other community supply bores in the area are over 4.5 km downgradient distance or over 1.8 km distance cross-gradient from the SMA and are not considered at risk of contamination from stormwater discharges within the SMA, which is supported by the modelling undertaken.

4.0 Source Flows and Concentrations

4.1 Rainfall/Stormwater Flow

The total volume of stormwater flow being discharged to ground across the SMA is calculated based on two scenarios - average annual rainfall and a simulated high-intensity rainfall event.

It is assumed that 50% of the SMA comprises impermeable surfaces. The eastern SMA is a total of approximately 88 ha and the western SMA is a total of approximately 151 ha, so the assumed area of 50% impermeable surfaces is about 44 ha and 76 ha for the eastern/western SMA. The assumed 50% impermeable surfaces was checked by estimating impermeable surfaces from recent Sentinel-2 infrared imagery. Figure 5 suggests impermeable surfaces can be reasonably estimated at about 34% of the west SMA and at about 33% of the east SMA, however, due to the lower resolution of the infrared imagery and errors (in both directions) related to albedo and shadow effects and an allowance for future infill, an assumed 50% impermeable surface as described above is conservatively applied to the modelling inputs for both the east and west SMA.

Precipitation data available through the NIWA database indicates the closest station is at the Orari Estate about 6 km southeast of Geraldine. Daily precipitation totals from this station since 1897 suggest an average daily precipitation of about 2 mm/d. This equates to a total average daily flow into the infiltration systems within the east and west SMA of 586 m^3/d and 1,034 m^3/d respectively considering the estimated impervious areas (33 and 34%) described above. The assumed 50% impervious areas results in larger average daily discharges of 882 m^3/d and 1,508 m^3/d for the east and west SMA. Note that these average daily flows are conservatively high as it assumes that all rainfall on impermeable surfaces enters the stormwater system and neglects evaporation and misconnection effects. By inspection, it is estimated that 50% of the stormwater directed by impermeable surfaces in the west SMA flows into the Waihi River, so all west SMA modelled scenarios apply half of the estimated flows into infiltration systems. This gives a total average flow of 754 m^3/d (275,200 m^3/yr) being discharged to ground in the western SMA.

The high intensity rainfall event considered has been a first-flush (25 mm event) at 5 mm/hr for 5 hours. Higher microbial concentrations occur within a first flush rainfall event. This results in a flow rate of

2,205 m^3/hr and 3,770 m^3/hr over the 5 hours for the eastern and western SMA areas, respectively, assuming 50% impervious area, which results in a total daily flow of 11,027 m^3/d and 18,848 m^3/d for the eastern and western SMA areas, respectively. Assuming 50% of the western SMA stormwater flow from impervious areas discharges to ground, with the remainder to surface water, gives 1,885 m^3/hr and 9,424 m^3/d discharged to ground for a 5h duration storm at 5 mm/hr.

4.2 Contaminant Levels

Concentrations of *E. coli* within stormwater are highly variable. Three scenarios have been modelled to consider the range in input concentrations – an average annual concentration, a typical first flush concentration and a high first flush concentration. For all scenarios, it has been conservatively assumed that no *E. coli* is removed from stormwater as it filters through the unsaturated zone beneath the discharge location and the full initial concentration is applied at the water table.

For the average annual concentration scenario, Auckland Regional Council Technical Publication 10 (ARC TP 10, 2003) lists Faecal Coliform annual loading rates for a variety of different land uses, including Residential (high) landuse. The value of 1.5 x 10^{10} cfu / ha / year (Residential (high), Table 4-4) is considered to be representative of the residential setting in the SMA and a reasonable estimate of annual average loading rates and have been adopted for the modelling (note Residential (low) loading estimate is similar to the loading rate above at 9.3 x 10^9 cfu/ha/yr). For the purposes of the model, it is conservatively assumed that all Faecal Coliforms are *E. coli*. Based on the loading rate from ARC above and the average flow into the infiltration systems presented in the preceding section of his letter, a constant source concentration of 205 cfu / 100 ml has been used in the model.

For the typical first flush concentration, the initial *E. coli* concentration has been set to 2,500 cfu/100 ml. This is also comparable to *E. coli* measured in the Waihi River during higher flows. This has been assumed to apply to the whole 5-hour duration storm, which is considered to be conservative.

An additional first flush scenario that considers the effect of a much higher concentration of *E. coli* (24,000 cfu/100 ml) introduced during a first flush event has also been modelled. As above, this has been assumed to apply to the whole 5-hour duration storm, which is considered to be conservative.

The above concentrations of E-coli have been compared with documented levels of *E. coli* in stormwater as listed in the table below.

Table 1: Documented levels of E. coli in stormwater (count per 100 ml)

Study	No Of Samples	Max	Mean	Median	90%	Commentary
Urban stormwater studies						
CCC (2020)[1]	7	24,000	12,007	10,000	24,000	City wide Urban waterways
Boffa Miskell (2018)[2]	90	24,000	5,763	2,550	17,000	City wide Urban SW Outfalls
Williamson 1993[3]			97			Brough (2012)[4]
Brough et al 2012[4]	2	145	75			Residential Noted that highly variable and depended on land use

Table 1: Documented levels of E. coli in stormwater (count per 100 ml)

Study	No Of Samples	Max	Mean	Median	90%	Commentary
						and contributing greenspace
Roof Collection Studies (All sourced from MOH(2019))[5]						
Dennis (2002) - South Wairarapa[6]	60					Roof supplies Most < 500 /100 ml , only 2 > 550 / 100 ml
Sedouch(1999) Lower N island[7]	100					18% Roof Supplies > =1 /100 mL, 4% > 150/100 ml
Simons et al (Auckland)[8]	125					56% > WHO Drinking water guidelines
Verrinder & Keleher 2001 (Australia)[9]	100					38% >=1 /100 ml
Coombes et al 2000 (Australia)[10]			120			(no non compliances in hot water tanks)
WQRA(2010) Adelaide [11]	973	2,400	0			

Notes:

