Environment Committee Meeting

26 August 2021

This Report relates to Item 4 in the Agenda

"Rarangi Shallow Aquifer Saline Intrusion Risk Assessment Report"

Auckland Tauranga Wellington **Christchurch**

PATTLE DELAMORE PARTNERS LTD

Rarangi Shallow Aquifer Saline Intrusion Risk Assessment

Marlborough District Council

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Rarangi Shallow Aquifer Saline Intrusion Risk Assessment

Prepared for

Marlborough District Council

June 2021

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Limitations:

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1.0 Introduction

Pattle Delamore Partners Limited has been engaged by Marlborough District Council to investigate the potential effects of sea level rise on groundwater in the Rarangi Shallow Aquifer. The Rarangi Shallow Aquifer is used by local residents for domestic water supplies, who need some further information regarding the long-term response of their water supply aquifer to changes in sea level. Estimates of the likely rates of sea level rise are now relatively well characterised and therefore these data can be used to estimate how the saline-freshwater interface is likely to change. This letter report therefore covers the following topics:

- Review of current information to define the position of the saline-freshwater interface
- Description of future sea-level rise predictions
- Methodology to assess changes in the saline interface in response to sea-level rise
- Results of calculations to indicate potential changes in the interface position.

A map showing the location and boundary of the Rarangi Shallow Aquifer is provided in Figure 1.

2.0 Review of current information

2.1 Summary of hydrogeological setting

The Rarangi Shallow Aquifer (RSA) consists of a thin (< 10 m thick) surface veneer of relatively permeable sands and fine gravels overlying the less permeable marine sands and silts of the Dillons Point Formation. The RSA is bounded by the coast to the east, the Wairau Diversion Channel to the south, the Pukaka Drain to the west and the foothills of the Robertson Range to the north and north-west.

Generally, the aquifer is recharged by rainfall infiltration as well as some runoff from the hills. The main direction of groundwater flow is to the east towards Cloudy Bay, although a groundwater flow divide exists along the north-south central axis of the aquifer which directs a proportion of flow to the Pukaka Drain. Towards the south, some groundwater discharges directly into the Wairau Diversion channel. Consequently, the main aquifer discharge points are via discharge to the coast and via seepage into the Pukaka Drain and Wairau Diversion channel, however the aquifer also discharges via groundwater abstraction for domestic supplies and irrigation and via evaporation through the interdune wetlands, for example the Pipitea Wetland.

