Results of Ruamāhanga groundwater flow and transport modelling for the Ruamāhanga Whaitua Committee: Business As Usual (BAU), Silver and Gold scenarios

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EXECUTIVE SUMMARY

Here, we present the groundwater-related results of simulating the Greater Wellington Regional Council (GWRC) Proposed Natural Resources Plan (PNRP) for the Ruamāhanga Catchment. This is called the 'business as usual' (BAU) scenario and explains the outcome of continuing with current land and water management practices into the future (up to 2080) and complying with the PNRP. We also present the results of simulating the Silver and Gold scenarios, which assess different on-farm management options. This work is presented for GWRC and the Ruamāhanga Whaitua Committee (RWC). Baseline, BAU, Silver and Gold scenario technical details have been carried out in accordance with the specifications provided by GWRC. All scenarios are considered 'future-looking' to 2080.

The simulations were carried out using both groundwater flow computer models and groundwater nitrate-nitrogen transport computer models of the Ruamāhanga Catchment that were run for the climatic period 1st July 1992 – 30th June 2014. The models are composed of a number of different layers that represent the groundwater system. The results were summarised for the 17 groundwater management zones and were also compared against the "current" (baseline scenario) flow and nitrate-nitrogen results. The groundwater management zones (GMZ) are defined in the Greater Wellington's Regional Freshwater Plan and are used as a framework to help manage the region's groundwater resources.

The primary differences between the baseline and BAU flow scenarios are that the baseline scenario uses the historic changes in groundwater pumping (e.g., groundwater pumping steadily increases with time as more wells are commissioned until the current rate is reached), while the BAU scenario assumes all currently pumping wells are active over the entire climatic period. Additionally, annual allocations for GMZ groundwater takes and pumping restrictions associated with low surface water flows are enforced as per the expected PNRP implementation. The primary differences between the BAU, Silver, Gold and baseline nitrate-nitrogen transport scenarios are that different nitrate-nitrogen loading (in terms of both spatial application and concentration) is applied to the groundwater system. These loads are applied as per the expected loads at 2025, 2040 and 2080 if the on-farm management options for each scenario were implemented.

Overall, BAU shows slightly lower mean groundwater levels, head and flow to surface water compared to baseline, all of which are outcomes of increased pumping in BAU. The mean cell-by-cell difference between baseline and BAU groundwater mean levels is a lower depth in the BAU scenario of 15 cm in winter and 19 cm in summer. Although an analysis of the mean results shows this consistent view, an analysis of the median groundwater levels shows no difference (less than 1 mm) between baseline and BAU. This indicates that the differences are experienced at the extremes (e.g., dryer periods), but for most of the time there is no significant difference in groundwater levels between baseline and BAU.

In total, six wells within the Te Ore Ore and Huangarua GMZs (of 24 wells within these two GMZs) have pumping restrictions applied due to the enforcement of annual limits. All other GMZs currently have pumping below their annual limits. Pumping restrictions associated with surface water flows are not discussed in this report.

The nitrate-nitrogen concentration in groundwater was summarised within two concentration bands for an attribute matrix: 'potable groundwater' is below the human health threshold and thus safe to drink; and 'natural or low impacted groundwater' is below 50% of this human health threshold (a subset of the potable groundwater band), and thus immediate management intervention is not considered critical to maintain quantities of potable groundwater. The

structural volume of groundwater within each band was calculated as a percentage of the structural volume of layers 1 and 2 within the groundwater model for each GMZ. These are the layers of the groundwater model that are the most susceptible to nitrate-nitrogen contamination and the easiest to access for water supplies. Using this analysis, 98.71% of layer 1 and 2 groundwater is currently potable based on nitrate-nitrogen concentrations (baseline scenario). This increases to 99.00% under the BAU scenario and to 99.20% under all Silver and Gold scenarios. A 1% increase equates to approximately 190 m^3 of groundwater. In total, 91.17% of layer 1 and 2 groundwater has nitrate-nitrogen concentrations currently (baseline) better than 50% of the human health threshold. This increases to 91.85% under the BAU scenario, to 94.35% under the Silver scenarios and to 94.48% under the Gold scenarios. The impact of different scenarios varies for each GMZ and radar graphs are presented to make these differences quickly apparent. Specific details for each GMZ for each scenario are further presented in tables within an appendix.

Mapped outputs highlight four large areas with significant quantities of unpotable groundwater: the north-western shores of Lake Wairarapa; west of Martinborough town; east of Masterton town; and on the Ruamāhanga River plains east of Carterton. The BAU scenario displays a significant reduction in the nitrate-nitrogen concentrations on the north-western shores of Lake Wairarapa, but the nitrate-nitrogen concentrations in the other three areas are not much decreased by any of the scenarios. Also of note is a large area that is above 50% of the human health threshold within the Tauherenikau GMZ that is significantly reduced by the Silver and Gold scenarios. Zoomed-in maps of a selection of these areas are presented within an appendix.

1.0 SUMMARY AND RESULTS

Here, we present the groundwater-related results of simulating the Greater Wellington Regional Council (GWRC) Proposed Natural Resources Plan (PNRP) for the Ruamāhanga Catchment. This is called the 'business as usual' (BAU) scenario and explains the outcome of continuing with current land and water management practices into the future (up to 2080) and complying with the PNRP. We also present the results of simulating the Silver and Gold scenarios, which assess different on-farm management options. This work is presented for GWRC and the Ruamāhanga Whaitua Committee (RWC).

The simulations were carried out using both groundwater flow computer models and groundwater nitrate-nitrogen transport computer models of the Ruamāhanga Catchment that were run for the climatic period 1st July 1992 – 30th June 2014 (Moore et al. 2016). The models are composed of a number of different layers that represent the groundwater system. The results were summarised for the 17 groundwater management zones (Figure 1.1; Table 1.1) and were also compared against the "current" (baseline scenario) flow and nitrate-nitrogen results (Moore et al. 2016). The groundwater management zones (GMZ) are defined in the Greater Wellington's Regional Freshwater Plan and are used as a framework to help manage the region's groundwater resources.

Although the BAU, Gold and Silver Scenarios are run over the climatic period 1st July 1992 – 30th June 2014, these scenarios are considered 'future-looking' to 2080. As these scenarios do not consider impacts of climate change, the time period used is considered a representative climatic period for the model simulations. Other properties of the simulations are changed, such as pumping and nitrate-nitrogen loading inputs, to provide the 'future-looking' outcomes. In contrast, the baseline scenario simulated expected historical conditions over the period 1st July 1992 – 30th June 2014.

The primary differences between the BAU and baseline flow scenarios are:

1. the baseline scenario uses the historic changes in groundwater pumping (e.g., groundwater pumping steadily increases with time as more wells are commissioned until the current rate is reached), while the BAU scenario assumes all currently pumping wells are active over the entire climatic period. To allow a comparison of baseline and BAU, the time period 1st July 2004 – 30th June 2014 is used as most representative of both scenarios having a similar number of pumping wells.
2. Annual allocations for GMZ groundwater takes and pumping restrictions associated with low surface water flows are enforced as per the expected PNRP implementation.

The primary differences between the BAU, Silver, Gold and baseline nitrate-nitrogen transport scenarios are that different nitrate-nitrogen loading (in terms of both spatial application and concentration) is applied to the groundwater system. These loads are applied as per the expected loads at 2025, 2040 and 2080 if the on-farm management options (Tier 1, Tier 2 and Tier 3 as defined by RWC) for each scenario were implemented.

Baseline, BAU, Silver and Gold scenario technical details have been carried out in accordance with the specifications provided by GWRC (e.g., Ruamāhanga Whaitua Committee, 2017). Specific technical details of how the BAU, Silver and Gold scenarios differ to the baseline scenario is provided in Section 2.0.

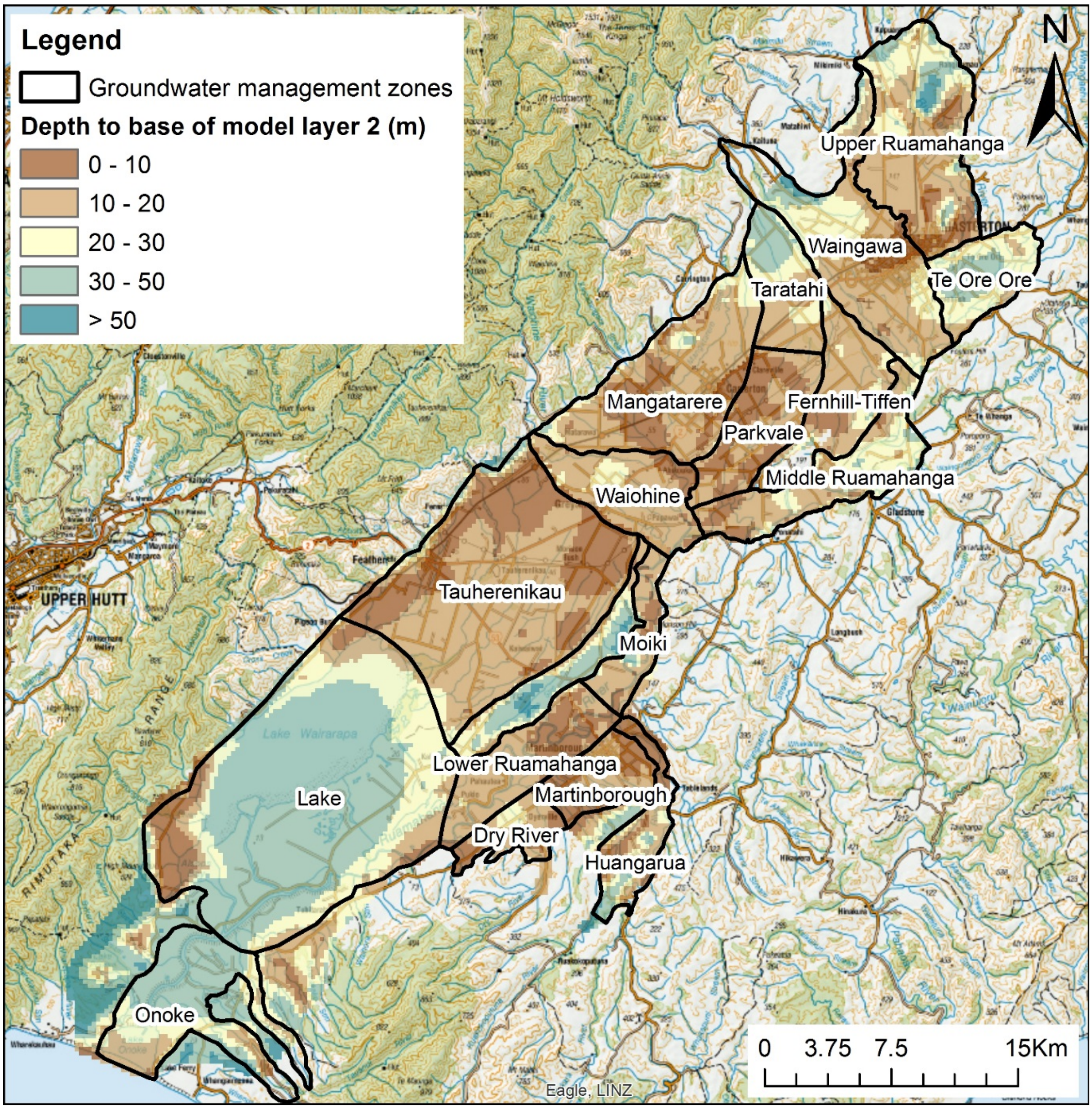

Figure 1.1 Groundwater management zones (17 in total) utilised to describe the results of the groundwater flow and transport models. The depth shown is from the ground surface to the base of layer two of the groundwater flow model. This corresponds to the base of the unconfined aquifer in areas where an aquitard confines deeper aquifer layers, as described in the Ruamāhanga model calibration report (Moore et al. 2016).

1.1 GROUNDWATER LEVELS

Groundwater level details are shown in Section 2.1. Overall, BAU shows slightly lower mean groundwater levels, head and flow to surface water compared to baseline, all of which are outcomes of increased pumping in BAU. The mean cell-by-cell difference between baseline and BAU groundwater mean levels is a lower depth in the BAU scenario of 15 cm in winter and 19 cm in summer. Although an analysis of the mean results show this consistent view, an analysis of the median groundwater levels shows no difference (less than 1 mm) between baseline and BAU. This indicates that the differences are experienced at the extremes (i.e., dryer periods), but for most of the time there is no significant difference in groundwater levels between baseline and BAU.

The median depth to groundwater for both summer and winter over the simulated period was summarised within five bands. The median depth represents the most typical groundwater levels. The mean of these median groundwater levels within each GMZ was calculated, which revealed no difference between baseline and BAU median groundwater levels. This indicates that most of the time groundwater levels where the same in baseline and BAU. Fifteen GMZ have a mean depth to median groundwater levels between 0 and 20 m in both summer and winter, i.e., relatively inexpensive drilling and pump equipment is required to extract groundwater over most of the Ruamāhanga Catchment. When assessed cell-by-cell[1], the mean difference between baseline and BAU groundwater median levels is less than 1 mm.

The mean depth to groundwater for summer and winter for the baseline and BAU scenario was calculated for the period 1st July 2004 – 30th June 2014. As the BAU scenario includes having all wells pumping from 1st July 1992, compared to the baseline that uses the real-life staggered onset of pumping, this period is considered to be the most similar in terms of having a similar number of pumping wells. For this period, the mean cell-by-cell difference between baseline and BAU groundwater mean levels is a lower depth in the BAU scenario of 15 cm in winter and 19 cm in summer. As the mean is more affected by extremes than the median, this suggests that the dryer extremes become dryer in the BAU scenario compared to the baseline. This is expected, as, although the period 1st July 2004 – 30th June 2014 is considered to be the most similar time period in terms of the number of pumping wells, there are still a significant number of wells that only start pumping after 2004 in the baseline model (i.e., BAU has higher pumping volumes over the entire period).

Compared to the groundwater level, which corresponds to the uppermost saturated model cell in the groundwater model, hydraulic head of a model layer is a measure of the pressure within that layer. The mean hydraulic head for layer 4 over the entire BAU period is shown, as well as the mean head difference between BAU and baseline for the period 1st July 2004 – 30th June 2014. Layer 4 of the groundwater model represents the uppermost confined aquifer where a confined aquifer is present. Most of the Ruamāhanga catchment has BAU with a lower head than baseline of between 0 and 0.1 m. As with the depth to groundwater calculations, this is expected to be due to higher pumping volumes in the BAU model. An area with a significantly higher head in BAU (largely in the Martinborough GMZ) is possibly due to annual allocation restrictions in the Huangarua GMZ reducing pumping in this area (see Section 1.2), because the groundwater flow in this higher head area in layer 4 comes from the Huangarua GMZ. However, this large difference in head may also be an artefact of the modelling, as the Martinborough and Huangarua GMZs are not well simulated in the groundwater models due to a lack of data to constrain the model calibration and lack of information on the geology of deeper aquifers (Moore et. al., 2016).

The exchange of water between groundwater and surface water is also displayed for various time periods, as well as the mean difference between BAU and baseline for the period 1st July 2004 – 30th June 2014. The most common difference is a decrease in the amount of water flowing towards surface water from groundwater (or an increase in the amount of water flowing to groundwater from surface water). This is again an expected result due to lower groundwater levels/head due to increased pumping in the BAU scenario.

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[1] The models split the Ruamāhanga Catchment into a grid composed of 250 m x 250 m grid cells.

1.2 PUMPING RESTRICTIONS

The baseline pumping restrictions were implemented based on a data file and information provided by GWRC (Thompson, 2016). The implementation of BAU pumping restrictions is described in Section 2.0. Most pumping restrictions implemented in the models are associated with surface water flows, however, these pumping restrictions are not further described in this report, and will be described by Jacobs in another technical report.