1. *CCC(2020) CRC190445 Comprehensive Stormwater Network Discharge Consent Annual Report June 2020 https://www.ccc.govt.nz/assets/Documents/Environment/Water/CSNDC-Annual-Reports/CSNDC-annual-report-2020.pdf*
2. *Tauranga Stormwater and SORE Monitoring % Year Monitoring Report Prepared for Tauranga City Council 5 June 2018 Boffa Miskell*
3. *Williamson (1993) Urban Runoff Data Book NIWA*
4. *Brough et al (2012) Runoff from Modern Subdivisions and Implications for Stormwater Treatment A Brough (PDP), R Brunton (PDP), M England (SDC), R Eastman (CCC) 2012 SW Conference*
5. *MOH(2019) Ministry of Health :Drinking Water Supply Guidelines Chapter 19*
6. *Dennis (2002) A Survey to Assess the Bacterial Quality of Roof-collected Rainwater in the Wairarapa. BHlthSc 214.318 Environmental Health Research Project. Massey University, Wellington, New Zealand*
7. *Sedouch(1999) - Sedouch V. 1999. Total Coliform and Faecal Coliform Detection in Roof Water. BAppSc 3330 NBSEH Environmental Health Research Project. Massey University, Wellington, New Zealand*
8. *Simons et al ( ) Simmons G, Gould J, Gao W, et al. 2000. The design, operation and security of domestic roof-collected rainwater in rural Auckland. Proceedings of the Water 2000 Conference 'Guarding the Global Resource'. Auckland: New Zealand Water and Wastes Association. Session 3; pp 1–16*
9. Verrinder G, Keleher H. 2001. Domestic drinking water in rural areas; are water tanks on farms a health hazard? *Environmental Health* 1: 51–6
10. *Coombes et al (2000) Coombes P, Argue J, Kuczera G. 2000. Rainwater Quality from Roofs, Tanks and Hot Water Systems at Fig Tree Place. Perth: Third International Hydrological and Water Resources Symposium, pp 1042–7*
11. *WQRA (2010) WQRA. 2010. Quality of stored rainwater used for drinking in metropolitan South Australia. Research Report 84. 56 pp. http://www.waterra.com.au/publications/featured-publications/.*

Brough (2012) commented that *E. coli* levels in stormwater can vary widely and depend on extent of greenspaces drained to the stormwater system. Stormwater runoff from greenspaces can be affected by "naturalised" levels of *E. coli* in the soil that can cause elevated concentrations of *E. coli* even though no faecal source with pathogens are present (Ferguson et al., 2011; Ishii et al., 2006; Ishii & Sadowsky, 2008).

High levels of *E. coli* can also be present from wastewater overflows that discharge to the stormwater system. A number of studies into roof water collected for water supplies all indicate that concentrations from roof drainage are comparatively low (typically < 500 *E. coli* /100 ml).

Therefore, provided wastewater overflows are not present we would expect that any levels of *E. coli* in stormwater discharged to ground at discrete discharge points in Geraldine will be relatively low and higher values will be derived from other sources or indicative of naturalised non-pathogenic bacteria.

The above hypothesis is supported by water quality monitoring of *E. coli* levels in the Waihi River, both within the stormwater management area at Wilson Street and upstream at the Waihi Gorge, which indicate the same maximum *E. coli* levels of approximately 2,500 cfu/100ml measured at both sites, (i.e. there is no evidence that stormwater discharges in Geraldine have a significant effect on the maximum *E. coli* levels in the Waihi River) (https://www.lawa.org.nz/explore-data/canterbury-region/swimming/waihi-river-upstream-of-wilson-street-bridge/swimsite and https://www.lawa.org.nz/explore-data/canterbury-region/swimming/waihi-r-at-waihi-gorge/swimsite (accessed 12/8/21))

5.0 Contaminant Transport Modelling

5.1 Modelling Methodology

The microbial transport within the groundwater system above has been modelled using a three-dimensional analytical model that allows for analytical solution of equations for contaminant transport. The analytical solutions used are those freely available in Dr Bruce Hunt's Function.xls (available here: https://sites.google.com/site/brucehuntsgroundwaterwebsite/). These are solutions to the advection-dispersion-reaction equation. Die-off of pathogens can be accounted for in the reaction component of the equations, via a temporal removal rate (inactivation over time), but other removal mechanisms are not accounted for (e.g., adsorption, which has a spatial removal rate). Ignoring adsorption provides for a conservative assessment.

The model assumes that the aquifer is infinite in extent, homogenous and isotropic. The stormwater discharge is modelled as a constant concentration and mass flux line source within the aquifer and this has been set at the downgradient (southeast) edge of the eastern and western stormwater management zone with a length equal to the maximum cross-gradient distance within the mid areas of the east and west SMA. This is conservative as in reality the discharge of stormwater contaminants is dispersed over a large area rather than concentrated along a discrete line along the downgradient edge. Groundwater flow velocity

Relatively limited information is available regarding hydraulic properties for the shallow aquifer in the area of the SMA, from which to calculate groundwater flow velocities. The only shallow aquifer pumping test information near the SMA is for bore K38/1312 (8 m deep about 310 m east of the eastern SMA, Figure 1) within an area of gravelly late last glacial alluvium (Q2A, Figure 3) that extends across most of both the east and west SMA. Aquifer transmissivity at bore K38/1312 is estimated at 822 m^2/d according to the ECan database with a geologic log showing claybound gravels interbedded with gravels. As no initial water level is reported for K38/1312 the adjacent bore K38/1311 (9.5 m, 100 m distance) could be applied with an initial depth to groundwater of 1 m bgl resulting in an estimated saturated thickness up to about 8.5 m to the depth of the bore, resulting in a bulk hydraulic conductivity estimate of about 100 m/d, if no flow in deeper strata is allowed for.

Bore K38/0232 (10 m deep within the middle of the east SMA) has a reported specific capacity of 6.33 l/s/m. Using the Bal (1996) relationship, relating specific capacities to transmissivity, results in an estimated aquifer transmissivity of 1756 m^2/d. A relatively deep borelog is available for bore BZ19/0042 (59.5 m deep and about 450 m southeast of the eastern SMA), which indicates a relatively continuous sequence of gravelly strata with some silt/sand content and no definitive aquitard layers. As a result, the transmissivity estimates above could be applied to greater saturated thicknesses resulting in hydraulic conductivity values lower than 100 m/d noted above. Overall, a hydraulic conductivity of 100 m/d is likely to be typical of gravel aquifers considering Kruseman and de Ridder 1994 and, given the description of the strata in the area, is considered a reasonable estimate, however, where the strata has a higher fines content the hydraulic conductivity would be expected to be lower and, conversley, preferential flow paths through interconnected gravelly lenses with less fines content may exhibit higher hydraulic conductivites (and lateral porewater velocities), which is considered in various contaminant transport scenarios described below.