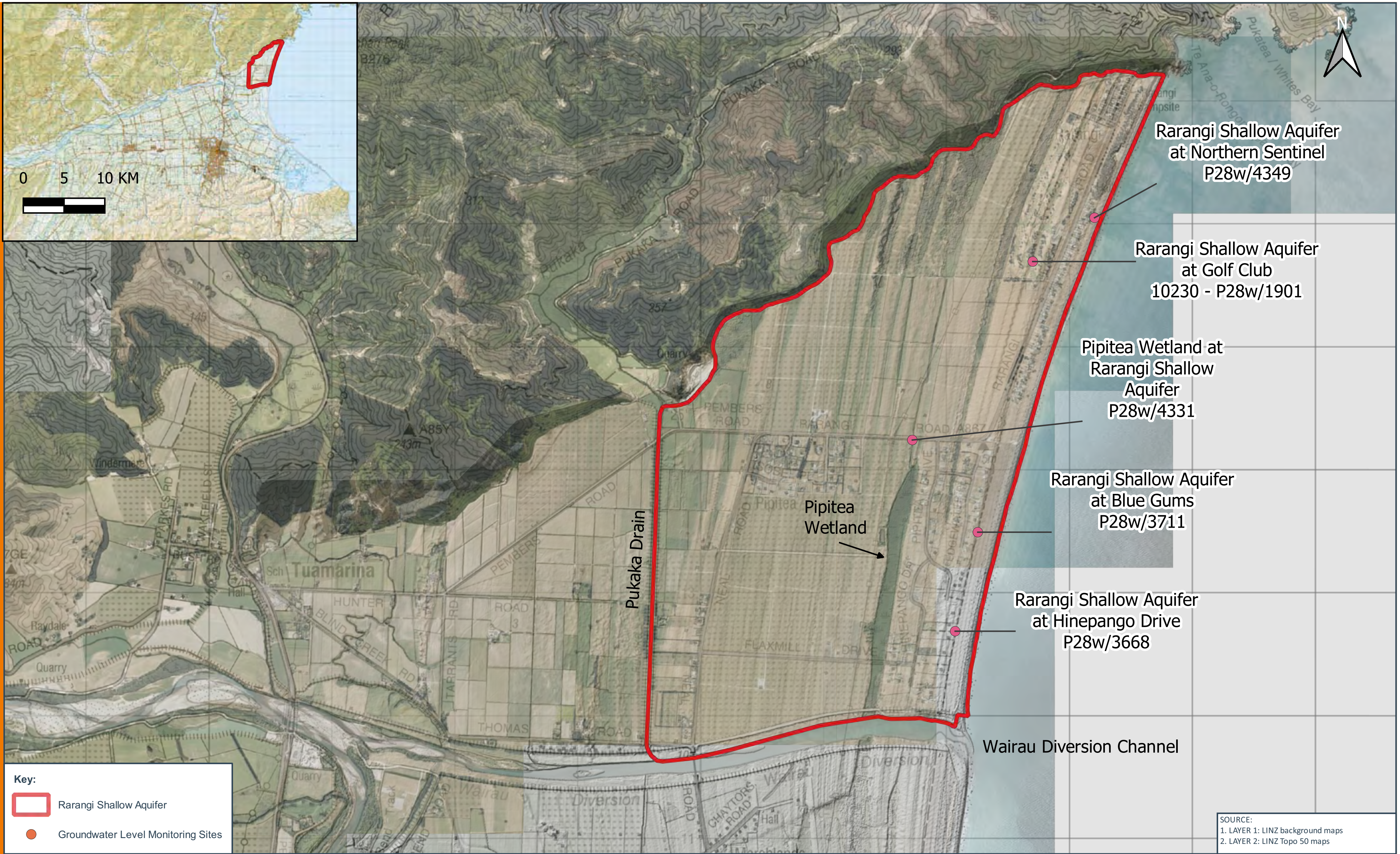

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FIGURE
FIGURE 1: Location of the Rarangi Shallow Aquifer and monitoring bores

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RARANGI SHALLOW AQUIFER SEA LEVEL RISE

Davidson (2011) indicates that the RSA is unconfined with a maximum saturated aquifer thickness of 7 m in the north and east, thinning to around 3 to 4 m in the south near the Wairau Diversion. As a result of the thin coastal nature of the RSA, it is vulnerable to changes in climate and there is potential for saline intrusion into the aquifer due to sea level rise, as well as other changes to the patterns of recharge to, and discharge from, the aquifer.

There are a variety of information sources to help define the position of the existing saline-freshwater interface including:

- groundwater level surveys
- electrical resistivity surveys
- groundwater level monitoring in bores located close to the coast; and
- groundwater electrical conductivity monitoring in bores located close to the coast

These sources are considered in more detail in the following sections of this report.

2.2 Groundwater level surveys

Groundwater level surveys typically extend across a wide spatial area and are used to estimate the likely pattern of groundwater levels based on a number of measured points. Two surveys are available for the Rarangi Shallow Aquifer, undertaken in 1989 which represent summer and winter groundwater levels. In general, the difference between summer and winter groundwater levels is small with winter levels close to the coast in the order of 0.5 m higher compared to summer levels. The differences are spatially variable and slightly greater differences appear to occur between the coast and the Rarangi Golf Course where difference appear to be around 0.6 m.

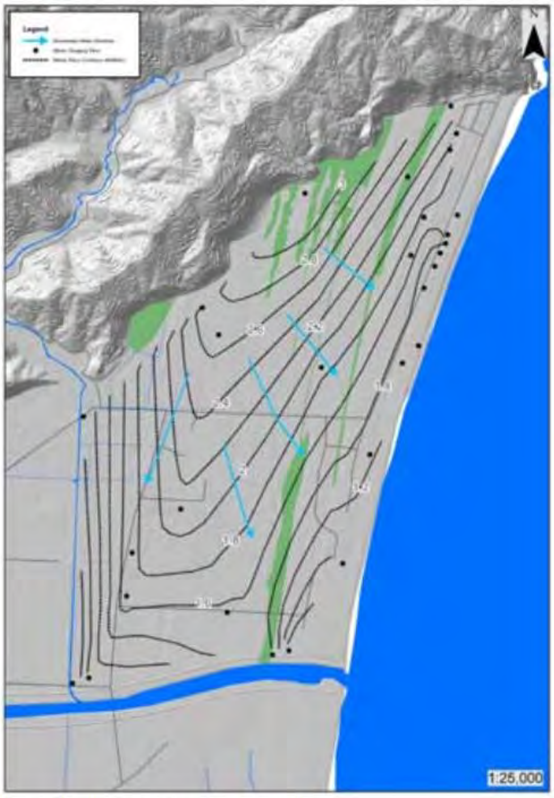

Figure 26.9: RSA winter water table

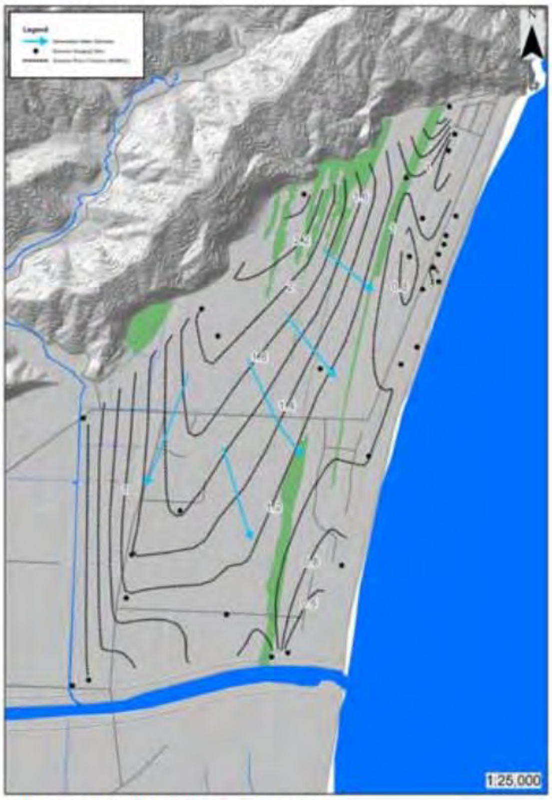

Figure 26.10: RSA summer water table

Figure 2: Groundwater level contours across the Rarangi shallow aquifer (after Davidson, 2011)

The most prominent feature from the groundwater level surveys is the presence of a groundwater divide running down the central axis of the aquifer which directs groundwater either towards the coast or towards the Pukaka Drain and the Wairau Diversion channel. The shape of the groundwater level surface as derived from the 1989 survey implies that the aquifer is recharged mainly via rainfall infiltration with little contribution from surface water seepage.