Annual limits for category B and C groundwater consents are also implemented within the BAU scenario, but not in the baseline scenario. Restrictions associated with annual limits are only required to be enforced within Te Ore Ore and Huangarua GMZ (as other GMZ are not allocated to their PRNP limits). In total, six wells have pumping restrictions applied in these two GMZ (of 24 wells within these two GMZ). One well in Huangarua GMZ has a mean of 39 and maximum of 126 annual restricted pumping days. All other wells restricted by annual limits have a mean of less than five and a maximum of 30 or less annual restricted pumping days. Pumping restriction details are shown in Section 2.1.

1.3 NITRATE-NITROGEN CONCENTRATIONS

The nitrate-nitrogen concentrations in groundwater are summarised within two concentration bands for an attribute matrix: ‘potable groundwater’ is below the human health threshold and thus safe to drink (Ministry of Health, 2005); and ‘natural or low impacted groundwater’ levels are below 50% of this human health threshold, and thus immediate management intervention is not considered critical to maintain quantities of potable groundwater. ‘Natural or low impacted groundwater’ is a subset of ‘potable groundwater’. In total, 98.71% of layer 1 and 2 groundwater is currently (baseline) potable based on nitrate-nitrogen concentrations. This increases to 99.00% under the BAU scenario and to 99.20% under the Silver and Gold scenarios. A 1% increase equates to approximately 190 m^3 of groundwater. In total, 91.17% of layer 1 and 2 groundwater has nitrate-nitrogen concentrations currently (baseline) better than 50% of the human health threshold. This increases to 91.85% under the BAU scenario, to 94.35% under the Silver scenarios and to 94.48% under the Gold scenarios.

The structural volume[2] of groundwater within each band was calculated as a percentage of the structural volume of layers one and two within the groundwater model for each GMZ. These are the layers of the groundwater model that are the most susceptible to nitrate-nitrogen contamination and the easiest to access for water supplies. As the thickness of the layers varies across the model (Figure 1.1), this measure is considered more representative than area for assessing the impact on groundwater supplies. However, percentages of area for each band were also calculated. Summaries of the results are shown in Figure 1.2 and Figure 1.3, which highlight that the impact of different scenarios varies significantly for each GMZ. Details are further described in Section 2.2 and Appendix 1.

The baseline scenario predicts that 15 GMZ have greater than 90% potable groundwater and greater than 50% natural or low impacted groundwater. Tauherenikau has the greatest volume of potable water (100.00%). Huangarua has the highest natural or low impacted groundwater (99.46%) and appears to be the only GMZ that requires no immediate management

[2] The term ‘structural volume’ is used because the volume calculation pertains to the aquifer volume that could be saturated with water, but no adjustment has been made for actual saturation (i.e., no adjustments are made for temporal fluctuations in groundwater level).

intervention. Te Ore Ore has the lowest amount of potable groundwater (85.53%) and Parkvale has the lowest natural or low impacted groundwater (42.01%), and these GMZ are most in need of management intervention to improve water quality. There are four areas that currently have a significant coverage of non-potable groundwater: the north-western shores of Lake Wairarapa (Lake GMZ); west of Martinborough town (Martinborough, Dry River, and Lower Ruamāhanga GMZ); east of Masterton town (Te Ore Ore GMZ); and on the Ruamāhanga River plains east of Carterton (Fernhill-Tiffen GMZ). In total, 98.71% of groundwater is potable and 91.17% of groundwater is natural or low impacted.

The BAU scenario also predicts that 15 GMZ contain greater than 90% potable groundwater and greater than 50% natural or low impacted groundwater. Of these, two GMZ have 100% potable groundwater (c.f. one for baseline) and eight GMZ have between 99% and 100% (c.f. six for baseline) potable groundwater. The mean GMZ change in potable water from baseline is a volume increase of 0.37%, and the total cell-by-cell change from baseline is a volume increase of 0.29%. Seven GMZ have greater than 90% (c.f. six for baseline) natural or low impacted groundwater. The mean GMZ change in natural or low impacted groundwater from baseline is a volume increase of 0.71%, and the total cell-by-cell change from baseline is a volume increase of 0.68%.

The Silver and Gold scenarios for all years have the equivalent volumes of potable groundwater. In these scenarios, 16 GMZ have greater than 90% potable groundwater (c.f. 15 for BAU). Of these, two GMZ have 100% (c.f. two for BAU) and nine GMZ have between 99% and 100% (c.f. eight for BAU) potable groundwater. The mean GMZ change from BAU is a volume increase of 0.54%, and the total cell-by-cell change from BAU is a volume increase of 0.20%.

All Silver and Gold scenarios for all years have all GMZ (17) with greater than 50% natural or low impacted groundwater (c.f. 15 for BAU), with eight GMZ having greater than 90% (c.f. seven for BAU) natural or low impacted groundwater. For Silver 2025, the mean GMZ change from BAU is a volume increase of 5.28%, and the total cell-by-cell change from BAU is a volume increase of 2.50%. For Silver 2040, the mean GMZ change from BAU is a volume increase of 5.33%, and the total cell-by-cell change from BAU is a volume increase of 2.50%. For Silver 2080, the mean GMZ change from BAU is a volume increase of 5.33%, and the total cell-by-cell change from BAU is a volume increase of 2.51%. All Gold scenario years have the have a mean GMZ change from BAU as a volume increase of 5.61%, and the total cell-by-cell change from BAU is a volume increase of 2.63%.

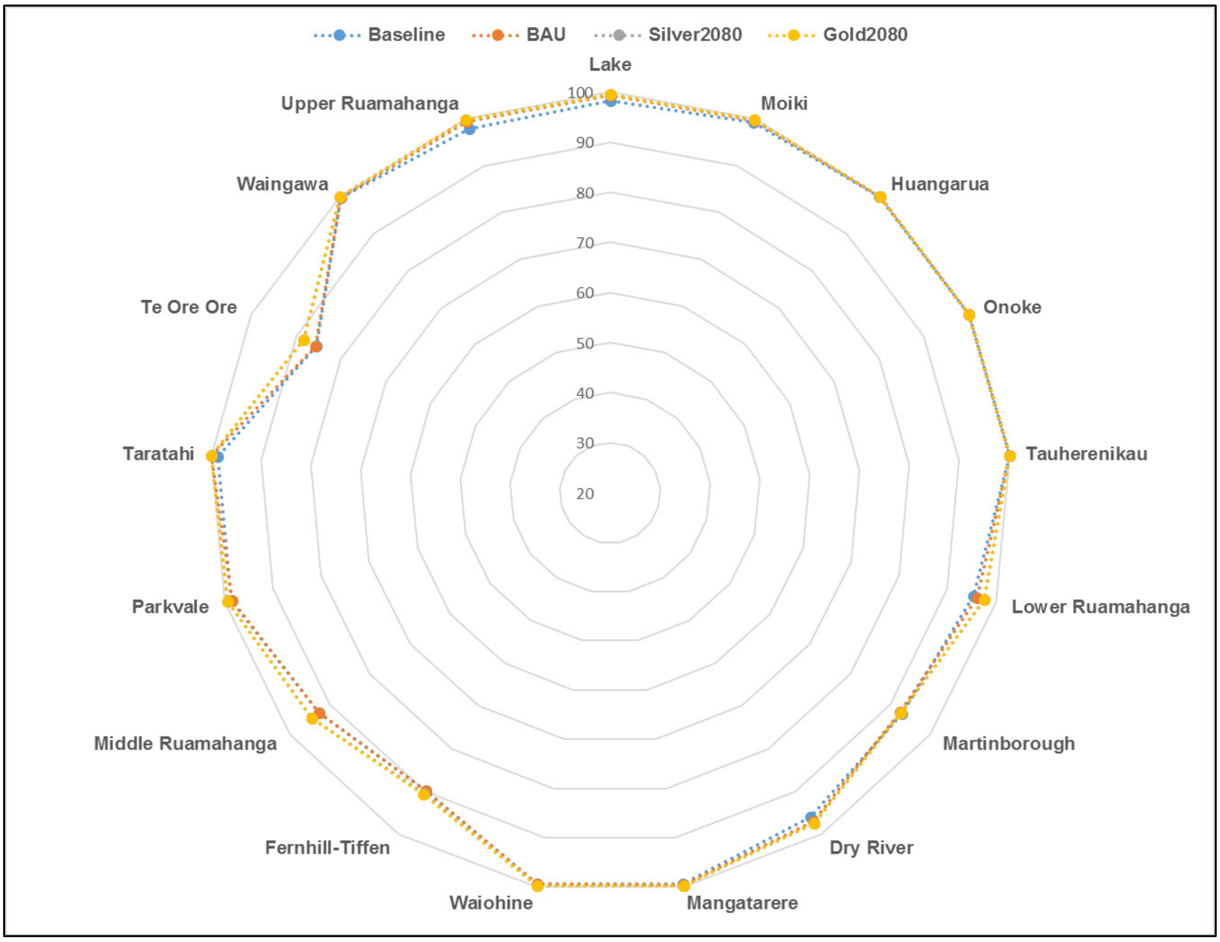

Figure 1.2 Radar graph summarizing the result of each scenario. The data points show the percentage of the structural volume of layers one and two of the groundwater model in each GMZ that could contain groundwater suitable for human consumption (potable) based on nitrate-nitrogen levels. Data points that lie closer to the outside of the circle (100%) indicate a greater volume of good quality water.

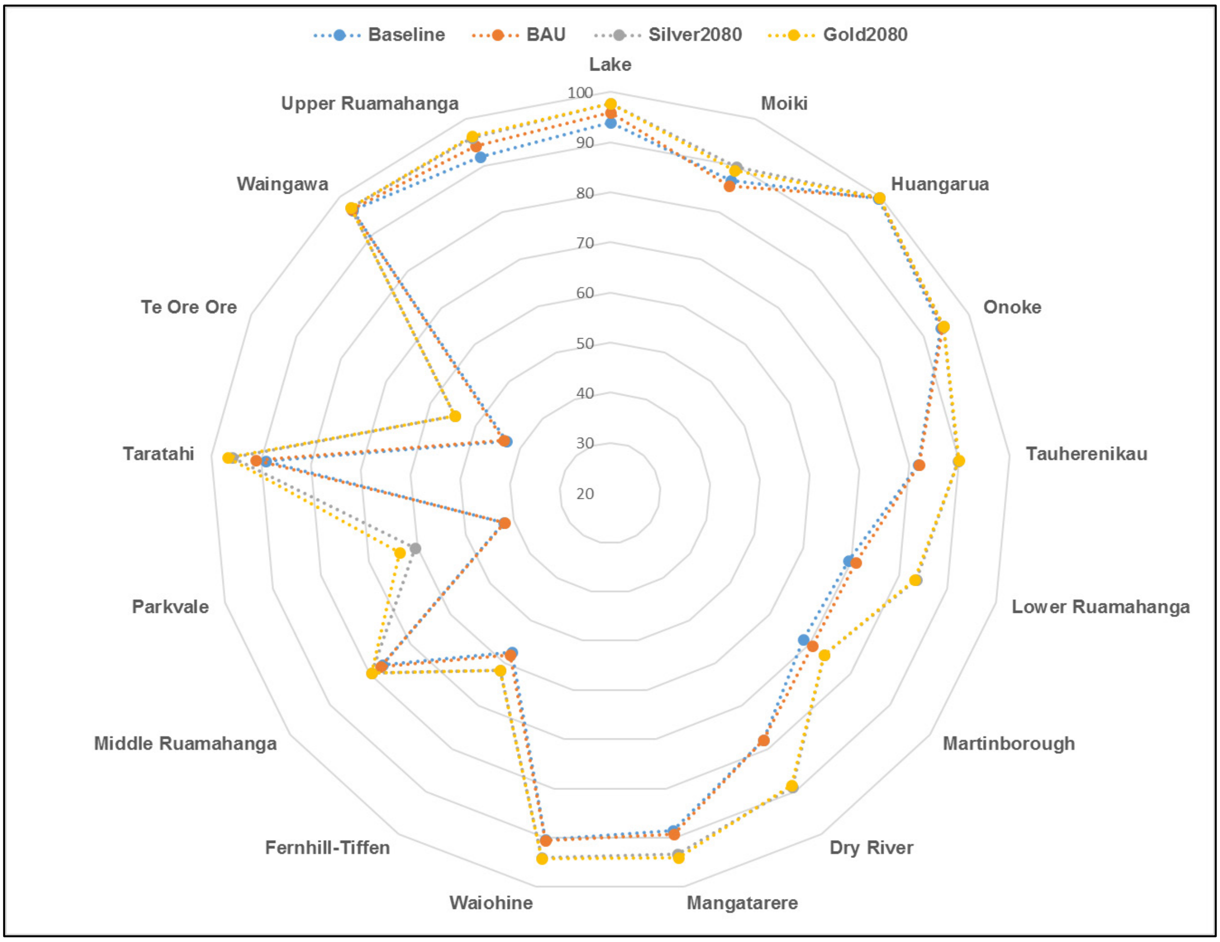

Figure 1.3 Radar graph summarizing the result of each scenario. The data points show the percentage of GMZ volume containing groundwater that has nitrate-nitrogen levels less than (better than) 50% of the human health limit. Data points that lie closer to the outside of the circle (100%) indicate a greater volume of good quality water.

Table 1.1 Summary of groundwater management zone depths, areas and volumes. The volume calculated is the structural volume of layers one and two within the groundwater model and does not consider changes in water levels. This volume is utilised for the nitrate-nitrogen concentration estimation presented in Section 3.2.

Groundwater Management Zone name	Mean depth to base of layer two (m)	Surficial area (km^2)	Volume of layers one and two in groundwater models (m^3)
Lake	30	219	6515 $x10^6$
Moiki	14	18	257 $x10^6$
Huangarua	17	23	375 $x10^6$
Onoke	31	55	1630 $x10^6$
Tauherenikau	12	152	1798 $x10^6$
Lower Ruamāhanga	13	39	517 $x10^6$
Martinborough	9	22	211 $x10^6$
Dry River	13	17	212 $x10^6$
Mangatarere	13	75	976 $x10^6$
Waiohine	15	39	603 $x10^6$
Fernhill-Tiffen	16	38	519 $x10^6$
Middle Ruamāhanga	18	44	784 $x10^6$
Parkvale	10	37	391 $x10^6$
Taratahi	23	29	679 $x10^6$
Te Ore	26	27	705 $x10^6$
Waingawa	19	78	1344 $x10^6$
Upper Ruamāhanga	20	72	1424 $x10^6$

2.0 MODEL ASSUMPTIONS AND INPUTS WHERE DIFFERENT TO BASELINE

All model assumptions and inputs described below were defined under advisement from Mike Thompson (Senior Environmental Scientist, Hydrology, Greater Wellington Regional Council) and John Bright (Director of Research & Development, Aqualinc Research Limited), and direction of the RWC (Ruamāhanga Whaitua Committee, 2017).

2.1 GROUNDWATER FLOW MODELLING

- The North and South Ruamāhanga groundwater models were run for the period 1st July 1992 – 30th June 2014 on a daily timestep, which equates to 8035 days of distinct data.
- Irrigation demand was provided from IRRICALC modelling (Dark, pers. comm. 2017) assuming all consented takes operated over the entire model run time. This means that only the current water usage is implemented, and no future increase in water use is modelled.
- The irrigation demand time series was modified for groundwater category B and C takes as follows: each well consent has an 'annual_take' limit, and Category B and C groundwater zones have annual allocation limits detailed in Ruamāhanga Whaitua Committee (2017). Wells were set to individually cease pumping when both the zone annual limit and the well annual limit had been reached. Annual limits were assessed on the hydrological year: 1st July to 30th June the following calendar year. As most zones are under-allocated, this only impacts on the Te Ore Ore and Huangarua GMZs.
- The irrigation demand time series was modified for surface water and groundwater category A takes as detailed in Ruamāhanga Whaitua Committee (2017): when either minimum flow, cease flow, or stepdown conditions were met, category A groundwater takes were applied as 50% of the daily take if this was less than the irrigation demand. For surface water takes, all takes cease at cease flow conditions where these exist, else at minimum flow conditions. Exceptions were consents that were categorised as "community" or "public" supplies, which were only reduced to 50%, and water race takes that are unrestricted. Specific 'constant consent' rates were set for some consents (Thompson, pers. comm. 2016; 2017).