About 200 m south of the west SMA, bore J38/0553 (screened 4.8 to 17.8 m bgl and located in an area of young terrace/plain alluvium (Q1a), Figures 1 and 4) has a reported specific capacity of 0.68 l/s/m. Using the Bal (1996) relationship, relating specific capacities to transmissivity, the calculated transmissivity for this bore is relatively low at about 205 m^2/d. A slightly higher transmissivity may be apparent at BZ19/0100 (10 m deep 50 m from the south of west SMA) with a specific capacity of 2 l/s/m resulting in an estimated transmissivity of about 580 m^2/d. The deeper borelog available for bore J38/0735 (34 m deep, about 400 m west of the west SMA) suggests the shallow aquifer in the western SMA may be limited to a depth of about 29 m bgl above a significant layer of clay with some gravel (from 29 to 34+ m bgl). Applying this potentially greater saturated thickness to the transmissivity estimates above would however result in hydraulic conductivities below 100 m/d. To provide a conservative estimate of transport, the contaminant transport modelling for the western SMA adopts the 100 m/d estimated from the aquifer test near the eastern area described above and also adopts a significantly higher conductivity to simulate preferential flow paths and possible higher linear porewater velocities that may not be captured by the limited specific capacity information in the area.

To calculate average linear velocities, the estimated hydraulic conductivity of 100 m/d was used together with the lateral hydraulic gradient of 0.009 m/m and an estimated effective porosity of 0.25 for the gravelly strata present. This provided an average linear velocity estimate of 3.6 m/d.

In addition to this, the possibility of preferential flow in higher hydraulic conductivity zones (for example buried paleo channels) was allowed for by considering flow at velocities of up to 200 m/d. If this preferential flow occurred, it would be expected to occur in relatively limited zones that may not connect for significant distances. The upper velocity limit of 200 m/d is based on a consideration of velocities measured in tracer tests in other gravel aquifers in New Zealand and may be much higher than velocities that could potentially occur here, depending on the degree of fines in the gravel matrix.

5.2 Die-off and Absorption Mechanisms

Bacterial concentrations will reduce over time through natural die-off and this decay is represented in the modelling as a decay constant of 0.15 d^{-1} in accordance with Foppen and Schijven, 2006, which suggests this is the average *E. coli* die-off at 10 ˚C. Foppen and Schijven (2006) suggest the die-off rate increases with temperature, and groundwater temperatures may be higher in Geraldine.

To provide a conservative assessment, other microbial removal processes such as adsorption have been ignored at present. Pang (2009) presents information on other removal processes such as adsorption based on field testing. Schijven, Pang, and Ying (2017) also summarise the removal rates from Pang (2009). Adsorption could be modelled if required, but at this stage, only die-off has been provided for.

5.3 Dispersion

The other major process that acts to reduce contaminant concentrations within groundwater is dispersion. Typical values for dispersion are used in the model where longitudinal dispersion is 10 % of the travel distance (i.e., dispersion in the direction of groundwater flow), lateral dispersion is set to 10 % of longitudinal dispersion (i.e., dispersion perpendicular to groundwater flow), and vertical dispersion is set to 10 % of lateral dispersion (Fetter, C. W., 1999., Figure 2.17).

5.4 Modelling Scenarios

Four different modelling scenarios were used, described below. All scenarios used the continuous line source models in Dr Bruce Hunt's Function.xls, which was appropriate for the both the yearly average and first flush scenarios given the time period of assessment and modelled flow velocities.

1. Yearly average scenario, where the source is represented as a line source extending across the downgradient edge of the stormwater management zone (line length of 1.2 km west SMA, 0.8 km east SMA). Hydraulic conductivity is set to 100 m/d (pore velocity of 3.6 m/d) and this scenario uses the average daily flows described above over the course of a year. Source concentrations are set to 205 cfu/100 ml.
2. A high conductivity yearly average scenario, where preferential groundwater flow occurs through interconnected, high permeability, gravelly lenses. The expected pore flow velocity was set to 200 m/d (which indicates a hydraulic conductivity of 5,557 m/d for a gradient of 0.009 and assumed effective porosity of 0.25) and a source concentration of 205 cfu/100 ml is applied with average daily flows over the course of a year. This scenario also considers that 1% of the stormwater discharge could flow into/through a preferential flow path. This is based on Dann et al. (2008), who suggest preferential flow paths occur within around 1% of an alluvial aquifer. Given the stormwater discharges in Geraldine are dispersed over numerous discharge points, it is assumed that 1% of these could discharge to preferential flow paths.
3. A first flush scenario that considers the effect of a concentration of *E. coli* (2,500 cfu/100 ml) introduced during a first flush event during the course of the first day of a storm with 25 mm/day rainfall (considering a storm event of 5 mm/hr for 5 hours) and pore velocity of 200 m/d. This scenario also considers that 1% of the stormwater discharge could flow into/through a preferential flow path).
4. A worse case high conductivity high concentration first flush scenario with the same parameters/timeframe as scenario 4 above but with a pore flow velocity adjusted to 200 m/d and the assumption that 1% of the stormwater could enter a preferential flow path.

Table 2: Model Scenario Summary Table

Scenario	Input E. coli Concentration (cfu / 100 mL)	Source Flow (m3/d)	Flow Velocity (m/d)	Effective Porosity	Die-off Rate (d^{-1})	(d)
Scenario 1 E SMA	205	882	3.6	0.25	0.15	365
Scenario 1 W SMA	205	754	3.6	0.25	0.15	365
Scenario 2 E SMA	205	8.8	200	0.25	0.15	365
Scenario 2 W SMA	205	7.5	200	0.25	0.15	365
Scenario 3 E SMA	2,500	110	200	0.25	0.15	1
Scenario 3 W SMA	2,500	94	200	0.25	0.15	1
Scenario 4 E SMA	24,000	110	200	0.25	0.15	1

5.5 Modelling Results

The Maximum Acceptable Value (MAV) for *E. coli* within drinking water is less than 1 cfu/100 ml and this is the standard against which the results have been assessed.