The groundwater elevation at the coast, based on 1989 surveys, appears to slope downwards from north to south with levels of around 1 m above mean sea level in the north of the area dropping to around 0.5 m in the south, close to the Wairau Diversion channel. Based on the Ghyben Herzberg relationship, which provides an estimate of the theoretical depth to the saline – freshwater interface based on the ratio of the density of sea water to freshwater, groundwater levels at 1 m above mean sea level would imply a saline-freshwater interface at around 40 m below groundwater levels, which is below the base of the aquifer. A shallower interface level is likely to be present around the south of the area, with water levels at 0.5 m above mean sea level would indicate a theoretical saline interface depth of 20 m (still below the base of the RSA).

2.3 Electrical resistivity surveys

In 2004, electrical resistivity surveys were carried out by the Victoria University of Wellington (Ingham, 2004) along three transects extending from the coast inland for around 200 m. The electrical resistivity surveys take advantage of the contrast between the low resistivity of saline water and high resistivity of freshwater and can allow the shape of the saline-freshwater interface to be identified. A copy of the results of that survey is shown in Figure 3 and the location of the survey lines is shown in Figure 4. The solid white lines on the right side of each of the surveys indicate the inferred position of the saline-freshwater interface, while the upper dashed lines represent the water table and the lower dashed lines represent the interface between the Rarangi Shallow Aquifer and the underlying Marine Sands of the Dillons Point Formation.

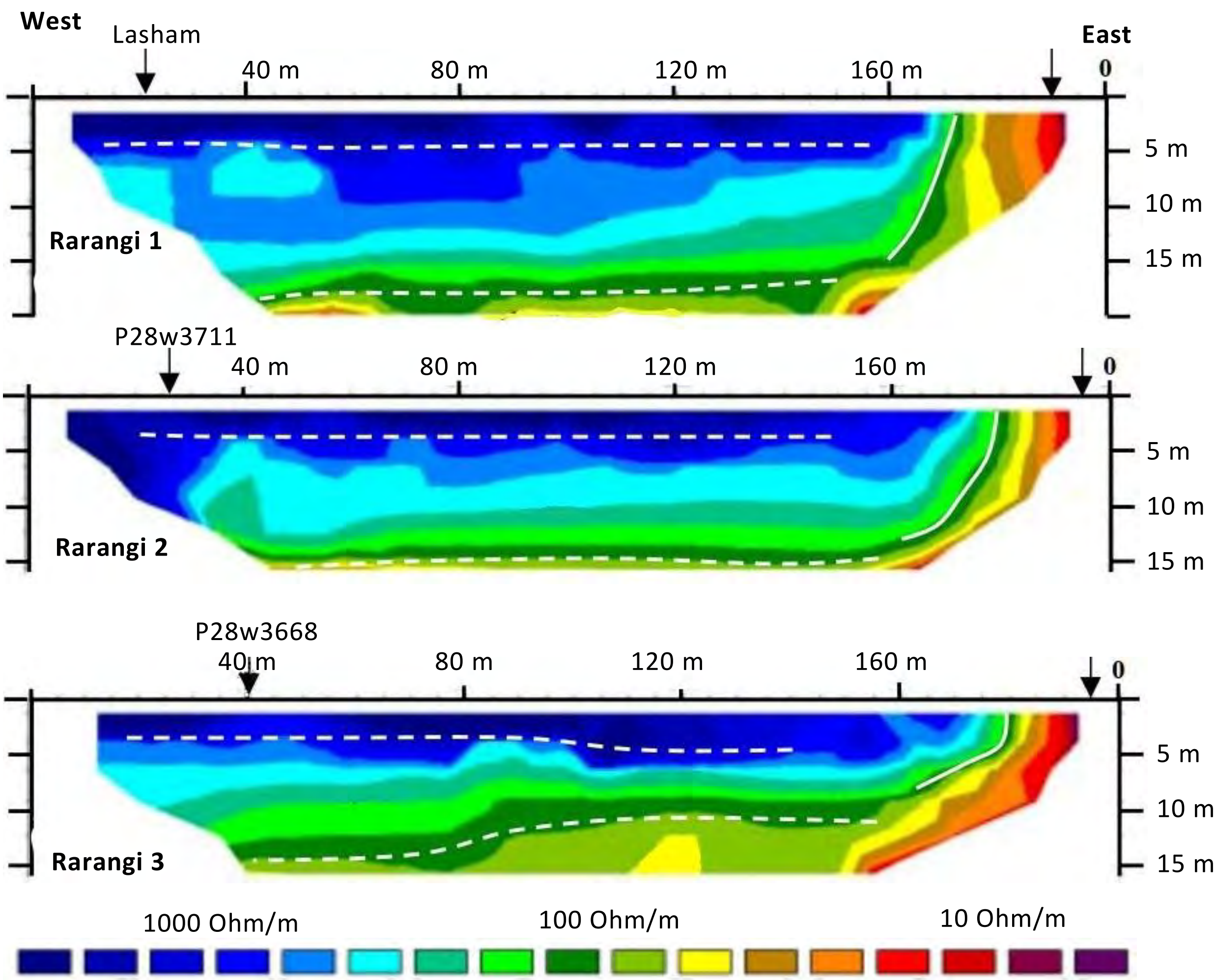

Figure 3: Results of electrical resistivity surveys (modified from Figure 8 in Ingham, 2004)