2.2 GROUNDWATER TRANSPORT MODELLING

- The pumping files from the BAU groundwater flow models were used that implement the take restrictions defined in Section 2.1.
- The North and South transport models utilised rainfall recharge and the groundwater flow solution over the period 1st July 1992 – 30th June 2014.
- Seven different datasets describing the nitrate-nitrogen concentrations of the groundwater recharge flux were supplied to the model. These datasets were calculated based on the average daily rainfall recharge data set used in the equivalent baseline analysis (Moore et al. 2016) and seven annual nitrate-nitrogen flux datasets from OVERSEER modelling on-farm management options (Tier 1, Tier 2 and Tier 3 as defined by RWC; Hastings, pers. comm. 2017; 20/04/2017; 18/08/2016), with any 'no-data' values set to zero:

1) Baseline: Stock exclusion but no Tier 1 mitigations
2) BAU: Tier 1
3) Silver 2025: 1/3 Tier 1 and 1/3 Tier 2 and 1/3 Tier 3 +5 m buffer
4) Gold 2025: 1/2 Tier 2 and 1/2 Tier 3 +10 m buffer
5) Silver 2040: 1/3 Tier 2 and 2/3 Tier 3 + 5 m buffer
6) Gold 2040 and Gold 2080: Tier 3 +10 m buffer
7) Silver 2080: Tier 3 +5 m buffer

- In-stream nitrate-nitrogen concentrations from losing streams were not transferred back to the groundwater system.

3.0 ATTRIBUTE MATRIX

3.1 GROUNDWATER FLOW MODELLING

Selected features of the groundwater flow model results are presented in Figure 3.1 – Figure 3.6 and are further summarised in Table 3.1. The annual median summer and winter depth to groundwater level (gw level) results are represented within five discrete depth bands (Figure 3.1):

A. gw level is >0 (artesian)

B. 0 ≤ gw level < 1.0 m

C. 1.0 m ≤ gw level < 7.5 m (can be pumped using a surface mounted pump).

D. 7.5 m ≤ gw level < 20 m (submersible pump required, modest pump lift)

E. 20 m ≤ gw level

The difference between mean baseline and BAU summer and winter depth to groundwater levels for the period 1st July 2004 – 30th June 2014 is shown in Figure 3.2. As the BAU scenario includes having all wells pumping from 1st July 1992, compared to the baseline that uses the real-life staggered onset of pumping, this period is considered to be the most similar in terms of pumping volumes. The groundwater pumping restrictions are displayed in Figure 3.3. Groundwater and surface water exchange and confined head are displayed in Figure 3.4 – Figure 3.6, but are not summarised as part of the attribute matrix based on the requirements of GWRC.

Table 3.1 Attribute matrix utilising information from groundwater flow modelling.

Attribute	Current (baseline): 1st July 1992 – 30th June 2014	BAU: 1st July 1992 – 30th June 2014
Groundwater levels (Figure 3.1 and Figure 3.2).	From the annual median winter groundwater levels, the mean of these groundwater levels for each GMZ has been calculated: One GMZ has mean levels in category B; twelve GMZ's have mean groundwater levels in category C; three GMZ's have mean groundwater levels in category D; and one GMZ has mean levels in category E. From the annual median summer groundwater levels, the mean of these for each GMZ has been calculated: ten GMZ's have mean groundwater levels in category C; five GMZ's have mean groundwater levels in category D; and two GMZ's have mean levels in category E.	From the median winter groundwater levels, the mean of these groundwater levels for each GMZ has been calculated: One GMZ has mean levels in category B; twelve GMZ's have mean groundwater levels in category C; three GMZ's have mean groundwater levels in category D; and one GMZ has mean levels in category E. From the median summer groundwater levels, the mean of these for each GMZ has been calculated: ten GMZ's have mean groundwater levels in category C; five GMZ's have mean groundwater levels in category D; and two GMZ has mean levels in category E. This is an identical summary to baseline. When assessed cell-by-cell, the mean difference between baseline and BAU groundwater median levels are less than 1 mm. When the difference between the mean depth to groundwater level between baseline and BAU is assessed for the period 1st July 2004 – 30th June 2014 (mean of each GMZ calculated), the largest variations are within: Martinborough (16 cm higher in BAU winter and 4 cm higher in BAU summer), Dry River (11 cm lower in BAU winter and 4 cm lower in BAU summer), Onoke (13 cm lower in BAU winter and 14 cm lower in BAU summer), Parkvale (7 cm lower in BAU winter and 6 cm lower in BAU summer), Mangatarere (2 cm lower in BAU winter and 6 cm lower in BAU summer), and Fernhill-Tiffen (3 cm lower in BAU winter and 6 cm lower in BAU summer) GMZ. The remaining GMZ have lower BAU levels in both winter and summer of less than 5 cm. For this period, the mean cell-by-cell difference between baseline and BAU groundwater mean levels is a lower depth in the BAU scenario of 15 cm in winter and 19 cm in summer.
Number of days with pumping restrictions due to groundwater annual allocation limits (Figure 3.3).	No annual allocation limits were set in the baseline scenario.	Restrictions associated with annual limits are only required to be enforced within Te Ore Ore and Huangarua GMZ (as other GMZ are not allocated to their PRNP limits). Wells were set to individually cease pumping when both the zone annual limit and the well annual limit had been reached. In Te Ore Ore, this results in four wells with pumping restrictions. These four wells have a maximum of 30 restricted days and a mean of 3 restricted days. in Huangarua GMZ, this results in two wells with pumping restrictions. One well has a mean of 39 and maximum of 126 annual restricted pumping days, the other has a mean of 1 and a maximum of 8 annual restricted pumping days.

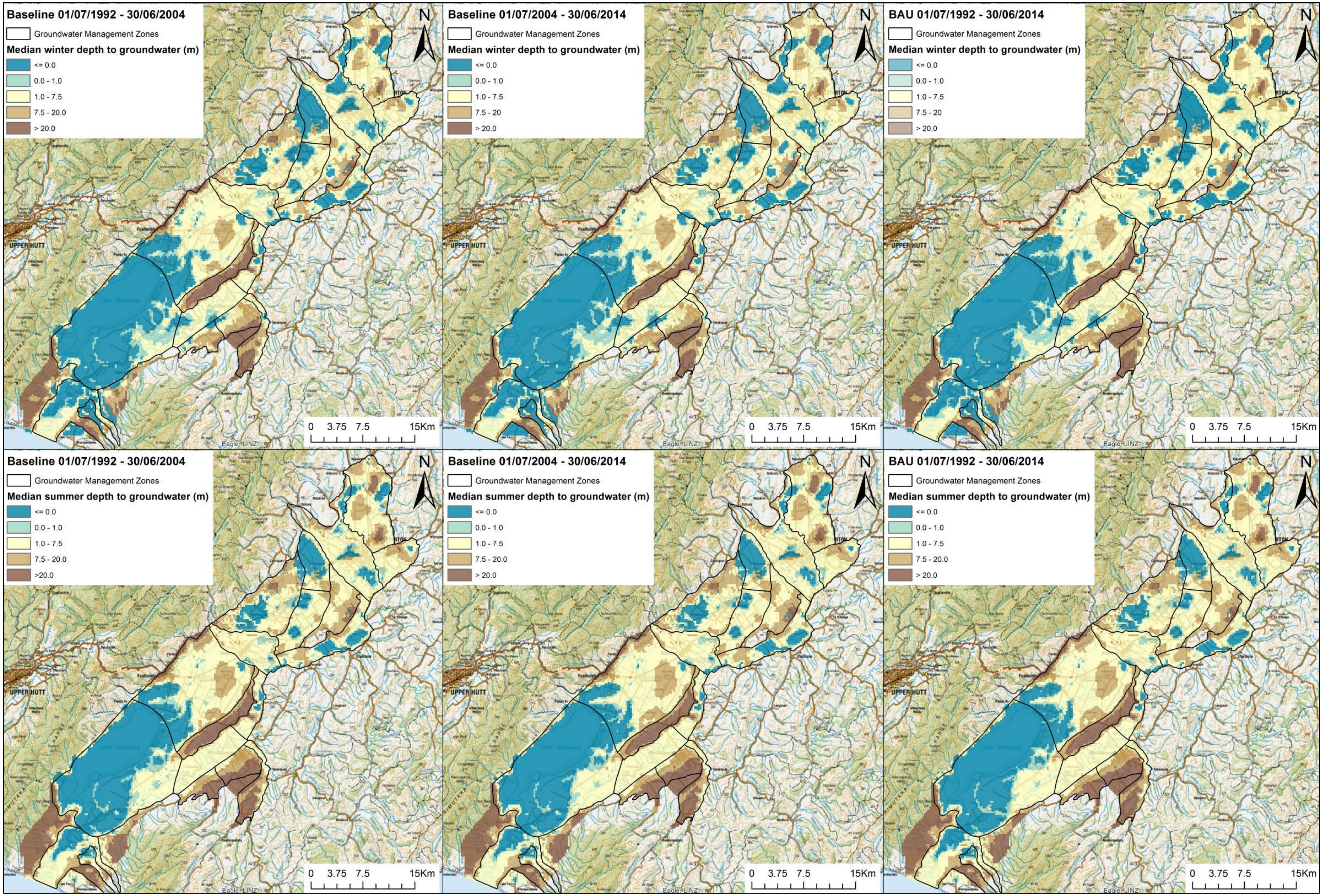

Figure 3.1 Median depth to groundwater level for summer and winter for baseline and BAU.

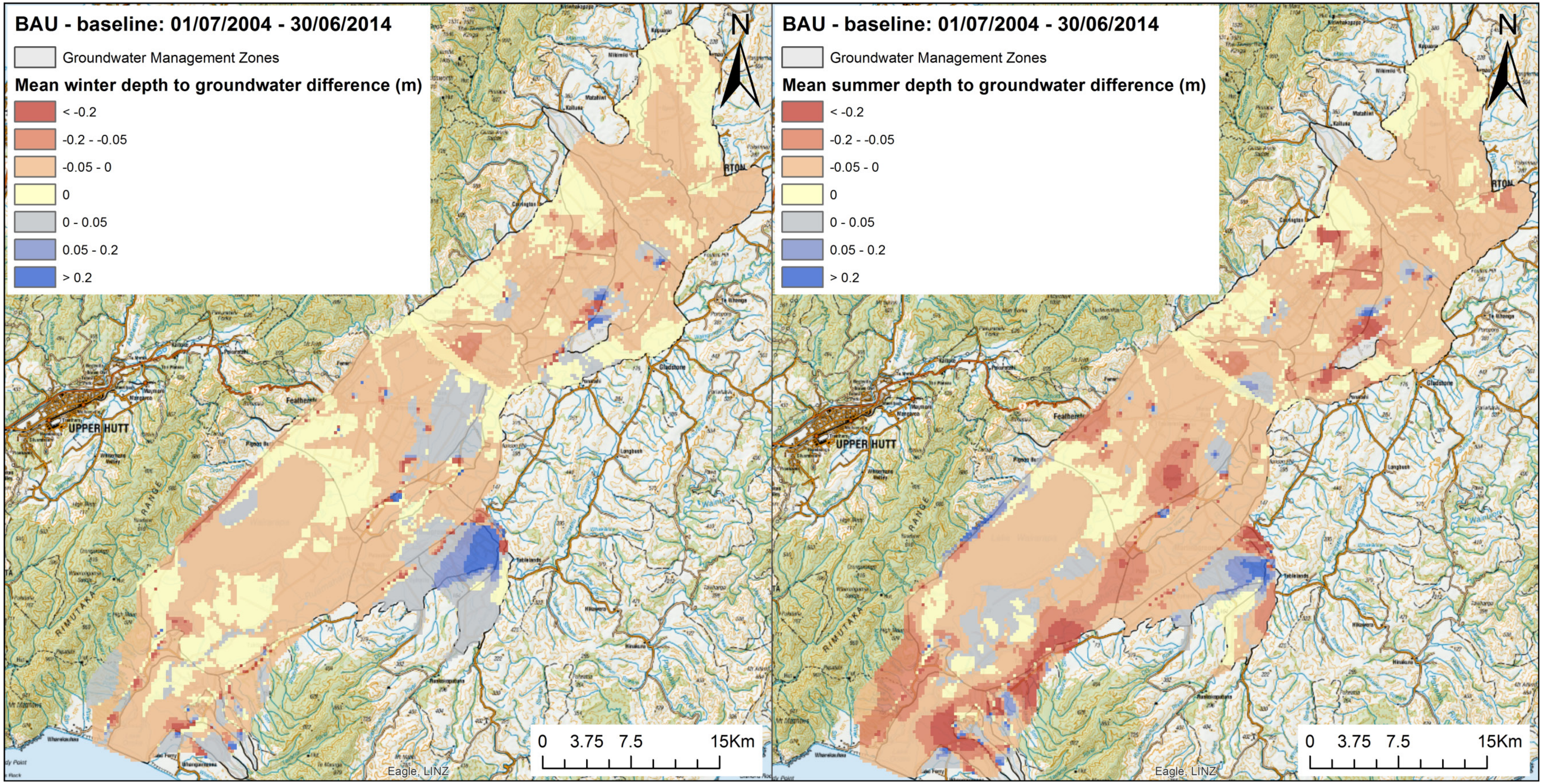

Figure 3.2 Mean winter and summer depth to groundwater difference between BAU and baseline for the period 1st July 2004 – 30th June 2014. Negative values correspond to where BAU depth to groundwater is deeper than baseline.