1. The results from Scenario 1 (yearly average scenario) indicate that concentrations of *E. coli* are likely to exceed the MAV no more than approximately 90 m downgradient of the east SMA and 70 m downgradient of the west SMA. This result is conceptually consistent with the input parameters for the scenario; the advective velocity within the aquifer (3.6 m/d) and the decay of *E. coli* (0.15 log cycles/d) means that the initial concentration of *E. coli* would reduce to the MAV within about 36 days. Considering the timeframe and advective velocity above, the addition of dispersion/dilution effects somewhat reduces the downgradient extent where exceedances could be expected. The results from this scenario indicate that no shallow domestic supply wells or public supply wells at further downgradient distances of the east/west SMA are likely to be at risk from contamination by *E. coli* in terms of average daily discharges and the expected bulk porewater velocity. This scenario also suggests that the active domestic bores within/immediately adjacent to the east SMA (Figure 1) could be considered at risk of exceedances of the MAV, as already identified in the introduction to this letter.

2. The results from Scenario 2 (yearly average scenario with a high permeability preferential flow path) indicate that concentrations of *E. coli* are not likely to exceed the MAV beyond 10 m downgradient of the east and west SMA in a preferential flow path primarily because of significant dilution effects (introduced by the high porewater velocity of 200 m/d) and the low input volumes (average daily rainfall) and relatively low input concentration (205 cfu/100 mL).

3. The results from Scenario 3 (first flush scenario into a preferential groundwater flow path) indicate that concentrations of *E. coli* are not likely to exceed the MAV more than 60 m downgradient of the east and west SMA. This result is primarily a result of the limited timeframe of the first flush model that only considers transport over a day but relatively higher inputs and porewater velocities during that time.

4. The results from Scenario 4 (first flush scenario with high initial concentration into a preferential groundwater flow path) are considered as a worst-case scenario that could still be considered hypothetically plausible in terms of the environmental setting. The results indicate that concentrations of *E. coli* are likely to exceed the MAV no more than 210 m downgradient of the east SMA and no more than 180 m downgradient of the west SMA.

One uncertainty with the modelling inputs and results above is the effective porosity constant of 0.25 used for all scenarios. This is considered reasonable for the gravelly strata present, but as illustrated by Dann et al. (2008) in Table 3 of that paper, a range of values may be present. A minimum of value 0.13 could however be expected based on the findings from the study above and if a value of 0.13 is conservatively applied in addition to all the other conservative inputs to the worst-case scenario 4, exceedances of the MAV from the SMAs are modelled to extend further. For the lower porosity, allowing the same mass of contaminants to enter over a longer time period indicates a greater potential extent of exceedances of the MAV and suggests that these effects could extend up to 330 m from the downgradient edge of the east SMA after 2 days.

It should be noted that modelling preferential flow paths over this scale (hundreds of metres) is considered unrealistic, with a low probability of occurrence, as the likelihood of a channel continuing over this distance and directly connecting a discharge point to a drinking water supply bore is considered very low. The available bore testing in the vicinity to date indicates lower aquifer hydraulic conductivity.

Overall, the risk of any impacts of the stormwater discharge from Geraldine on *E. coli* concentrations in down-gradient supply bores is expected to occur over a much shorter distance. The risk of elevated *E. coli* concentrations occurring in groundwater decreases with distance from the stormwater discharge locations. The modelling in this letter has indicated that the 500 m distance originally proposed for identification of potentially affected bores is conservative.

6.0 Other Sources

Regardless of the stormwater discharges present, all groundwater bores identified as potential receptors in terms of this assessment are considered to be classified as unsecured Drinking Water Sources, as classified by the NZ Drinking Water Supply Guidelines (2019) and should not be relied on as a potable drinking water supply source unless a reliable/appropriate level of treatment is provided.

This classification is supported by the groundwater quality information available from Environment Canterbury water quality database as outlined in the AEE.

Principal contaminant sources include but are not limited to:

a) Domestic and non-domestic animals including agricultural land use

b) The Waihi River

c) Stormwater and wastewater discharges outside the SMA

On-site wastewater discharges and agricultural land use typically have higher source *E. coli* concentrations and depending on their proximity to the affected bores and level of leaching, would also be expected to present a risk to some of the bores.

Owing to the volume of water potentially lost from the river to groundwater, the Waihi River is considered a significant source of *E. coli* to groundwater and is considered to present a similar or greater risk to the bores identified as potentially affected from stormwater in this letter. The LAWA water quality data base records maximum *E. coli* levels of up to 2500 cfu/100 mL both at the upstream Waihi Gorge (https://www.lawa.org.nz/explore-data/canterbury-region/swimming/waihi-r-at-waihi-gorge/swimsite) and Wilson Street Site within Geraldine (https://www.lawa.org.nz/explore-data/canterbury-region/swimming/waihi-river-upstream-of-wilson-street-bridge/swimsite). For the first flush scenario, a total of 237 L/s of stormwater is discharged to ground (11,027 + 9,424 m^3/d). Considering the river width, depth to groundwater and reach length through Geraldine and likely bed permeability, the Waihi River could easily lose more water to groundwater than the stormwater discharges, especially during flooding. On this basis, the expected impact on pathogen concentrations in groundwater from the river is likely to be typically higher than the stormwater discharges.

It should also be noted that the permitted baseline level for stormwater is five properties discharging stormwater from 1,500 m^2, equating to a first flush volume of 37.5 m^3/d. The worse-case scenario if this discharge occurred at a first flush concentration of 24,000 cfu/100 ml as a point source within a preferential flow path at 200 m/d would give an estimated distance of MAV exceedances greater than Scenario 4, due to it being concentrated as a point source.

7.0 Mitigation Measures and Requirements

A review of treatment performance of various stormwater treatment options to remove *E. coli* has been undertaken from International Stormwater Best Management Practice Database (https://bmpdatabase.org/). Of a total of 952 records, only 26 measurements recorded *E. coli* at less than 1 cfu/100 ml. Removal rates varied from 0.004% -29,500% of influent levels. A total of 263 samples recorded higher levels of EC discharged than the influent and 276 samples (29%) with greater than 90% removal rate (i.e., 1 log removal rate)

Therefore, we would conclude that in general it is unrealistic for conventional stormwater treatment systems to be expected to provide effective treatment of microbial contaminants beyond 1 log removal rate or realistic to ensure compliance with *E. coli* levels at the point of discharge of less than 1 EC/100ml.