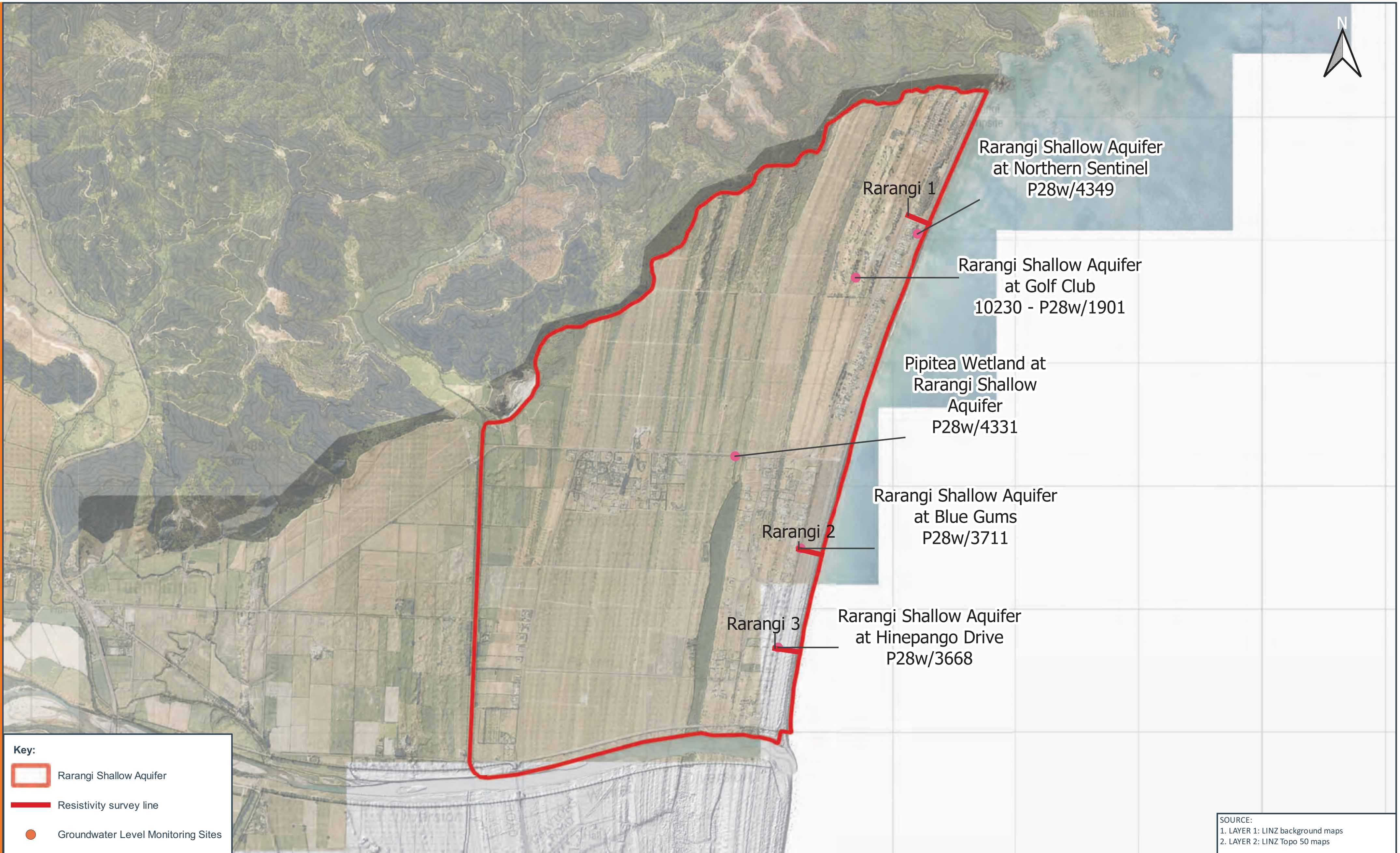

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FIGURE

FIGURE 4: LOCATIONS OF MONITORING BORES AND ELECTRICAL RESISTIVITY SURVEY LINES

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RARANGI SHALLOW AQUIFER SEA LEVEL RISE

The northern most survey (Rarangi 1) shows the steepest interface between saline and freshwater, which may reflect the higher groundwater pressures in that location noted above. Further south (in survey lines Rarangi 2 and 3), the saline freshwater interface is apparently shallower and less steep, which is also consistent with the apparently lower coastal groundwater pressures in the south of the aquifer boundary. The gradational change in resistivity values shown in Figure 3 demonstrates that the sea water – freshwater interface is not a sharp distinct line, but a broad transition zone that can extend over a distance of around a few 10's of m (based on the change in resistivity from 50 – 200 Ohm/m).

The results also indicate that the saline-freshwater interface is at least 100 m seawards from the monitoring bores located along each of the traverse lines. Therefore, it is generally unlikely that the monitoring bores intersect the current saline-freshwater interface, but do perform a sentinel function for any movement of the interface in a landward direction. This is discussed further in the next sections of this report.