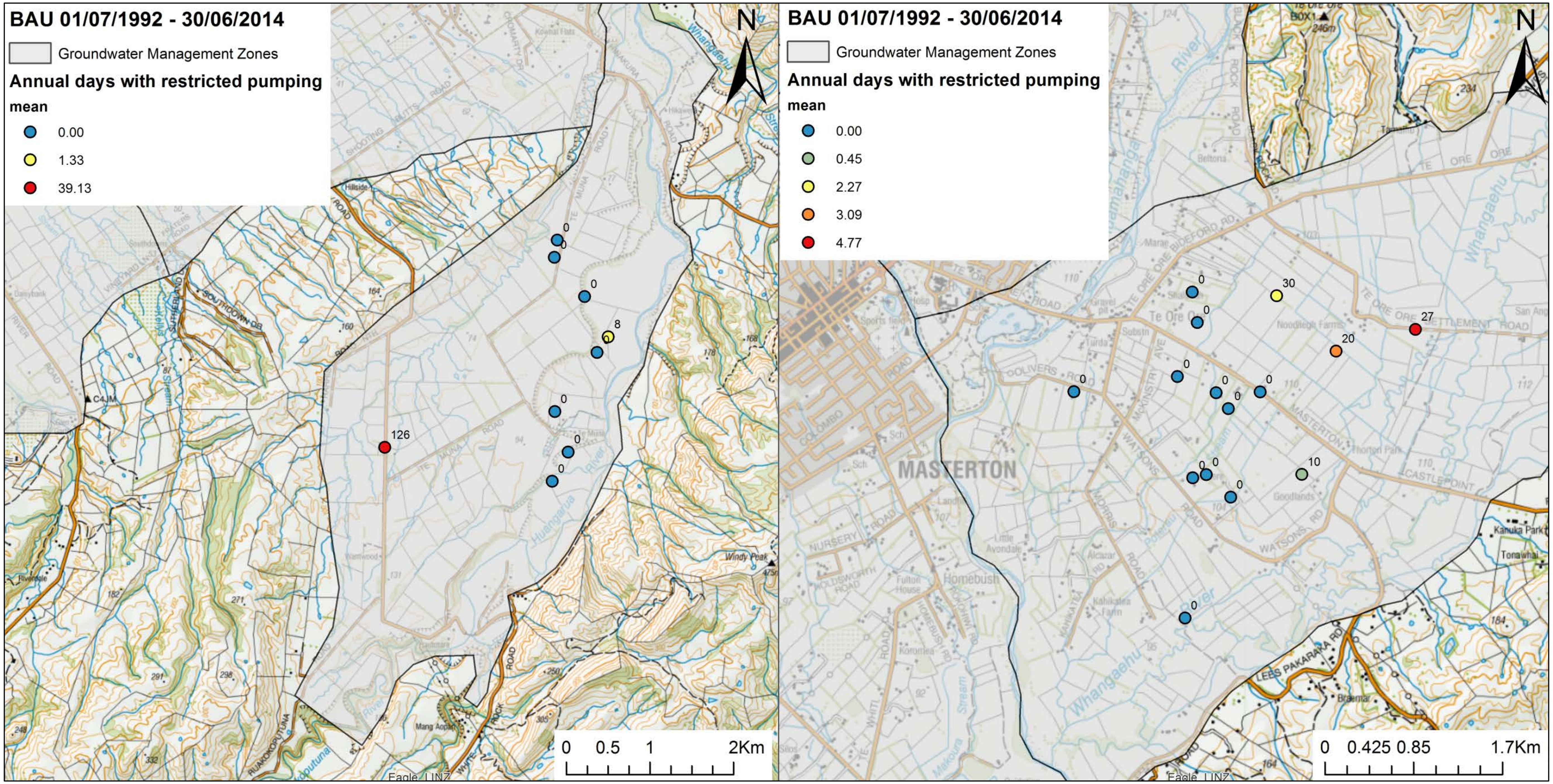

Figure 3.3 Summary of annual groundwater pumping restrictions associated with annual limitations for BAU. Wells are coloured by their mean and labelled with their max annual number of days with pumping restrictions. Left) Huangarua GMZ, Right) Te Ore Ore GMZ.

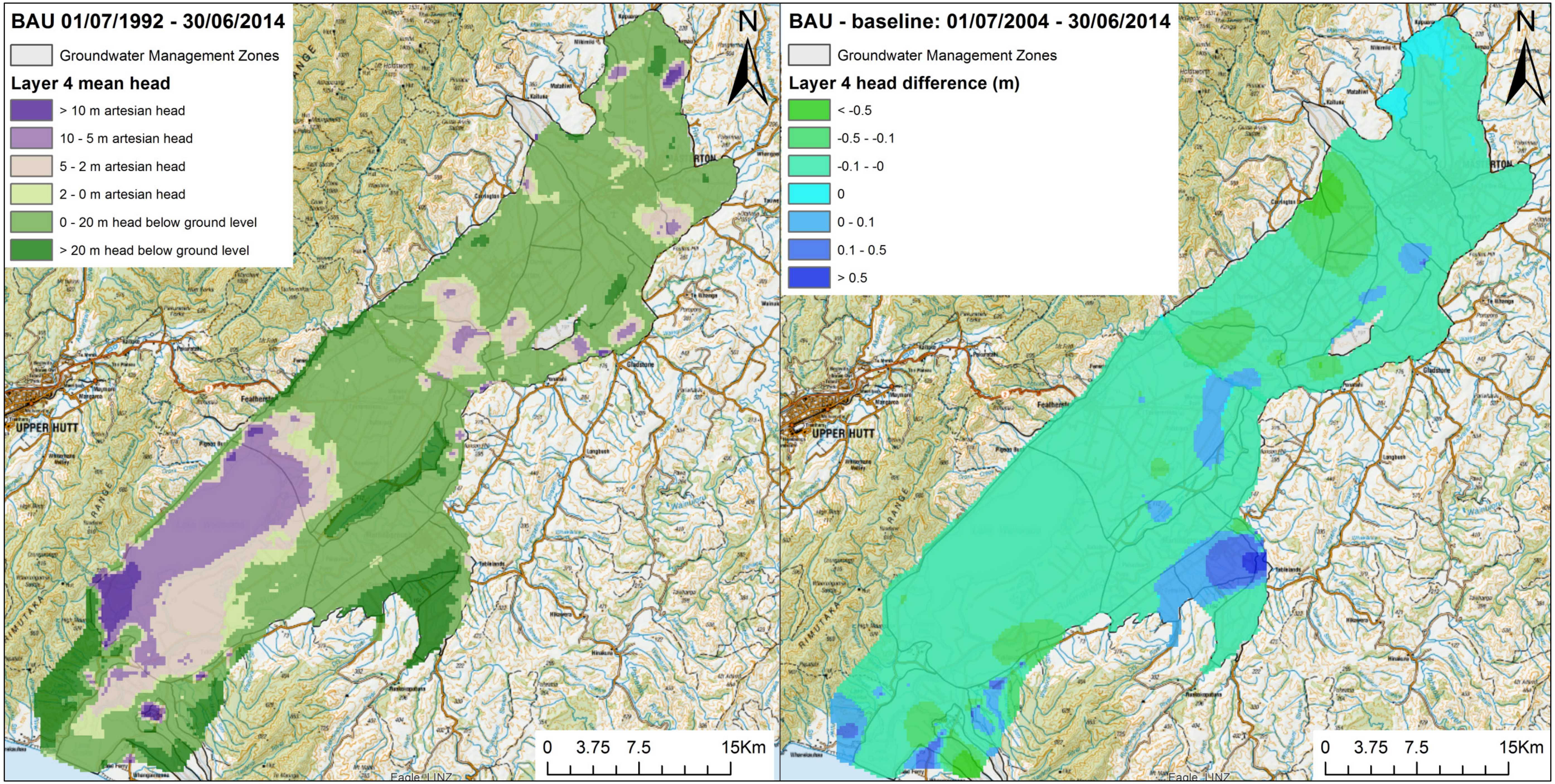

Figure 3.4 Left) Mean head in layer 4 of the groundwater models for BAU. This layer represents the uppermost confined aquifer where a confined aquifer is present; Right) The difference in the mean head for layer 4 between BAU and baseline for the period 1st July 2004 – 30th June 2014, where negative values correspond to BAU having a lower head.

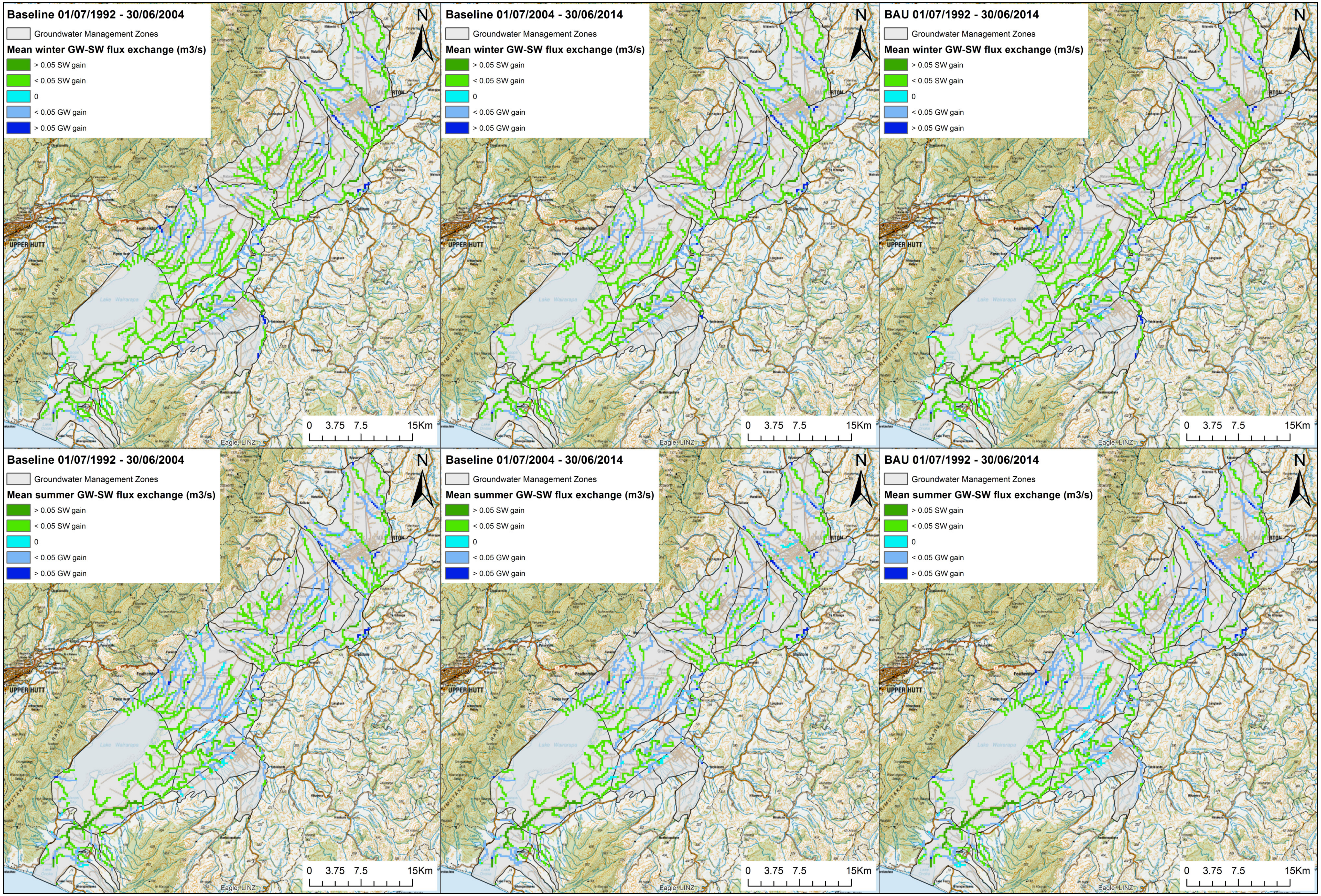

Figure 3.5 Mean groundwater (GW) - surface water (SW) flux exchange for summer and winter for baseline and BAU.

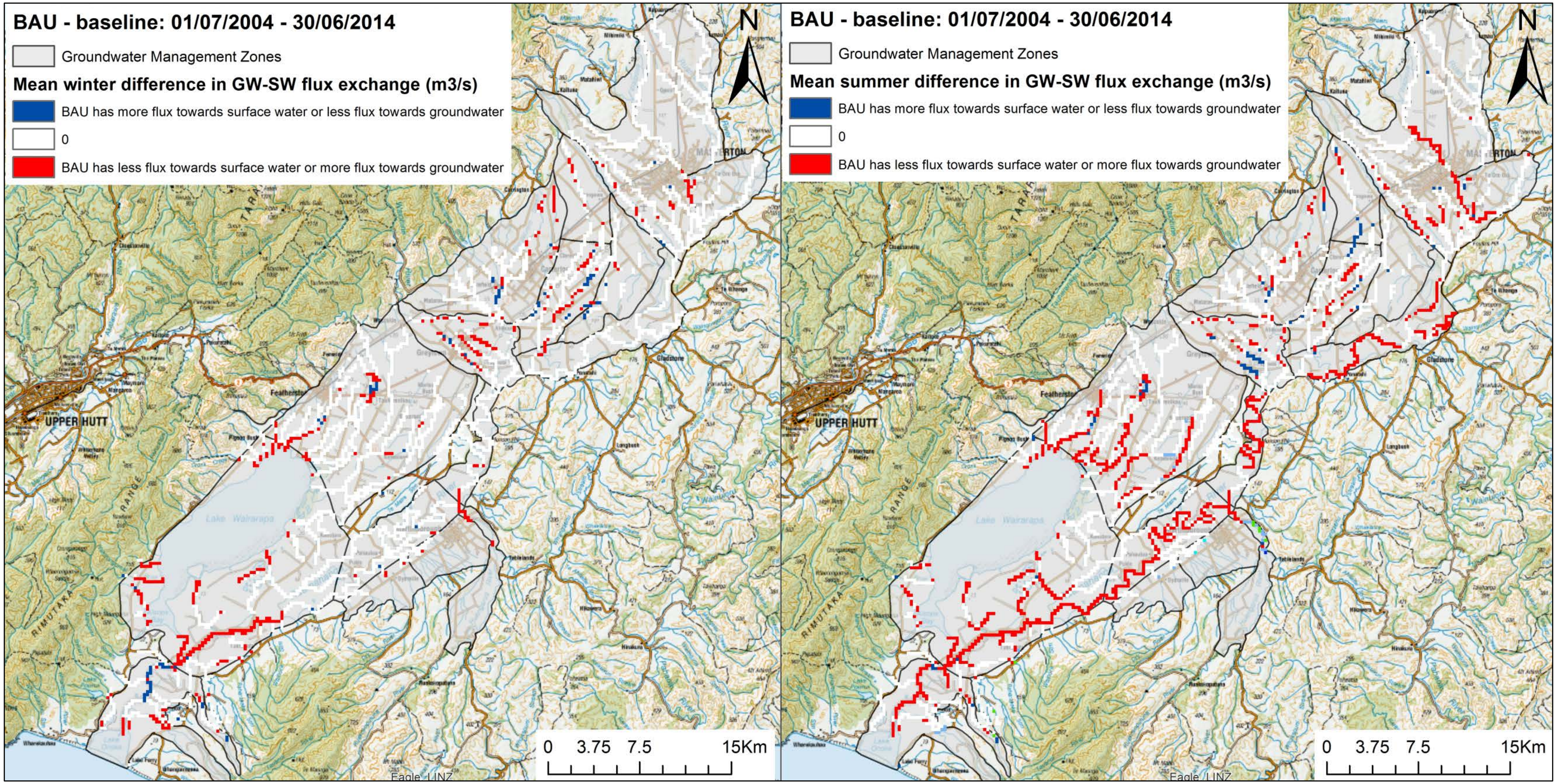

Figure 3.6 Mean winter and summer groundwater (GW) - surface water (SW) flux exchange difference between BAU and baseline for the period 1st July 2004 – 30th June 2014.

3.2 GROUNDWATER TRANSPORT MODELLING

The groundwater transport model nitrate-nitrogen concentration results for the uppermost saturated layer of the groundwater model are presented in Figure 3.7 – Figure 3.8. Additional zoomed-in maps of select areas are supplied in Appendix A1.3. This uppermost saturated layer represents the groundwater layer most susceptible to contamination by nitrate-nitrogen from the land surface. The results are represented within five discrete nitrate-nitrogen concentration (N Conc) bands:

A. N Conc < 1 mg/l

B. 1 ≤ N Conc < 2.4 mg/l

C. 2.4 ≤ N Conc < 5.65 mg/l

D. 5.65 ≤ N Conc < 11.3 mg/l

E. 11.3 ≤ N Conc

Bands (A) and (B) are consistent with the excellent and good categories, respectively, of the National Objectives Framework (NOF) nitrate-nitrogen (NO_3-N) toxicity values for surface water (NIWA, 2014). Band (E) describes nitrate-nitrogen levels above the human health standard (Ministry of Health, 2005). Band (D) describes nitrate-nitrogen levels that exceed 50% of the drinking water standard: this (50%) is often used to trigger management intervention to try to prevent deterioration.