This highlights somewhat of anomaly between Schedule 8 of the LWRP and the permitted activity requirements rule which permits discharges to land.

However, as highlighted above, the Drinking Water Supply Guidelines (MOH, 2019) require treatment of shallow unconfined drinking water sources regardless of the presence of stormwater discharges. In the case of Geraldine, it is likely that other sources, such as the Waihi River provide, similar or much greater contaminant risks than stormwater discharges within Geraldine.

When considering the stormwater discharge as the sole contaminant source, the above modelled separation distances show that TDC are able to consider making available alternative water supplies to all the sources that may be identified as potentially affected drinking water sources in Geraldine.

The SWMP provides for ongoing monitoring of groundwater quality to understand specific effects of stormwater discharges and includes management of land use activities that may limit microbial contaminants with stormwater discharges to land (and surface water).

The SWMP also recommends best practice treatment for all new soakage discharges to minimise potential discharges of microbial contaminants to groundwater. This is anticipated to introduce new requirements such as a raingarden or other infiltration-based treatment device e.g., first flush sand bed to be introduced prior to soak holes. These measures will need to be developed for inclusion in TDC's Engineering Standards/ Code of practice as provided for in the SWMP.

Such measures have the potential to be retrofitted to existing road sumps and downpipes, should ground water monitoring indicate significant effects of stormwater discharges is unexpectedly occurring.

8.0 Summary

The modelling in this letter has indicated that the 500 m distance originally proposed for identification of potentially affected bores is conservative. The bores identified from ECan's online GIS database within a 500 m distance are shown on Figure 1 and summarised in Table 3.

There are considerable uncertainties and variabilities of the aquifer parameters and levels of *E. coli* in stormwater that affect the actual extent over which downgradient bores may be impacted.

Modelled effects from measured levels of *E. coli* in stormwater and aquifer characteristics in the surrounding area indicate that the cumulative effect of the discharges as potentially causing *E. coli* levels to exceed 1 cfu/100 ml no more than 100 m from the SMA.

A sensitivity analysis using very high *E. coli* levels based on national and international stormwater studies and highly permeable aquifer conditions observed elsewhere in alluvial gravel aquifers on the east coast of New Zealand, indicates that the cumulative effects from the discharges could be between 180 to 210 m. This is a similar distance to the accepted effect from a permitted activity discharge to land from up to five residential properties

It is important to note that these bores identified in the vicinity of the SMA, particularly shallow bores, will be vulnerable to microbial pathogens from a number of other sources, such as wastewater discharges, agricultural land use and river water recharge from the adjacent Waihi River and should be receiving appropriate treatment if they are in use, regardless of the discharge of stormwater to ground.

Table 3: Potentially affected bores (over conservative 500 m distance)

Distance Downgradient from SMA (m)	Well Number	NZTMX	NZTMY	Address	Listed Owner
0	K38/1283	1460098	5116276	595 Orari Station Road	Young, Alan
0	K38/0232	1460038	5116686	Tancred Road	Omelvena K A
0	BZ19/0205	1460129	5117146	Connolly Street	McKenzie Lifestyle Village
52	K38/1714	1460198	5117116	49 Connolly Street	Mr M R Kean
188	J38/0553	1459519	5114086	Geraldine-Winchester Highway	AD Dunstan
307	J38/0732	1459649	5113977	842 State Highway 72	Mr & Mrs Fj & Cm Daly
400	J38/0404	1459639	5113887	State Highway 72	Williams, R

9.0 Limitations

This report has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Environment Canterbury and others (not directly contracted by PDP for the work). PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the report. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

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References

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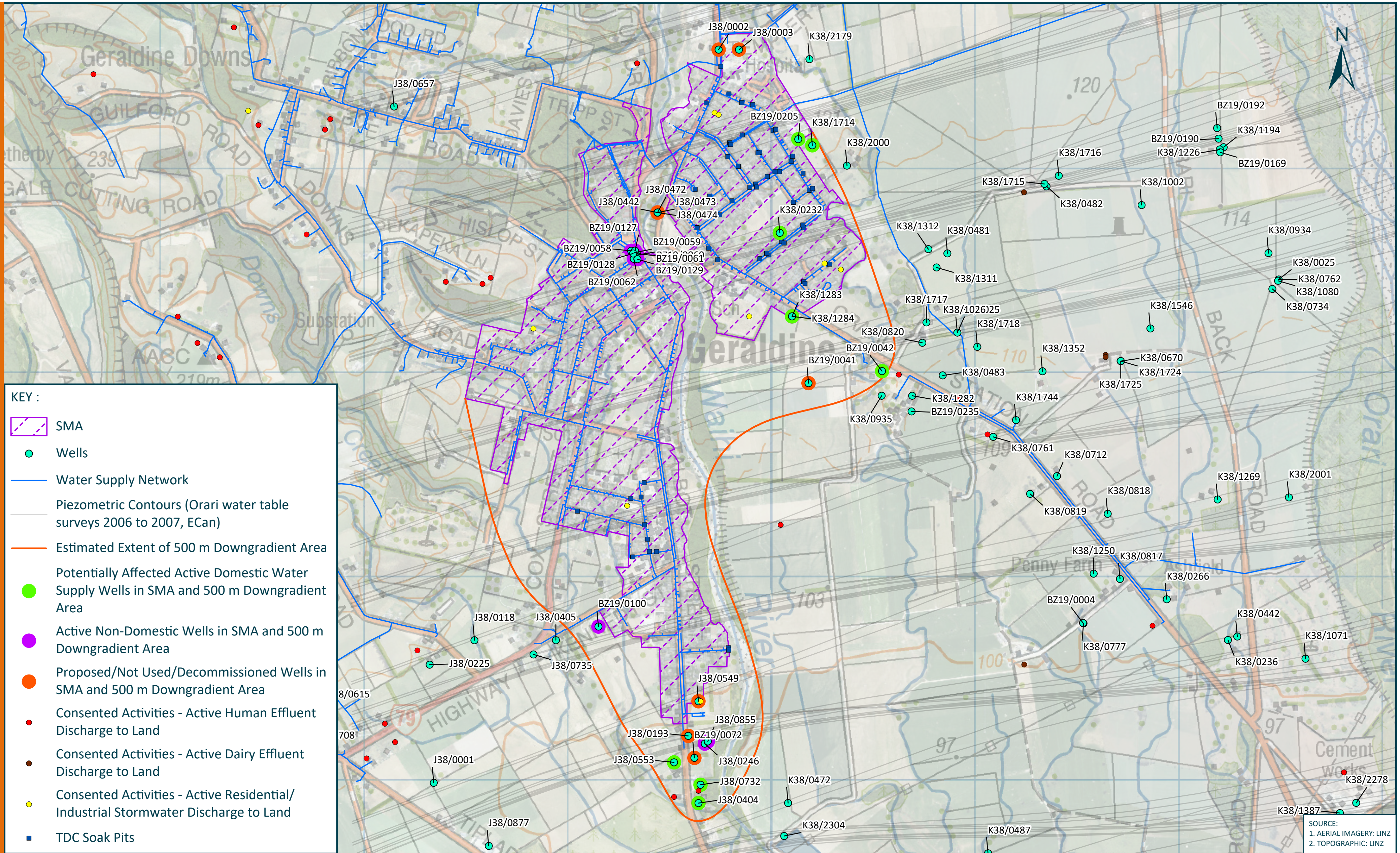
Ferguson D, Signoretto C. Environmental persistence and naturalization of fecal indicator organisms. Microbial Source Tracking: Methods, Applications, and Case Studies: Springer; 2011. p. 379-97.