2.4 Groundwater level monitoring

Groundwater levels are monitored at five locations along the coast in the Rarangi Shallow Aquifer, shown in Figure 1 and 4. The results of that monitoring is shown in Figure 5.

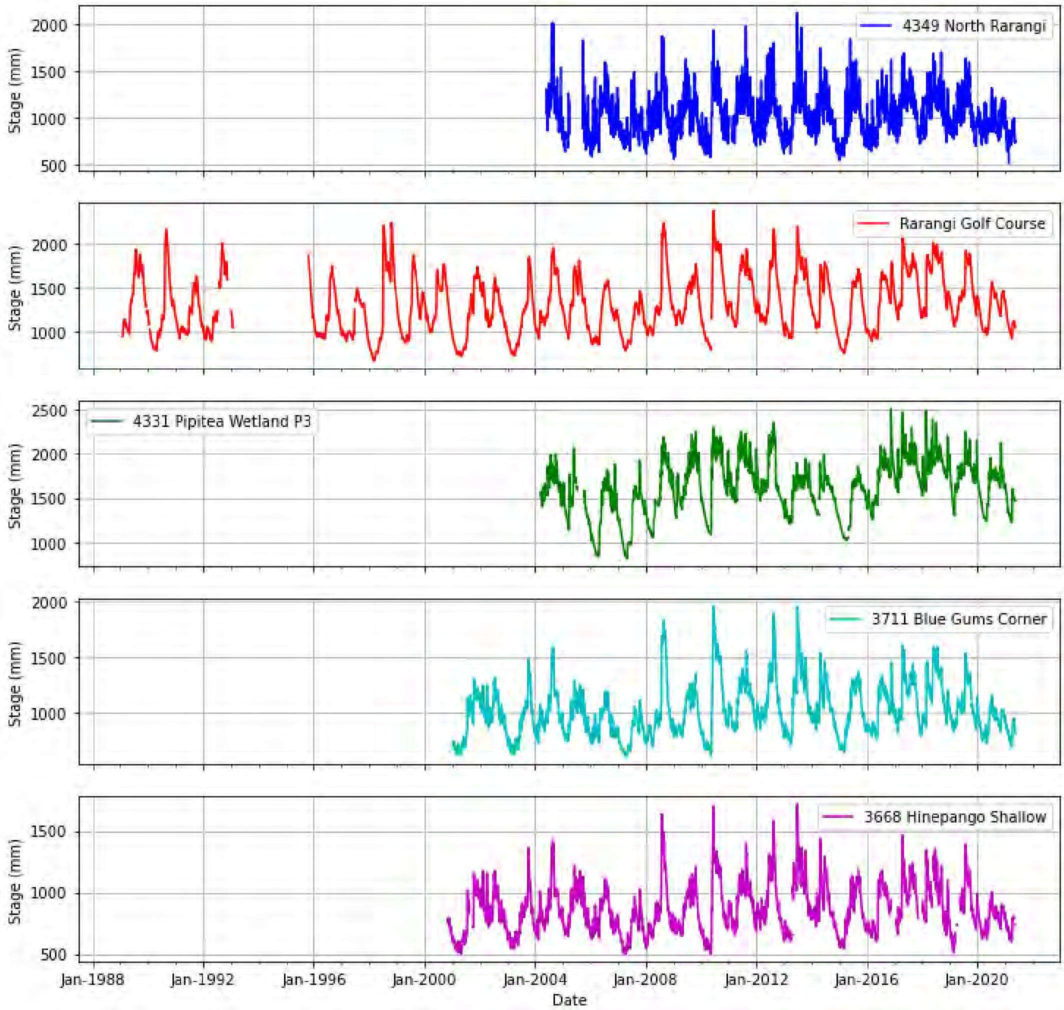


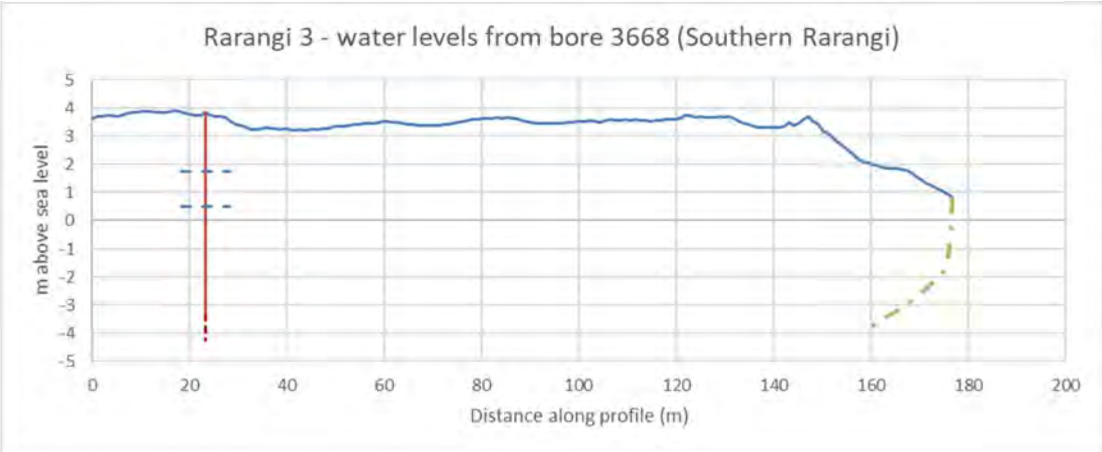
Figure 5: Results of groundwater level monitoring from MDC coastal monitoring bores