The groundwater transport model nitrate-nitrogen concentration results are further summarised in Table 3.2, with supplemental graphs supplied in Figure 3.9 – Figure 3.13. The results presented in Table 3.2 were calculated as follows:

1) Nitrate-nitrogen concentration results for the uppermost two layers of the North and South Ruamāhanga models were selected. These layers correspond to the unconfined aquifer in areas where an aquitard confines deeper aquifer layers (Moore et al. 2016). Volumes and depths for each groundwater management zone are shown in Table 1.1.
2) From these selected results, those model cells with concentrations below (better than) the defined thresholds (5.65 mg/L for category D and 11.3 mg/L for category E) were selected.
3) For these selected cells, the corresponding percentage of each groundwater management zone structural volume[3] was calculated.
4) The results were rounded to two decimal places. An analysis of the percentage difference that can be considered statistically significant has not been carried out.

A similar analysis was carried out for the uppermost saturated layer. Additional details of the analysis are presented in Appendix A1.1 and more detailed result tables are supplied in Appendix A1.2.

[3] The term ‘structural volume’ is used because the volume calculation pertains to the aquifer volume that could be saturated with water, but no adjustment has been made for actual saturation (i.e., no adjustments are made for temporal fluctuations in groundwater level).

Table 3.2 Attributes matrix utilising information from groundwater transport modelling.

Attribute	Baseline	BAU (Tier 1)	Silver 2025	Silver 2040	Silver 2080	Gold 2025	Gold 2040 and 2080
Structural volume of layers one and two of the groundwater model that could contain groundwater suitable for human consumption (potable) based on nitrate-nitrogen levels (Bands A-D < 11.3 mg/L). See Figure 3.9.	One GMZ has 100%; Fourteen GMZ have between 90% and 100%; and two GMZ have less than 90%. Tauherenikau has the greatest percentage, with 100.00%; and Te Ore Ore has the lowest percentage, with 85.53%. Cell-by-cell: 98.71%.	Two GMZ have 100%; thirteen GMZ have between 90% and 100%; and two GMZ have less than 90%. Upper Ruamahanga has the greatest percentage improvement: up 1.47% from Baseline. Cell-by-cell: 99.00%.	Two GMZ have 100.0%; fourteen GMZ have between 90% and 100%; and one GMZ has less than 90%. Te Ore Ore has the greatest percentage improvement: up 2.84% from BAU. Cell-by-cell: 99.20%.	Same as Silver 2025. Cell-by-cell: 99.20%.	Same as Silver 2025. Cell-by-cell: 99.20%.	Same as Silver 2025. Cell-by-cell: 99.20%.	Same as Silver 2025. Cell-by-cell: 99.20%.
Structural volume of layers one and two of the groundwater model that could contain groundwater that has nitrate-nitrogen levels less than (better than) 50% of the human health limit (Bands A-C < 5.65 mg/L). See Figure 3.10 and Figure 3.11.	Six GMZ have greater than 90%; nine GMZ have between 50% and 90%; and two GMZ have less than 50%. Huangarua has the greatest percentage, with 99.46%; and Parkvale has the lowest percentage, with 42.01%. Cell-by-cell: 91.17%.	Seven GMZ have greater than 90%; eight GMZ have between 50% and 90%; and two GMZ have less than 50%. Upper Ruamahanga has the greatest percentage improvement: up 2.26% from Baseline. Cell-by-cell: 91.85%.	Eight GMZ have greater than 90%; nine GMZ have between 50% and 90%; and zero GMZ have less than 50%. Parkvale has the greatest percentage improvement: up 18.39% from Baseline. Cell-by-cell: 94.35%.	Same as Silver 2025. Cell-by-cell: 94.35%.	Same as Silver 2025. Cell-by-cell: 94.36%.	Same as Silver 2025. Cell-by-cell: 94.48%.	Same as Silver 2025. Cell-by-cell: 94.48%.
Surficial area of the uppermost saturated layer of the groundwater model that could contain groundwater suitable for human consumption (potable) based on nitrate-nitrogen levels (Bands A-D < 11.3 mg/L). See Figure 3.12.	One GMZ has 100%; twelve GMZ have between 90% and 100%; and four GMZ have less than 90%. Cell-by-cell: 98.09%.	Two GMZ have 100%; eleven GMZ have between 90% and 100%; and four GMZ have less than 90%. Cell-by-cell: 98.51%.	Two GMZ have 100%; eleven GMZ have between 90% and 100%; and four GMZ have less than 90%. Cell-by-cell: 98.85%.	Same as Silver 2025. Cell-by-cell: 98.85%.	Same as Silver 2025. Cell-by-cell: 98.85%.	Same as Silver 2025. Cell-by-cell: 98.85%.	Same as Silver 2025. Cell-by-cell: 98.85%.
Surficial area of the uppermost saturated layer of the groundwater model that could contain groundwater that has nitrate-nitrogen levels less than (better than) 50% of the human health limit (Bands A-C < 5.65 mg/L). See Figure 3.13.	Three GMZ have greater than 90%; ten GMZ have between 50% and 90%; and four GMZ have less than 50%. Cell-by-cell: 88.32%.	Four GMZ have greater than 90%; ten GMZ have between 50% and 90%; and three GMZ have less than 50%. Cell-by-cell: 89.30%.	Seven GMZ have greater than 90%; nine GMZ have between 50% and 90%; and one GMZ has less than 50%. Cell-by-cell: 92.68%.	Same as Silver 2025. Cell-by-cell: 92.69%.	Same as Silver 2025. Cell-by-cell: 92.69%.	Eight GMZ have greater than 90%; eight GMZ have between 50% and 90%; and one GMZ has less than 50%. Cell-by-cell: 92.82%.	Same as Gold 2025. Cell-by-cell: 92.82%.

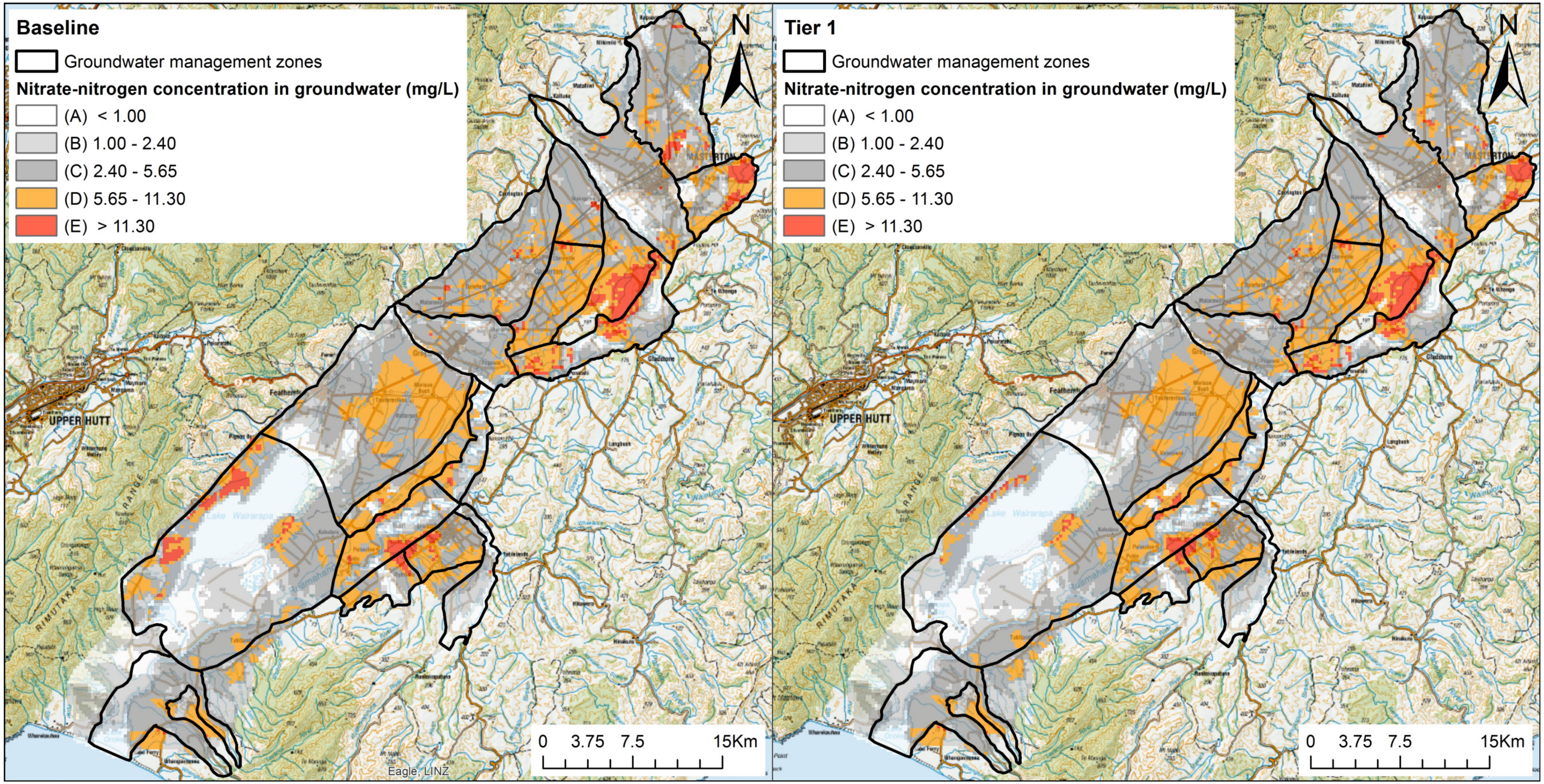

Figure 3.7 Nitrate-nitrogen concentrations within the uppermost saturated layer of the North and South Ruamāhanga groundwater models. “Baseline” results are from the baseline flow solution and nitrate-nitrogen loading using “stock exclusion but no Tier 1 mitigations”. “Tier 1” results are from the BAU flow solution and nitrate-nitrogen loading using “Tier 1”. Red represents those areas that exceed the threshold for human health as defined by Ministry of Health (2005), and orange represents those areas that exceed 50% of this threshold.

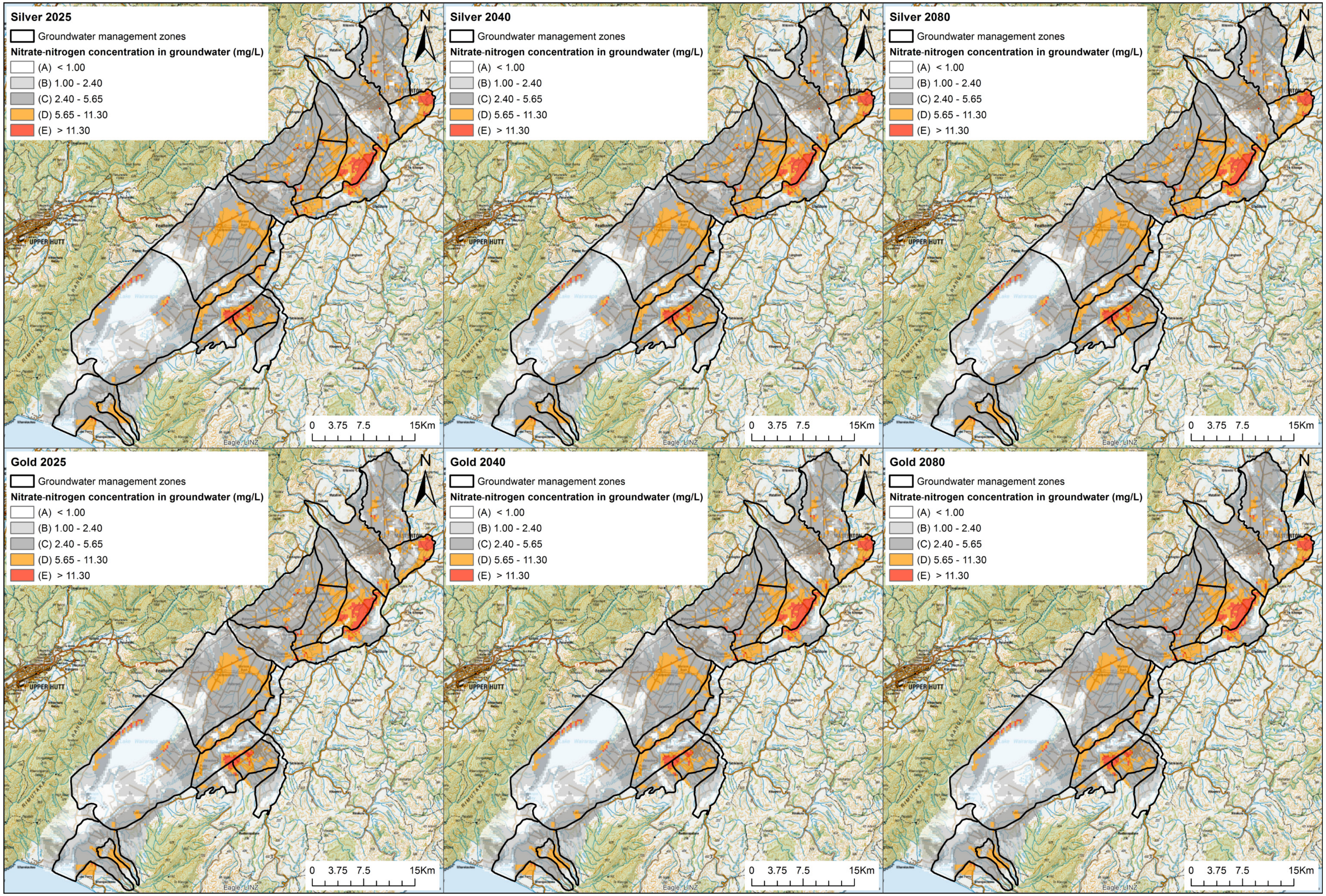

Figure 3.8 Nitrate-nitrogen concentrations within the uppermost saturated layer of the North and South Ruamāhanga groundwater models. All results are from the BAU flow solution and nitrate-nitrogen loading from the Silver and Gold scenarios specified. Red represents those areas that exceed the threshold for human health as defined by Ministry of Health (2005), and orange represents those areas that exceed 50% of this threshold.