Ishii S, Ksoll WB, Hicks RE, Sadowsky MJ. Presence and growth of naturalized Escherichia coli in temperate soils from Lake Superior watersheds. Appl Environ Microbiol. 2006;72(1):612-21.



C03489300.aprx - C03489300_FIGURE_1_POTENTIALLY_AFFECTED_WATER_SUPPLY_WELLS

0 155 310 620
METRES
SCALE : 1:25,000 (A4)

NO.	REVISION	DATE	BY
A	ISSUED FOR REVIEW		CJ

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FIGURE
FIGURE 1: POTENTIALLY AFFECTED WATER SUPPLY WELLS

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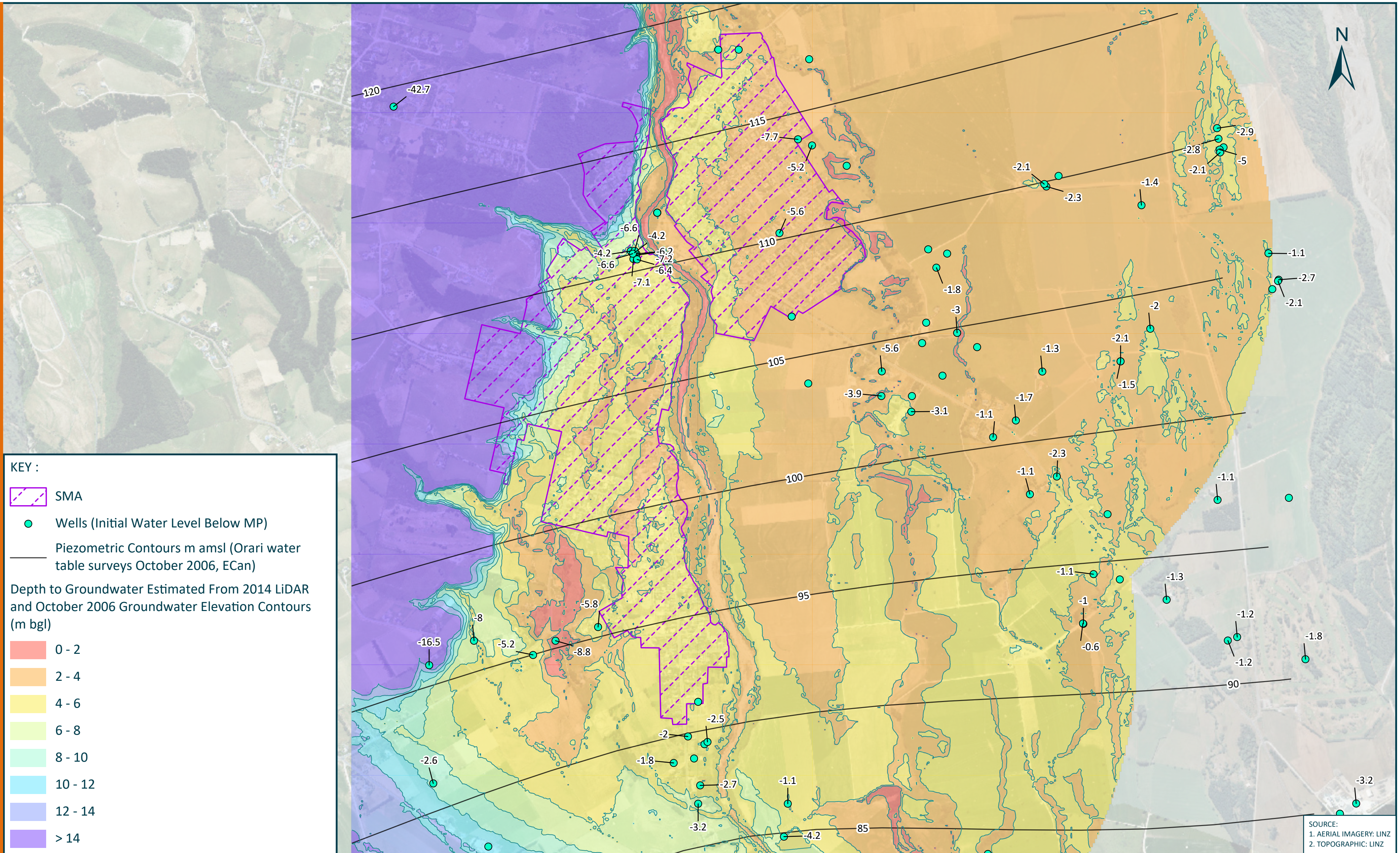
GERALDINE STORMWATER MANAGEMENT PLAN



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NO.	REVISION	DATE	BY
A	ISSUED FOR REVIEW		CJ