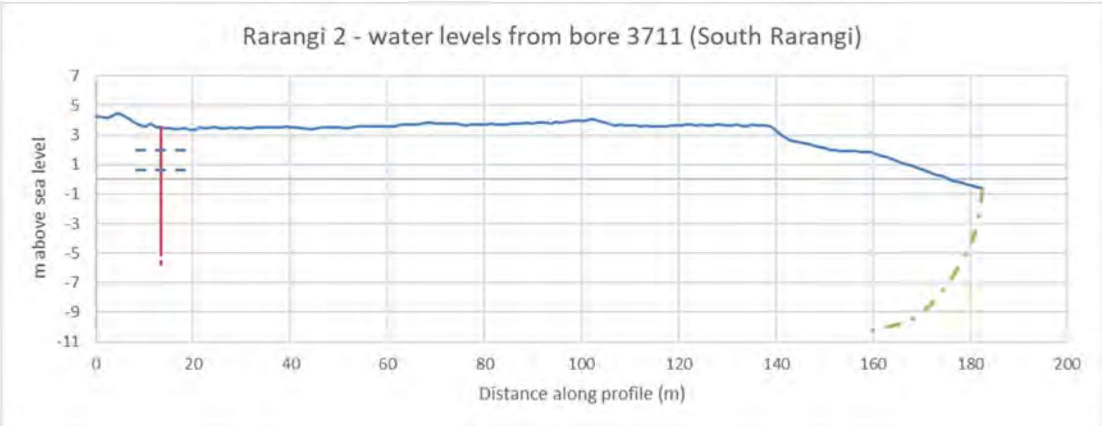
Bore 4331 and 1901 (Golf Course) are both located inland, at least 400 m from the coast, whereas bores 3668 and 3711 are located within around 150 m of the coast and bore 4349 located within around 50 m of the shoreline. Groundwater levels in the more inland bores are generally slightly higher compared to those located closer to the coast.

Groundwater levels show distinct seasonal variations, with the lowest groundwater levels typically occurring in late summer / early autumn (February/March) and higher groundwater levels occurring in late winter / early spring (August/September). All the groundwater level plots appear to show a recent, short term declining trend in response to recent dry winters, although groundwater levels are well within their historical range of fluctuations and the long-term trends are stable.

Seasonal fluctuations in groundwater levels are likely to correspond to seasonal changes in the location of the saline-freshwater interface because the change in groundwater levels is likely to reflect a change in rates of groundwater discharge to the coast. The resistivity sections shown in Figure 3 above were undertaken in December 2003 at a time when groundwater levels were low. Figure 6 illustrates cross sections along the electrical resistivity profiles (shown in Figure 4) and shows:

- the land surface profile (based on LiDAR data) between each of the monitoring bores located close to the coast (3668, 3711 and 4349) and the sea;
- the depth of each monitoring bore;
- the full range of groundwater levels in each bore; and
- how they relate to the position of the sea-water interface that was inferred from the electrical resistivity surveys discussed above.





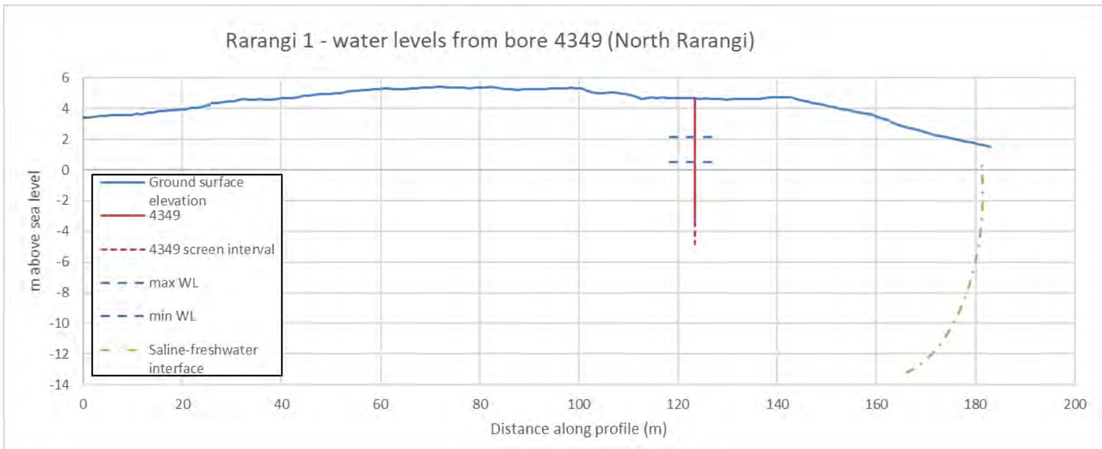


Figure 6: Cross sections between the coastal monitoring bores and the coast along the line of the electrical resistivity surveys

The profiles shown in Figure 6 illustrate that the monitoring bores are all generally located away from the inferred saline-freshwater interface. Based on their respective drillers logs, the monitoring bores are drilled to the base of the RSA, which suggests that the saline freshwater interface is unlikely to extend far inland at depth.