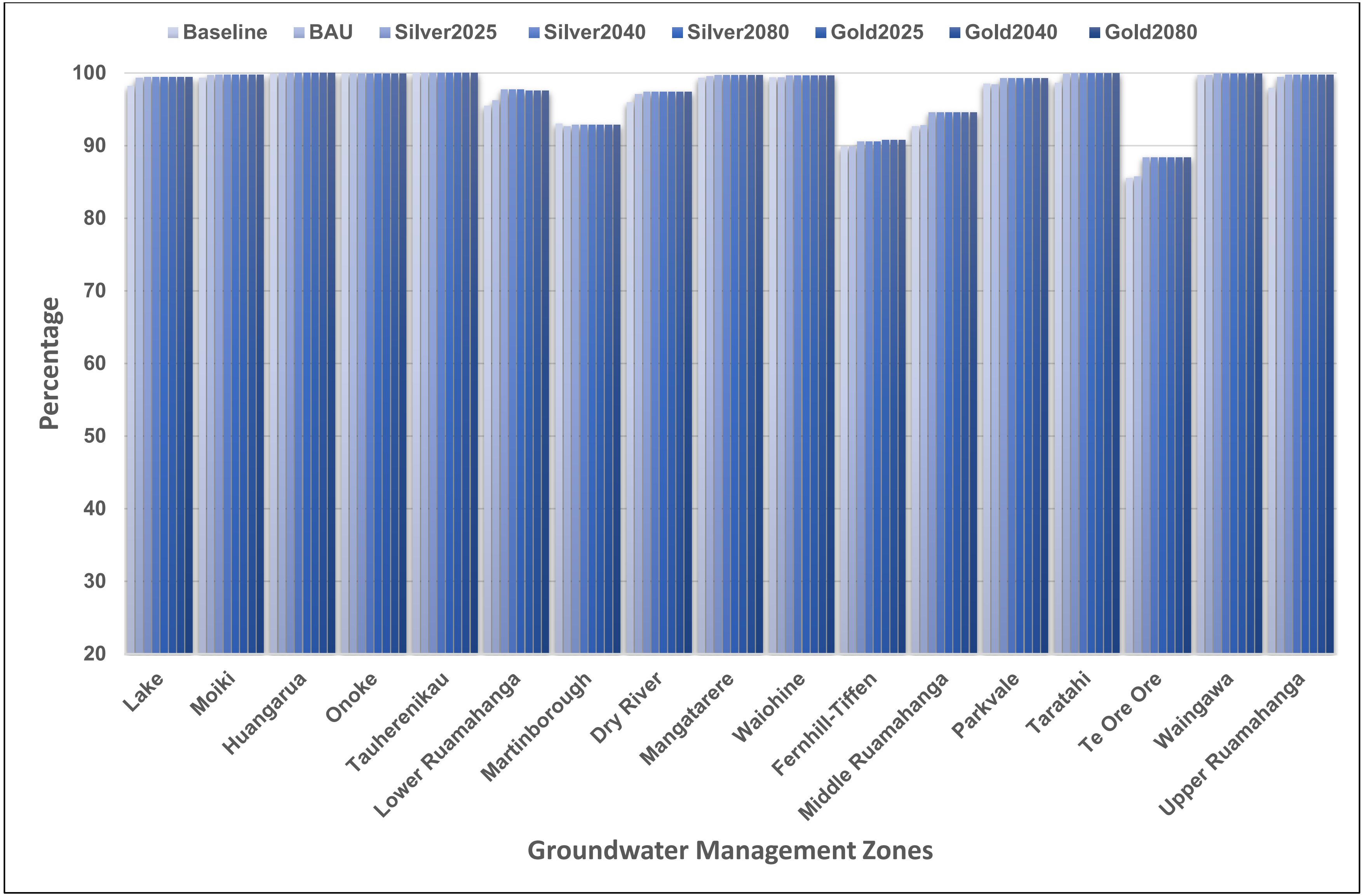

Figure 3.9 For each scenario, the percentage of the structural volume of layers one and two of the groundwater model in each GMZ that could contain groundwater suitable for human consumption (potable) based on nitrate-nitrogen levels.

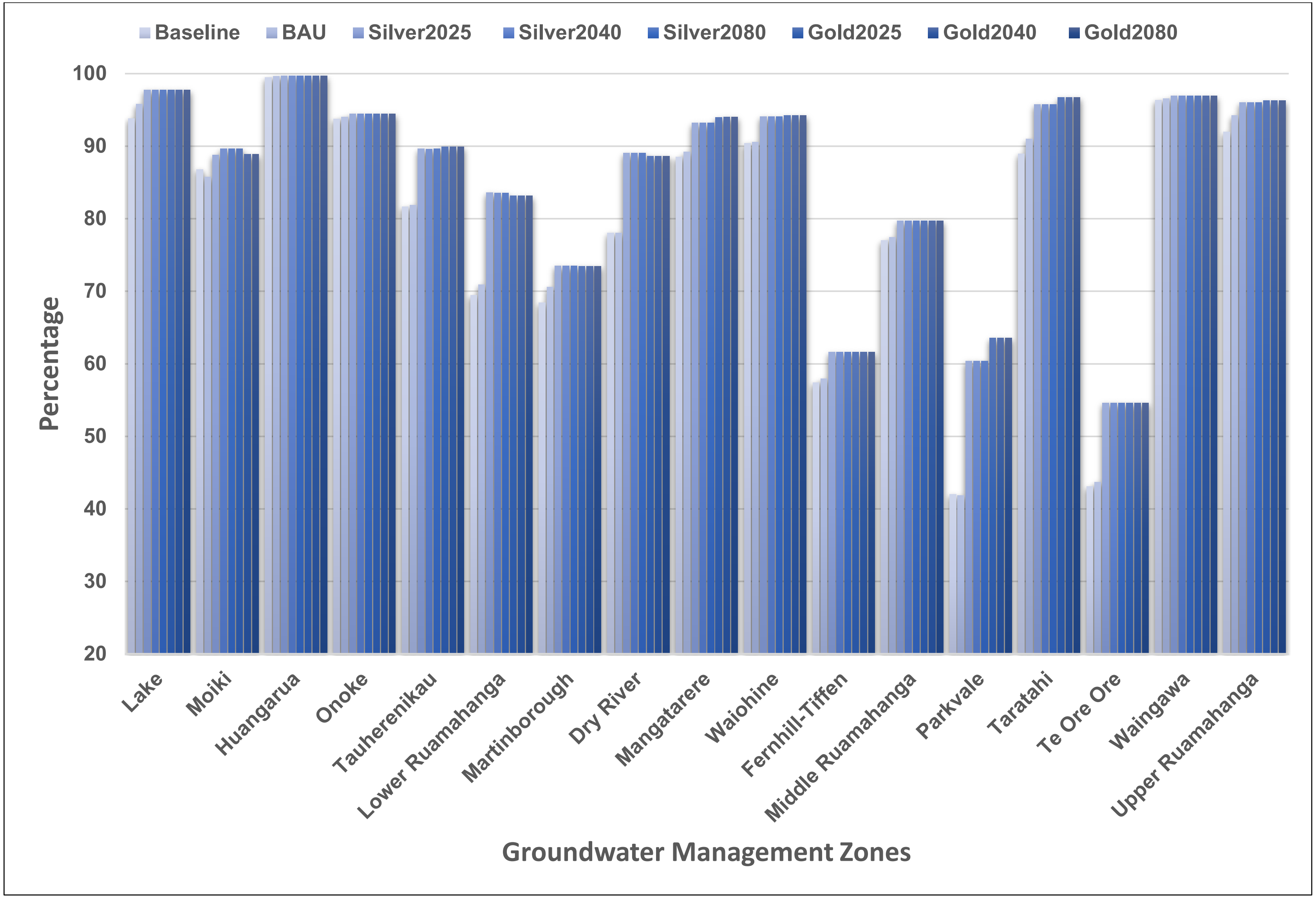

Figure 3.10 For each scenario, the percentage of the structural volume of layers one and two of the groundwater model in each GMZ that could contain groundwater that has nitrate-nitrogen levels less than (better than) 50% of the human health limit.

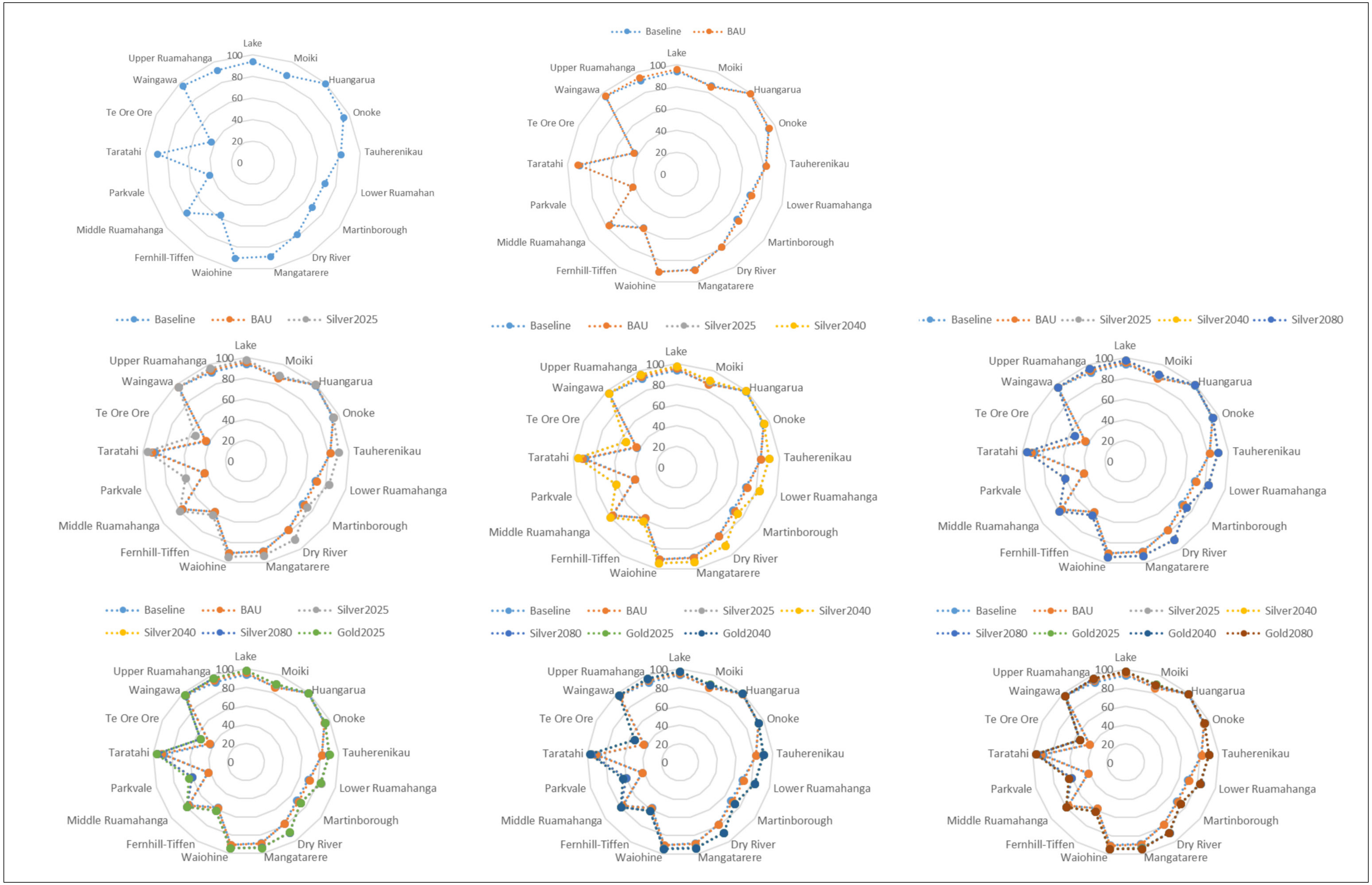

Figure 3.11 Radar graph for each scenario. The data points show the percentage of GMZ volume containing groundwater that has nitrate-nitrogen levels less than (better than) 50% of the human health limit. Data points that lie closer to the outside of the circle (100%) indicate a greater volume of good quality water.

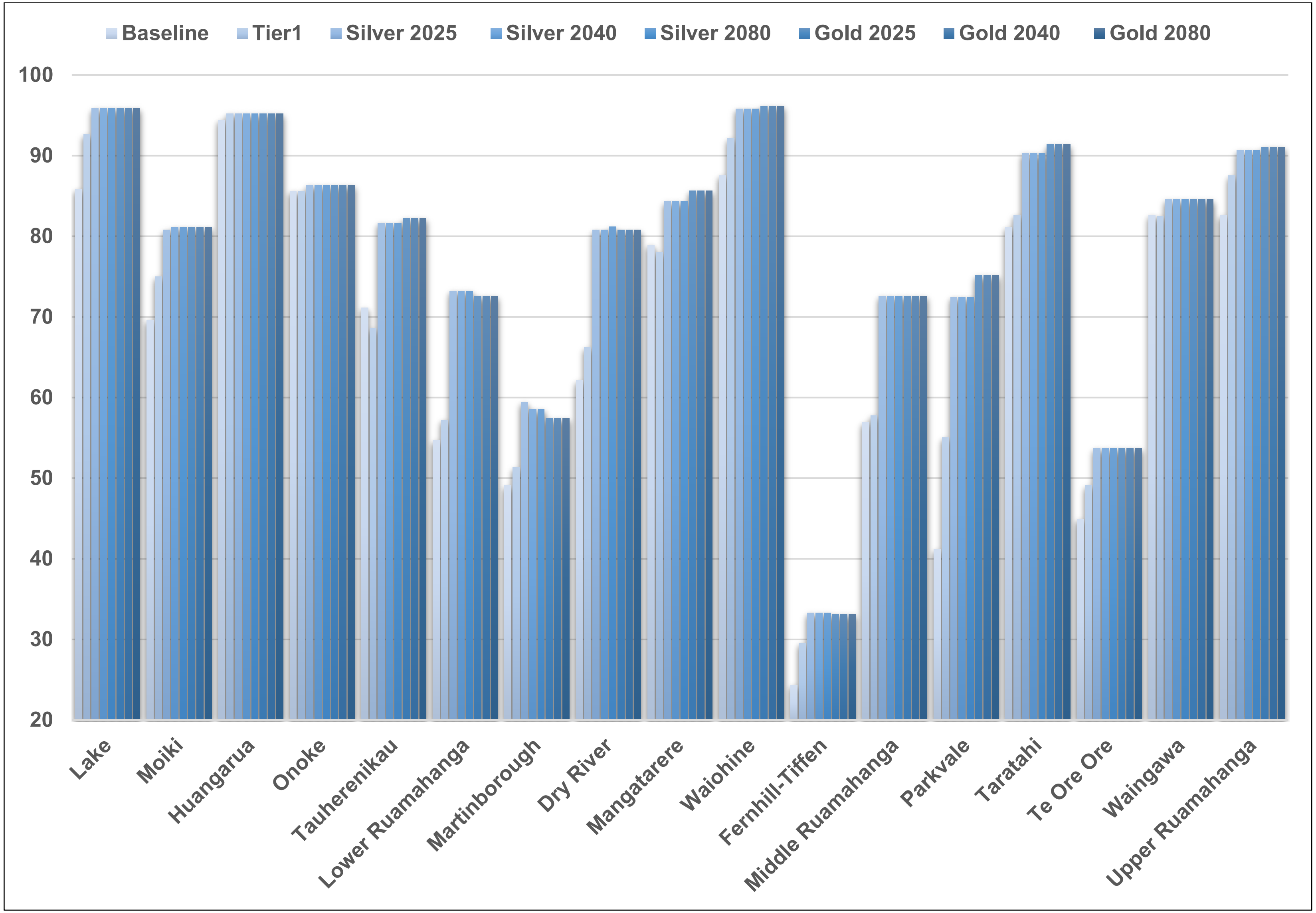

Figure 3.12 For each scenario, the percentage of the surficial area of the uppermost saturated layer of the groundwater model in each GMZ that could contain groundwater suitable for human consumption (potable) based on nitrate-nitrogen levels.

Figure 3.13 For each scenario, the percentage of the surficial area of the uppermost saturated layer of the groundwater model for each GMZ that could contain groundwater that has nitrate-nitrogen levels less than (better than) 50% of the human health limit.

4.0 LIMITATIONS

The BAU flow scenario utilised only existing consented takes and so does not simulated any impacts associated with increasing pumping up to the zone limits set in the PRNP.

See Appendix 2 for an additional discussion regarding limitations associated with the implementation of flow restricted groundwater takes.

The BAU flow scenario uses historical recorded climate data for simulation purposes and therefore does not simulate any potential impacts associated with climate change.

The resolution of the results presented is limited by the groundwater computer model uncertainties, including the model cell size and layer thicknesses (Moore et al., 2016).

5.0 REFERENCES

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APPENDICES

APPENDIX 1: NITRATE NITROGEN RESULT STATISTICS AND MAPS

A1.1 ANALYSIS

Table A 1.1 and Table A 1.2 describe the volume of model layers 1 and 2 in each GMZ that correspond to less than a particular nitrate-nitrogen concentration and Table A 1.3 and Table A 1.4 describe the area in each GMZ that correspond to less than a particular nitrate-nitrogen concentration. These volumes and areas were calculated largely using a Python script (v 2.7) and ESRI ArcGIS software (ArcMap 10.3.1). Note that for analysis purposes, the model grids were re-sampled from 250 x 250 m to 10 x 10 m.