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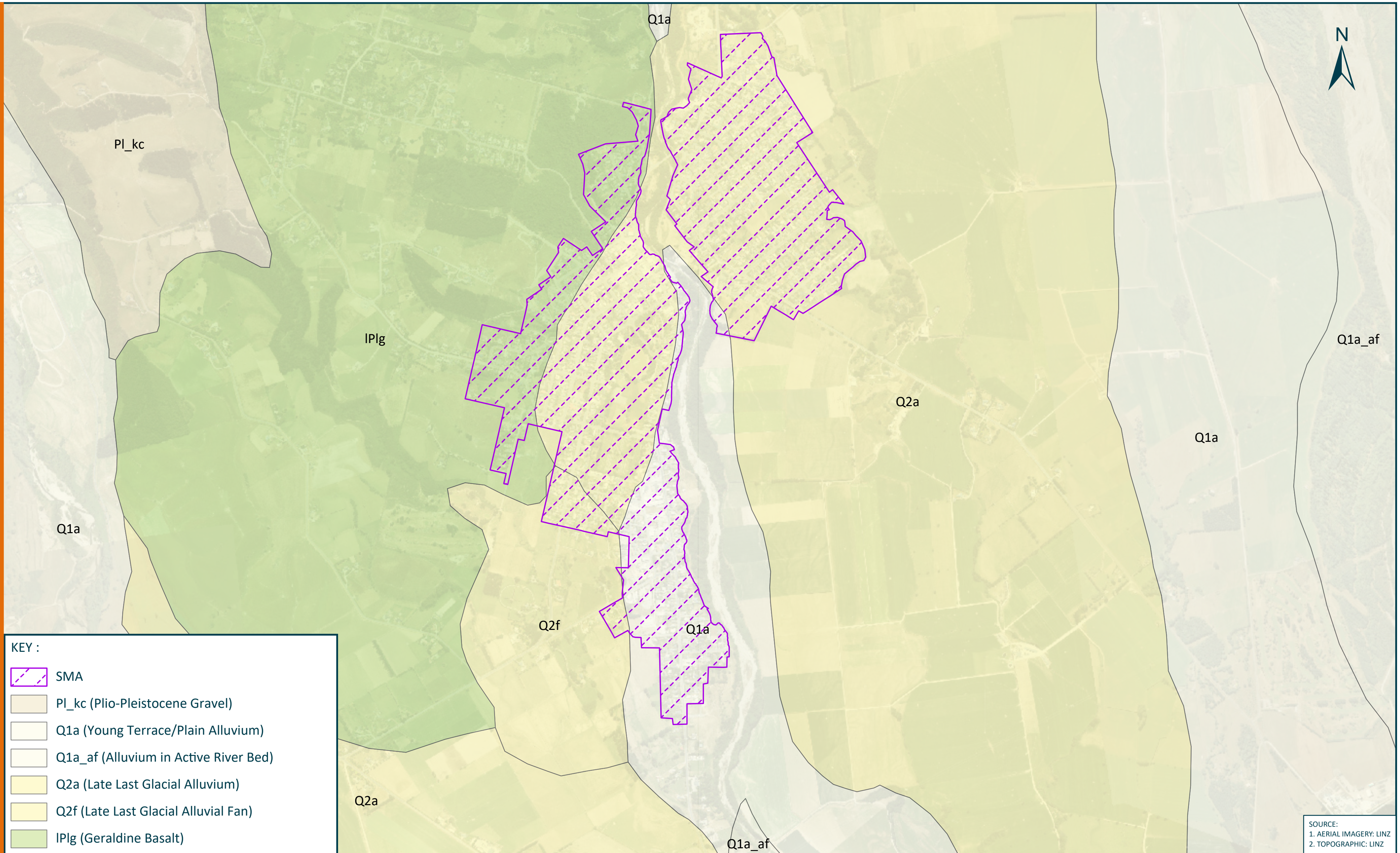
FIGURE
FIGURE 2: DEPTH TO GROUNDWATER

PROJECT
GERALDINE STORMWATER MANAGEMENT PLAN

C03489300.aprx - C03489300_FIGURE_2_DEPTH_TO_GROUNDWATER



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SCALE : 1:25,000 (A4)

NO.	REVISION	DATE	BY
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FIGURE
FIGURE 3: GEOLOGY

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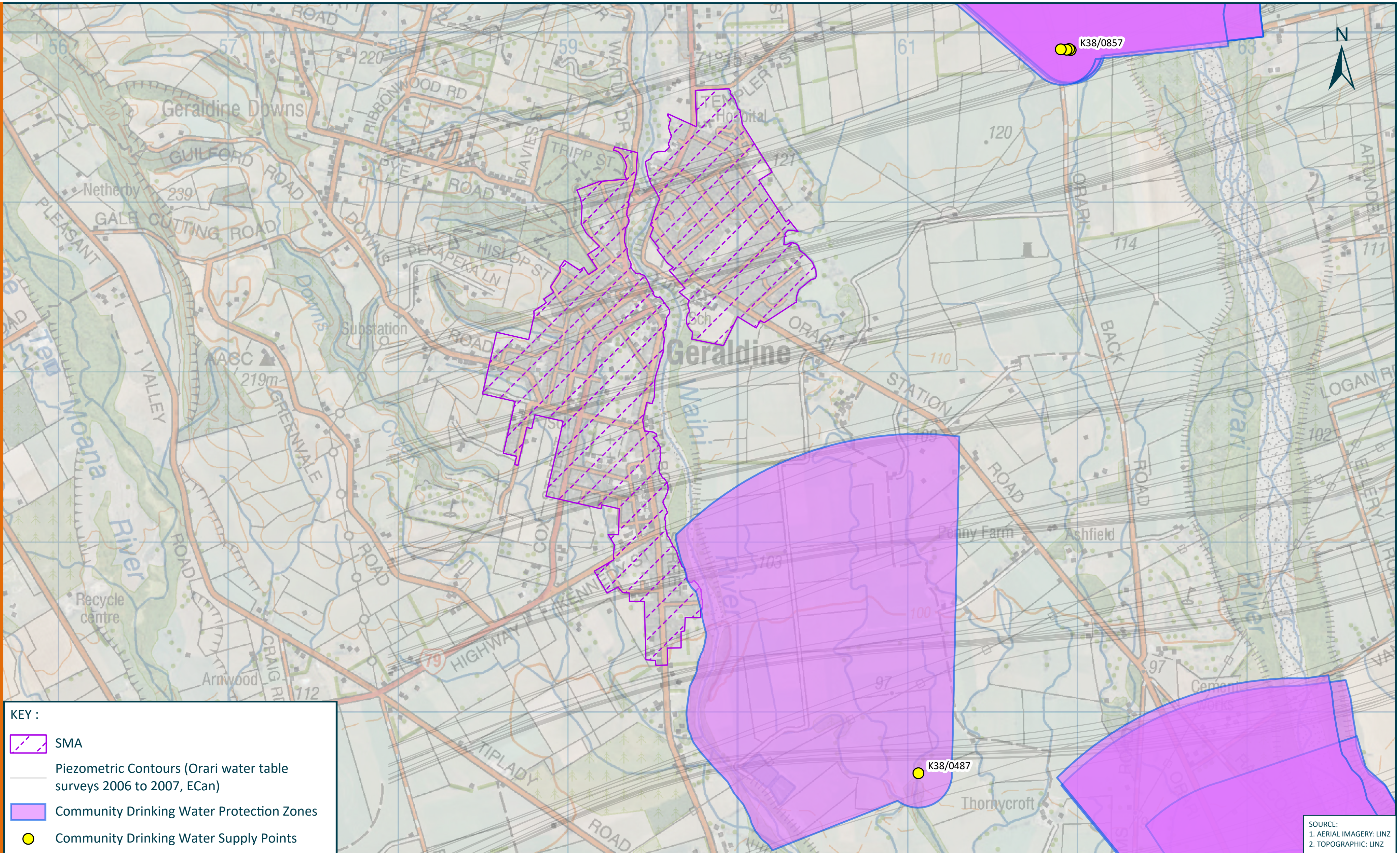
C03489300.aprx - C03489300_FIGURE_3_GEOLOGY