The range of water level fluctuations in each of the bores indicates that at times, water levels in all the bores are within around 0.5 m of sea level. Based on the information in the Ingham (2004) report, water levels in the bores were between 0.5 m amsl (Lasham) and 0.87 m amsl (bore 3711) at the time of their survey, which would correspond to a time of relatively lower water levels. Therefore, the estimated location of the saline-freshwater interface from the electrical resistivity surveys (Figure 6) is likely to be close to its maximum inland extent.

2.4.1 Groundwater electrical conductivity

Electrical conductivity data is collected from bores 3711 and 3668 along with water level data. Figure 7 shows the full range of data available for each bore from around 2001 to the present day, while Figure 8 shows a subset of the data from 2016 to 2021.

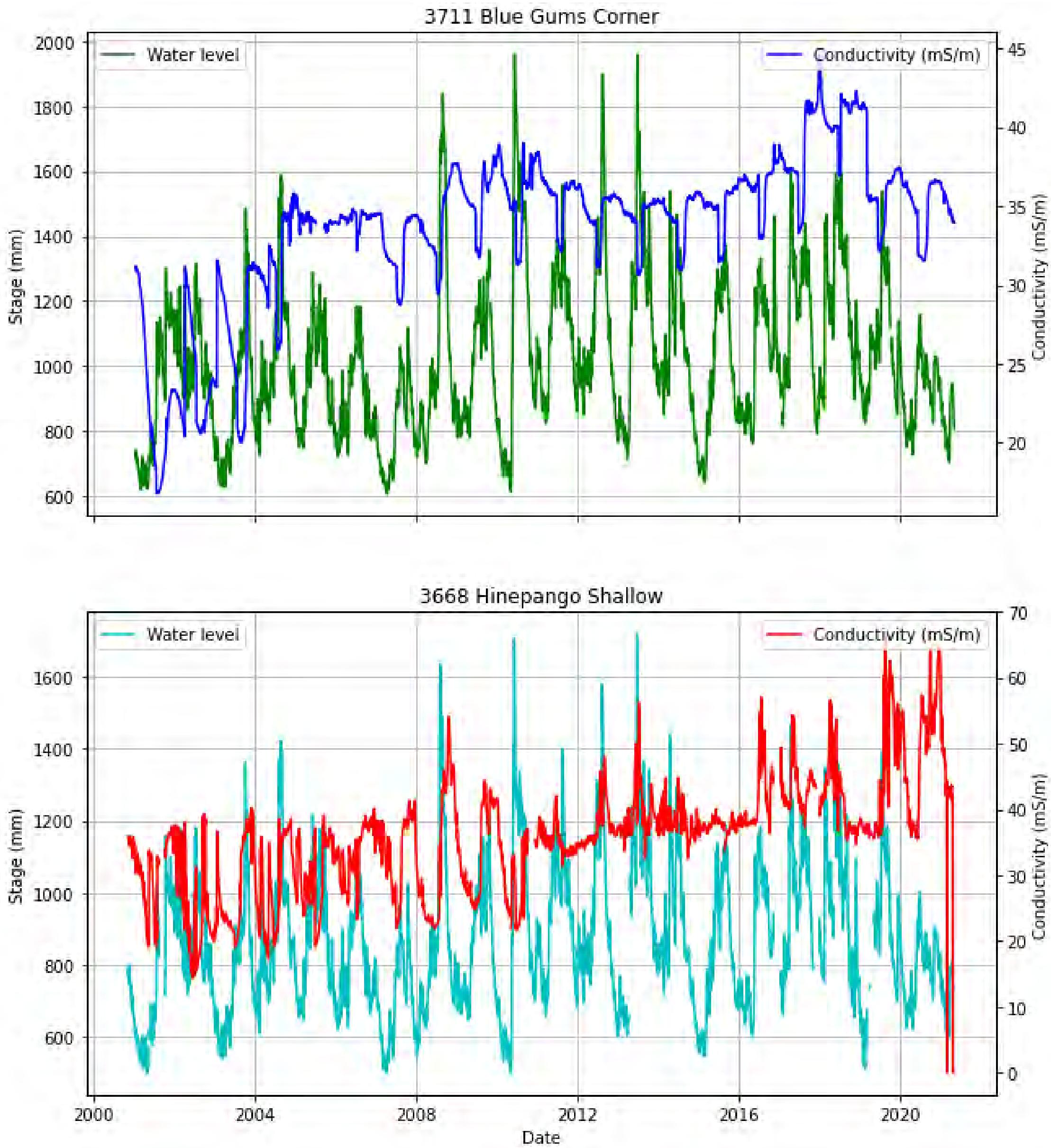


Figure 7: Full range of water level and electrical conductivity data from bore 3711 and 3668.

Both bores 3711 and 3668 show an apparent rising trend in conductivity levels since monitoring began in 2001 although the change is not generally substantial. In bore 3711 conductivity rises from around 25 mS/m in 2001 to around 35 mS/m in 2021. In bore 3668, located further south towards the Wairau Diversion Channel, conductivity increases from an average of around 30 mS/m in 2001 to an average of around 50 mS/m in 2021. To put these numbers in perspective, the taste threshold for chloride associated with saline water is likely to occur at an electrical conductivity value of around 120 mS/m.