For each model (North and South models) the following preparatory work was carried out:

1. Layer thickness rasters for each model layer (layers 1 and 2) that were previously created (Moore, et. al., 2016) were converted into numpy arrays using the osgeo, gdal package. These were then re-sampled to 10 x 10 m grid cells using the scipy, ndimage package, and were converted into volumes by multiplying each thickness value by the model cell size (10 x 10 m). The dimensions of these volume layers were used to create a numpy array of model cell area (10 x 10 m).
2. In ArcGIS, the GMZ polygon shapefile was converted to a raster with a 10 x 10 m cell size and the extent of the model using the ‘Feature to Raster’ tool.

For each scenario, the following was carried out for each model (North and South models):

1. The unformatted MT3DMS nitrate-nitrogen concentration output file (*.ucn) was converted into a numpy array of nitrate-nitrogen concentrations for each model layer and for the uppermost saturated layer using the package ‘mt3d’ (developed by Mike Toews, GNS Science). Layers 1 and 2 and the uppermost saturated layer were extracted as separate numpy arrays and resampled to 10 x 10 m grid cells using the scipy, ndimage package.
2. The GMZ raster was converted into a numpy array using the python osgeo, gdal package.
3. For each layer (layers 1 and 2 and the uppermost saturated layer) concentration raster and each threshold (category D and E thresholds) a numpy mask was used to select only volume and area raster cells below the threshold value within the concentration array; the output arrays were then used along with the GMZ array to select only those cells within each GMZ and sum these volumes and areas; the total volume of layers 1 and 2 for each GMZ and the total area of each GMZ were also used to calculate percentages; details were saved into a pandas DataFrame.

The pandas DataFrame was used to compile the volume and area results per threshold and the results were exported to csv files.

A1.2 TABLES

Table A 1.1 Scenario result: percentage of GMZ Layer 1 and 2 volume with nitrate-nitrogen concentrations less than 50% of the human health threshold (category D).

	GMZ Layer 1 and 2 properties			Scenario result: % of GMZ Layer 1 and 2 volume with nitrate-nitrogen concentrations less than 50% of the human health threshold (category D)							
GMZ Name	**Mean depth (m)**	**Area (km^2)**	**Volume (m^3)**	**Baseline**	**Tier1**	**Silver 2025**	**Silver 2040**	**Silver 2080**	**Gold 2025**	**Gold 2040**	**Gold 2080**
Lake	30	219	6515×10^6	93.84	95.81	97.76	97.76	97.76	97.76	97.76	97.76
Moiki	14	18	257×10^6	86.82	85.78	88.81	89.68	89.68	89.68	88.90	88.90
Huangarua	17	23	375×10^6	99.46	99.63	99.72	99.72	99.72	99.72	99.72	99.72
Onoke	31	55	1630×10^6	93.75	94.05	94.44	94.44	94.44	94.44	94.44	94.44
Tauherenikau	12	152	1798×10^6	81.68	81.87	89.66	89.62	89.66	89.92	89.92	89.92
Lower Ruamāhanga	13	39	517×10^6	69.46	70.94	83.59	83.53	83.53	83.15	83.15	83.15
Martinborough	9	22	211×10^6	68.41	70.60	73.49	73.51	73.51	73.47	73.47	73.47
Dry River	13	17	212×10^6	78.06	78.06	89.08	89.08	89.08	88.65	88.65	88.65
Mangatarere	13	75	976×10^6	88.52	89.21	93.21	93.21	93.21	93.98	94.05	94.05
Waiohine	15	39	603×10^6	90.42	90.55	94.11	94.11	94.11	94.23	94.23	94.23
Fernhill-Tiffen	16	38	519×10^6	57.41	57.95	61.60	61.60	61.60	61.60	61.60	61.60
Middle Ruamāhanga	18	44	784×10^6	77.01	77.47	79.74	79.74	79.74	79.74	79.74	79.74
Parkvale	10	37	391×10^6	42.01	41.84	60.40	60.40	60.40	63.59	63.59	63.59
Taratahi	23	29	679×10^6	88.95	90.98	95.76	95.76	95.76	96.73	96.73	96.73
Te Ore Ore	26	27	705×10^6	43.09	43.69	54.63	54.63	54.63	54.63	54.63	54.63
Waingawa	19	78	1344×10^6	96.38	96.57	96.96	96.96	96.96	96.96	96.96	96.96
Upper Ruamāhanga	20	72	1424×10^6	91.97	94.23	96.04	96.04	96.04	96.30	96.30	96.30

Table A 1.2 Scenario result: percentage of GMZ Layer 1 and 2 volume with nitrate-nitrogen concentrations less than the human health threshold (category E).

	GMZ Layer 1 and 2 properties			**Scenario result: % of GMZ Layer 1 and 2 volume with nitrate-nitrogen concentrations less than the human health threshold (category E)**							
GMZ Name	**Mean depth (m)**	**Area (km^2)**	**Volume (m^3)**	**Baseline**	**Tier1**	**Silver 2025**	**Silver 2040**	**Silver 2080**	**Gold 2025**	**Gold 2040**	**Gold 2080**
Lake	30	219	6515 $x10^6$	98.21	99.31	99.45	99.45	99.45	99.45	99.45	99.45
Moiki	14	18	257 $x10^6$	99.31	99.68	99.74	99.74	99.74	99.74	99.74	99.74
Huangarua	17	23	375 $x10^6$	99.89	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Onoke	31	55	1630 $x10^6$	99.92	99.92	99.92	99.92	99.92	99.92	99.92	99.92
Tauherenikau	12	152	1798 $x10^6$	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Lower Ruamāhanga	13	39	517 $x10^6$	95.46	96.21	97.71	97.71	97.71	97.56	97.56	97.56
Martinborough	9	22	211 $x10^6$	93.01	92.63	92.86	92.86	92.86	92.86	92.86	92.86
Dry River	13	17	212 $x10^6$	95.94	97.10	97.42	97.42	97.42	97.42	97.42	97.42
Mangatarere	13	75	976 $x10^6$	99.31	99.54	99.70	99.70	99.70	99.70	99.70	99.70
Waiohine	15	39	603 $x10^6$	99.36	99.36	99.64	99.64	99.64	99.64	99.64	99.64
Fernhill-Tiffen	16	38	519 $x10^6$	89.87	89.87	90.54	90.54	90.54	90.75	90.75	90.75
Middle Ruamāhanga	18	44	784 $x10^6$	92.67	92.80	94.57	94.57	94.57	94.57	94.57	94.57
Parkvale	10	37	391 $x10^6$	98.53	98.41	99.28	99.28	99.28	99.28	99.28	99.28
Taratahi	23	29	679 $x10^6$	98.66	99.88	99.99	99.99	99.99	99.99	99.99	99.99
Te Ore Ore	26	27	705 $x10^6$	85.53	85.77	88.37	88.37	88.37	88.37	88.37	88.37
Waingawa	19	78	1344 $x10^6$	99.70	99.71	99.92	99.92	99.92	99.92	99.92	99.92
Upper Ruamāhanga	20	72	1424 $x10^6$	97.96	99.43	99.74	99.74	99.74	99.74	99.74	99.74

Table A 1.3 Scenario result: percentage of GMZ surface area with nitrate-nitrogen concentrations in the uppermost saturated layer that are less than 50% of the human health threshold (category D).

		Scenario result: % of GMZ surface area with nitrate-nitrogen concentrations in layer 1 that are less than 50% of the human health threshold (category D)							
GMZ Name	**Area (km^2)**	**Baseline**	**Tier1**	**Silver 2025**	**Silver 2040**	**Silver 2080**	**Gold 2025**	**Gold 2040**	**Gold 2080**
Lake	219	85.85	92.65	95.71	95.71	95.71	95.71	95.71	95.71
Moiki	18	69.92	70.97	79.11	79.66	79.66	79.66	79.42	79.42
Huangarua	23	98.21	99.03	99.61	99.61	99.61	99.61	99.61	99.61
Onoke	55	92.57	92.80	93.23	93.23	93.23	93.23	93.23	93.23
Tauherenikau	152	70.62	71.29	83.85	83.76	83.85	84.35	84.35	84.35
Lower Ruamāhanga	39	54.02	53.78	74.93	75.09	75.09	74.32	74.32	74.32
Martinborough	22	49.38	50.40	56.65	56.70	56.70	56.59	56.59	56.59
Dry River	17	64.09	64.61	80.87	80.87	80.87	80.12	80.12	80.12
Mangatarere	75	81.60	82.79	89.00	89.00	89.00	90.25	90.34	90.34
Waiohine	39	87.85	88.18	91.84	91.84	91.84	91.84	91.84	91.84
Fernhill-Tiffen	38	38.98	39.38	42.59	42.59	42.59	42.54	42.54	42.54
Middle Ruamāhanga	44	58.68	59.11	62.55	62.55	62.55	62.55	62.55	62.55
Parkvale	37	40.97	40.61	61.83	61.83	61.83	65.61	65.61	65.61
Taratahi	29	82.58	83.13	91.44	91.44	91.44	92.96	92.96	92.96
Te Ore Ore	27	48.09	49.78	55.57	55.57	55.57	55.57	55.57	55.57
Waingawa	78	92.77	93.58	94.16	94.16	94.16	94.16	94.16	94.16
Upper Ruamāhanga	72	83.83	87.11	90.77	90.77	90.77	91.29	91.29	91.29

Table A 1.4 Scenario results: percentage of GMZ surface area with nitrate-nitrogen concentrations in the uppermost saturated layer that are less the human health threshold (category E).

		Scenario result: % of GMZ surface area with nitrate-nitrogen concentrations in layer 1 that are less the human health threshold (category E)							
GMZ Name	**Area (km^2)**	**Baseline**	**Tier1**	**Silver 2025**	**Silver 2040**	**Silver 2080**	**Gold 2025**	**Gold 2040**	**Gold 2080**
Lake	219	96.13	98.99	99.19	99.19	99.19	99.19	99.19	99.19
Moiki	18	97.35	98.72	98.97	98.97	98.97	98.97	98.97	98.97
Huangarua	23	99.72	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Onoke	55	99.93	99.93	99.93	99.93	99.93	99.93	99.93	99.93
Tauherenikau	152	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Lower Ruamāhanga	39	91.90	92.86	94.83	94.83	94.83	94.67	94.67	94.67
Martinborough	22	89.31	89.05	89.60	89.60	89.60	89.60	89.60	89.60
Dry River	17	91.60	93.86	94.62	94.62	94.62	94.62	94.62	94.62
Mangatarere	75	98.75	99.17	99.51	99.51	99.51	99.51	99.51	99.51
Waiohine	39	98.90	98.90	99.30	99.30	99.30	99.30	99.30	99.30
Fernhill-Tiffen	38	73.17	73.17	74.79	74.79	74.79	75.13	75.13	75.13
Middle Ruamāhanga	44	83.77	84.21	89.50	89.50	89.50	89.50	89.50	89.50
Parkvale	37	97.53	97.37	98.51	98.51	98.51	98.51	98.51	98.51
Taratahi	29	98.30	99.60	99.98	99.98	99.98	99.98	99.98	99.98
Te Ore Ore	27	82.45	82.68	86.90	86.90	86.90	86.90	86.90	86.90
Waingawa	78	99.34	99.34	99.59	99.59	99.59	99.59	99.59	99.59
Upper Ruamāhanga	72	95.95	98.84	99.48	99.48	99.48	99.48	99.48	99.48

A1.3 ZOOMED-IN MAPS

Zoomed-in nitrate nitrogen concentration maps are shown for three select areas in Figures A 1.1 – A 1.3.

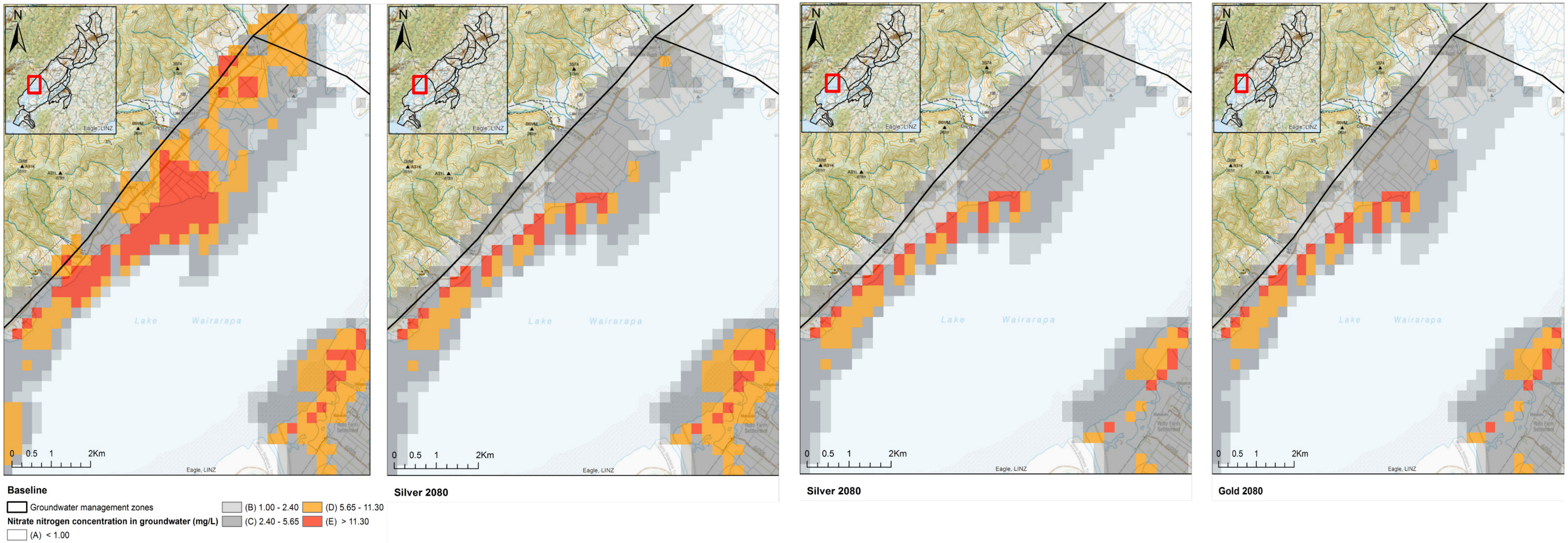

Figure A 1.1 Zoomed-in maps of the western side of Lake Wairarapa. Nitrate-nitrogen concentrations within the uppermost saturated layer of the South Ruamāhanga groundwater model. All results are from the BAU flow solution and nitrate-nitrogen loading from the Silver and Gold scenarios specified. Red represents those areas that exceed the threshold for human health as defined by Ministry of Health (2005), and orange represents those areas that exceed 50% of this threshold.