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METRES

SCALE : 1:30,000 (A4)

NO.	REVISION	DATE	BY
A	ISSUED FOR REVIEW		CJ

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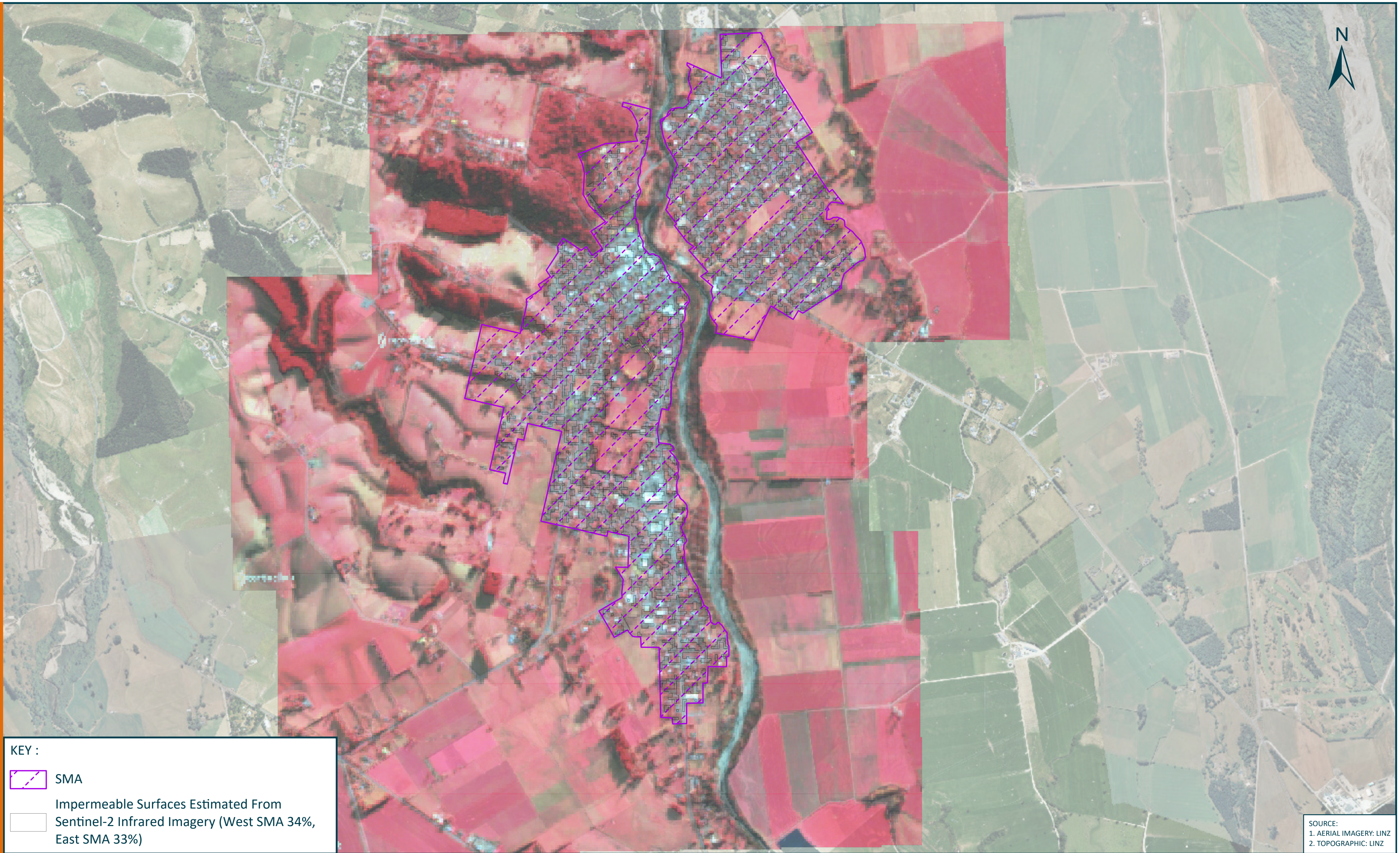
FIGURE

FIGURE 4: COMMUNITY SUPPLIES

PROJECT

GERALDINE STORMWATER MANAGEMENT PLAN

C03489300.aprx - C03489300_FIGURE_4_COMMUNITY_SUPPLIES



C03489300.aprx - C03489300_FIGURE_5_IMPERMEABLE_SURFACES

pdp

0 155 310 620
METRES
SCALE : 1:25,000 (A4)

NO.	REVISION	DATE	BY
A	ISSUED FOR REVIEW		CJ

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FIGURE
FIGURE 5: IMPERMEABLE SURFACES

PROJECT
GERALDINE STORMWATER MANAGEMENT PLAN