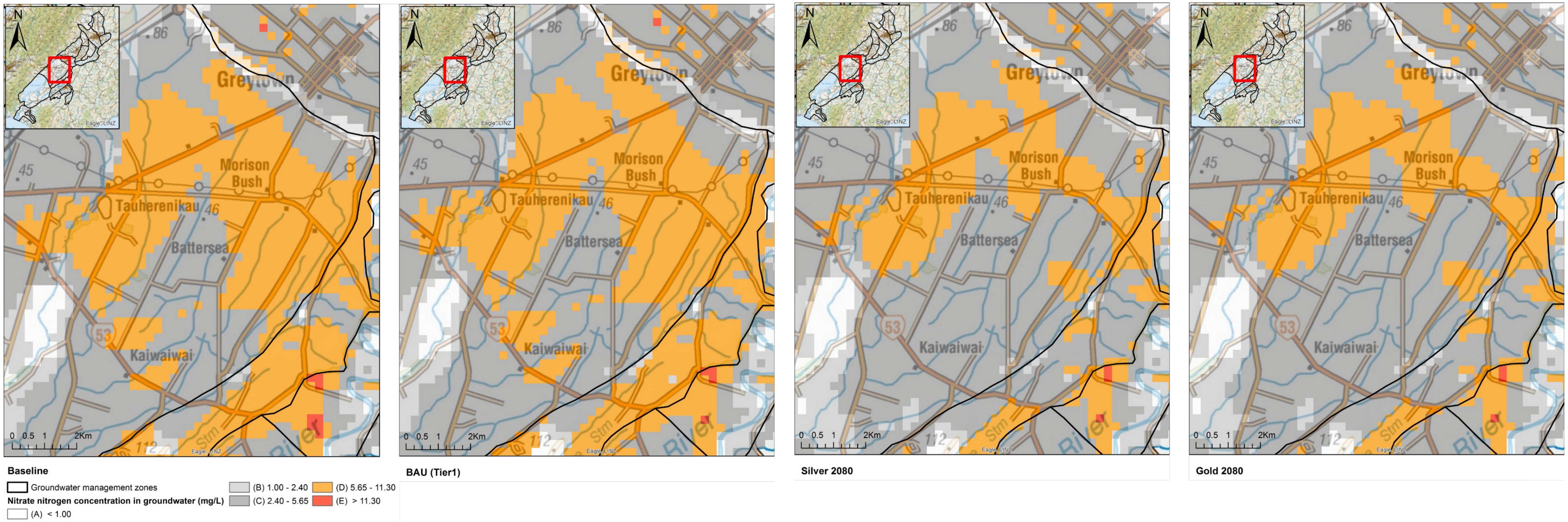

Figure A 1.2 Zoomed-in maps of Tauherenikau. Nitrate-nitrogen concentrations within the uppermost saturated layer of the North and South Ruamāhanga groundwater models. All results are from the BAU flow solution and nitrate-nitrogen loading from the Silver and Gold scenarios specified. Red represents those areas that exceed the threshold for human health as defined by Ministry of Health (2005), and orange represents those areas that exceed 50% of this threshold.

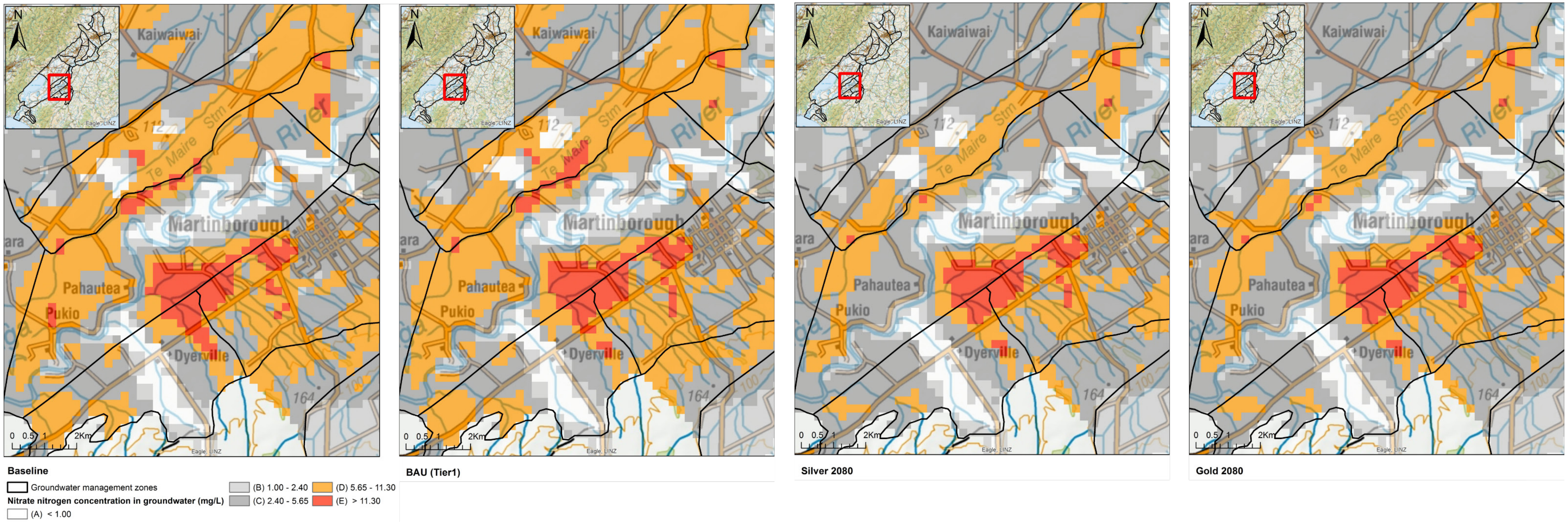

Figure A 1.3 Zoomed-in maps of Martinborough. Nitrate-nitrogen concentrations within the uppermost saturated layer of the South Ruamāhanga groundwater model. All results are from the BAU flow solution and nitrate-nitrogen loading from the Silver and Gold scenarios specified. Red represents those areas that exceed the threshold for human health as defined by Ministry of Health (2005), and orange represents those areas that exceed 50% of this threshold.

APPENDIX 2: CONSEQUENCES OF THE ASSUMPTIONS MADE FOR BAU

As described in Section 2.0, all model assumptions and inputs were defined under advisement from Mike Thompson (Senior Environmental Scientist, Hydrology, Greater Wellington Regional Council) and John Bright (Director of Research & Development, Aqualinc Research Limited), and direction of the RWC (Ruamāhanga Whaitua Committee, 2017). However, after the first analysis of results was supplied to GWRC in June 2017, it was determined that some of the assumptions made did not match what was expected for the implementation of the PNRP. Namely, the flow recorder sites “Dock Creek at Otakura Junction” and “Makoura Stream at Colombo Rd” were not included in the BAU scenario tables (Ruamāhanga Whaitua Committee, 2017) and so were removed for the BAU model runs, however, these are expected to be maintained at baseline levels for implementation of the PNRP. Additionally, the BAU scenario tables (Ruamāhanga Whaitua Committee, 2017) have stepdown flow rates for flow recorder sites that were used to place groundwater takes into stepdown conditions for BAU, however, it is expected for the PNRP that any changes in stepdown flow rates in the BAU scenario tables (Ruamāhanga Whaitua Committee, 2017) are only implemented for restricting surface water takes and all groundwater takes maintain stepdown conditions at the baseline stepdown flow thresholds. This was most significant for the flow recorder site “Ruamāhanga River at Wardells” that has a stepdown flow change from 2400 to 2700 L/s.

A test was carried out for just the north Ruamāhanga groundwater transport model using one of the nitrate-nitrogen loads (Figure A 2.1) to compare the nitrate-nitrogen concentration results between BAU as implemented, and BAU if the restrictions were changed as described above. The percentage of the model cells with differences of greater than 1 mg/L are small (1.24% of model cells). The difference in pumping between BAU as implemented, and BAU if the restrictions were changed as described above is also displayed for the north model (Figure A 2.2).

Following the assessment of the potential impacts of these changes and consultation with Mike Thompson (Senior Environmental Scientist, Hydrology, Greater Wellington Regional Council), John Bright (Director of Research & Development, Aqualinc Research Limited) and Natasha Tomic (Senior Science Coordinator, Science Strategy and Information Team, Greater Wellington Regional Council), it was determined that the models would not be re-run with adjusted restriction rules as the overall effect of the resultant differences are considered negligible.

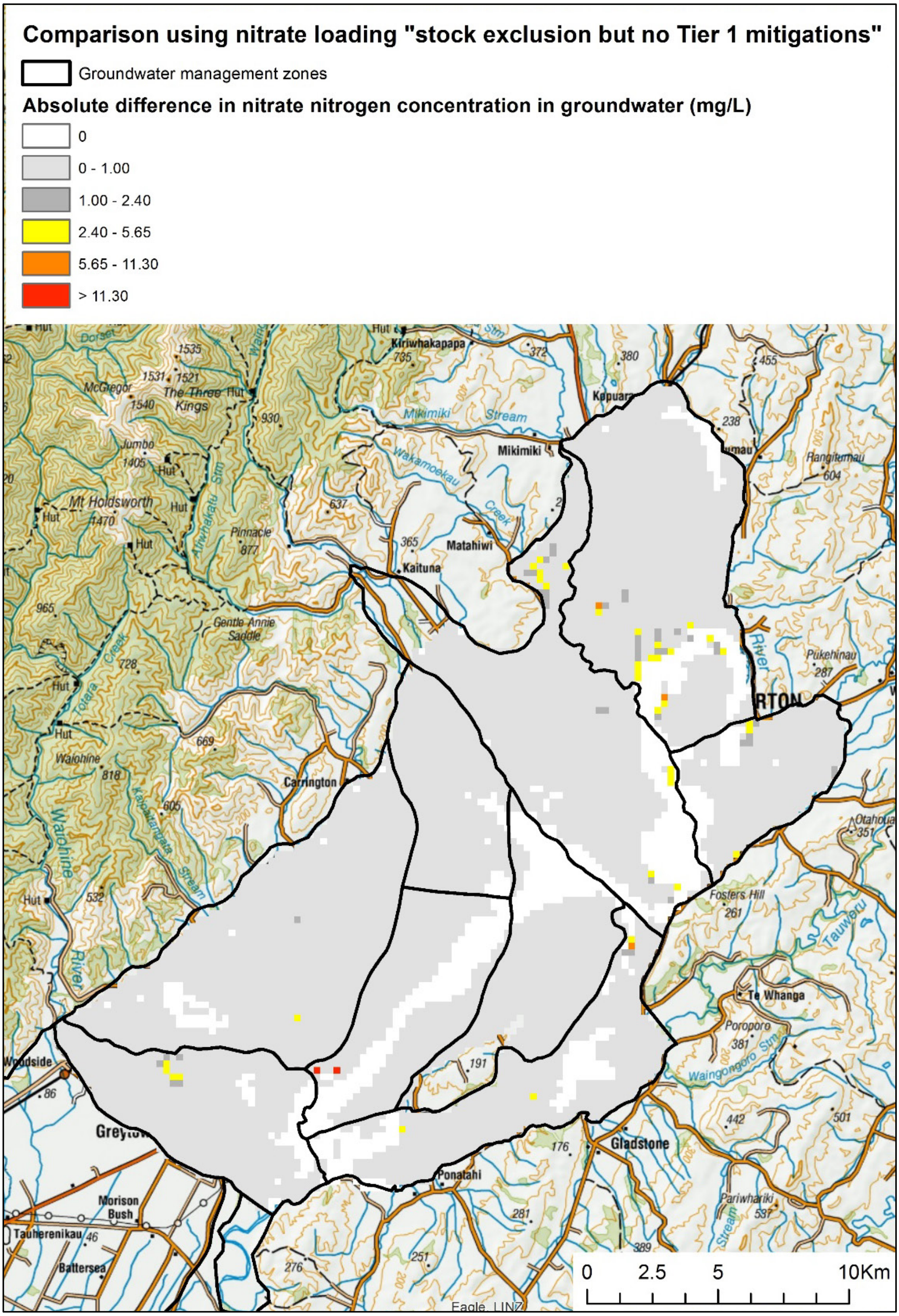

Figure A 2.1 Absolute difference in nitrate-nitrogen concentrations in groundwater for the north Ruamāhanga transport model between the BAU results presented in this report and adjustments made for flow restrictions considered truer to the PNRP implementation (described in the text).

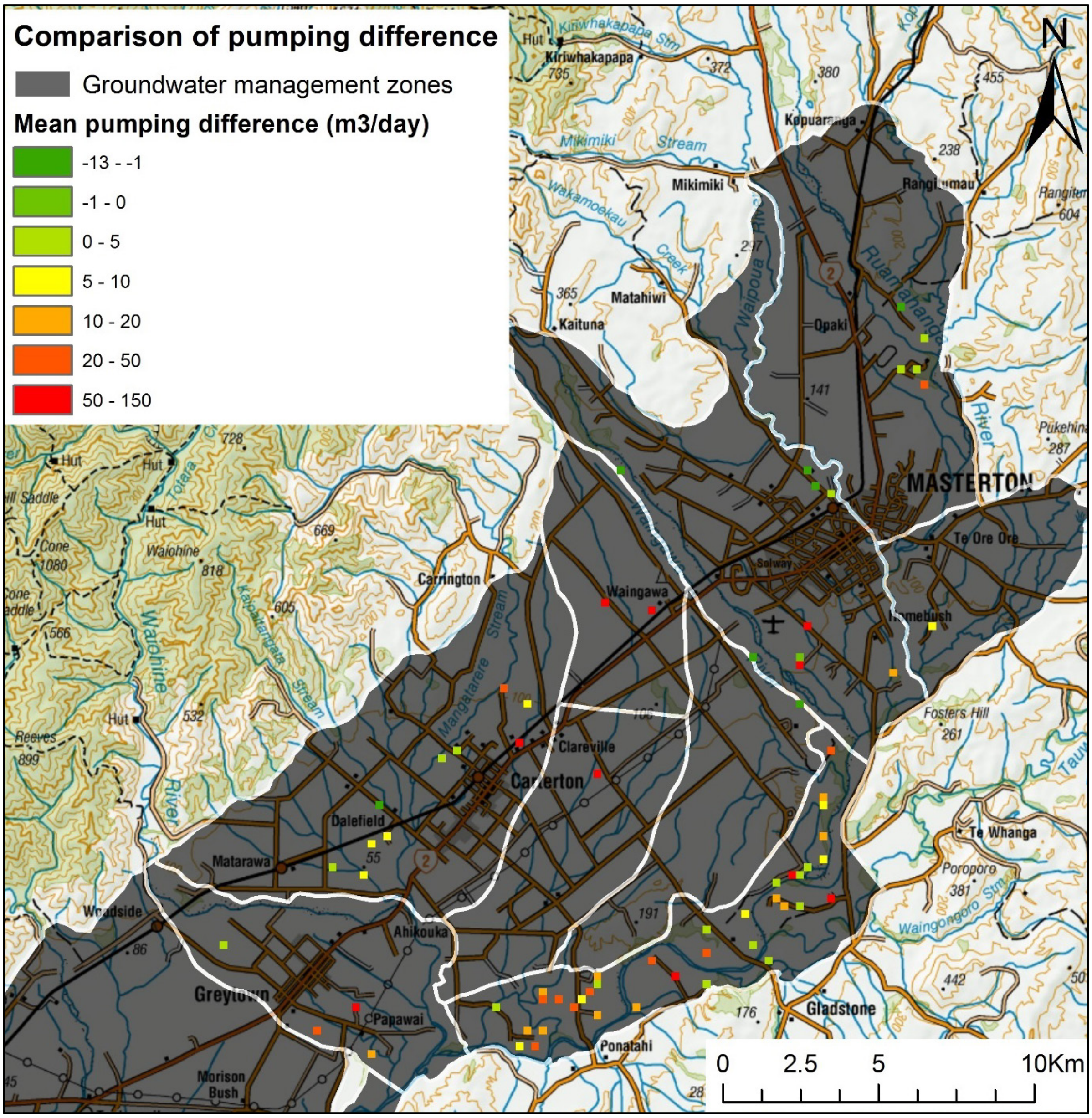

Figure A 2.2 Comparison of the difference in groundwater pumping volumes for the north Ruamāhanga groundwater model between the BAU results presented in this report and adjustments made for flow restrictions considered truer to the PNRP implementation (described in the text). The values are positive where BAU modelling has greater pumping than the expected PNRP implementation.

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