In Figure 7, broadscale correlations between groundwater levels and conductivity can be observed, where in general, groundwater level peaks in bore 3711 appear to correlate with distinct drops in conductivity although this pattern only appears to emerge in the data since 2007. This would suggest that the groundwater level peak is associated with the infiltration of freshwater at this monitoring bore. In bore 3668, a consistent pattern where higher groundwater levels correlate with higher conductivity is apparent. This effect is likely to be a result of rainfall infiltration into the aquifer in the coastal area, carrying dissolved salts caused by sea spray from the land surface into groundwater.

The data from electrical conductivity monitoring does not appear to indicate the presence of saline intrusion into the aquifer at these bore locations, which would be shown by increased conductivity at times of lower groundwater levels.

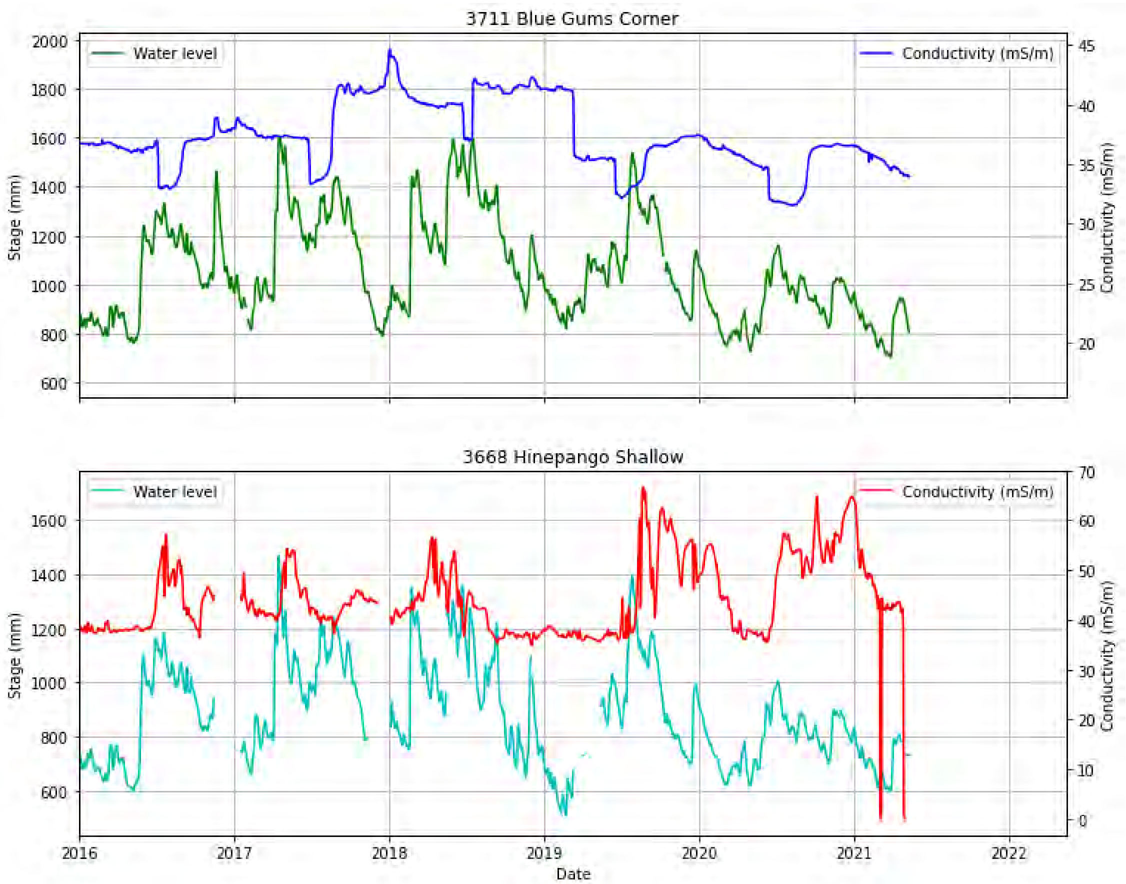


Figure 8: Water level and electrical conductivity data from bores 3711 and 3668 between Jan 2016 and May 2021

3.0 Description of future sea level rise predictions

Increases in sea level can result in the landward movement of seawater, which in turn can cause the saline-freshwater interface to move inland. Sea level varies due to a number of different factors, including (Dawe, 2007):

- Short term fluctuations due to changes in surface pressure (barometric pressures), winds and waves. A 0.1 hPa drop in barometric pressure results in around 0.01 m of sea level rise, so low pressure systems can cause a rise of up to 0.3 m.

- Medium term (i.e., annual) fluctuations caused by seasonal temperature fluctuations and the Southern Oscillation (El Nino / La Nina), which can alter sea levels by around 0.1 m.
- Longer term fluctuations (inter decadal) for example the Interdecadal Pacific Oscillation, which occurs over 20-30 years and can alter sea levels by around 0.05 m.

Super-imposed on these variations is the forecast long term change in sea levels due to climate change, which reflects the response of the ocean to increased global temperatures, causing thermal expansion of the ocean and thus rises in sea level.

Estimates of the effects of climate change on sea level rise are not precisely constrained, however Figure 9 presents a range of possible effects depending on the global emissions scenarios. By 2100, the largest mean sea level rise forecast is around 1.15 m (under RCP8.5 H, compared to the 1986-2005 average level), with smaller rises forecast under lower emission scenarios.

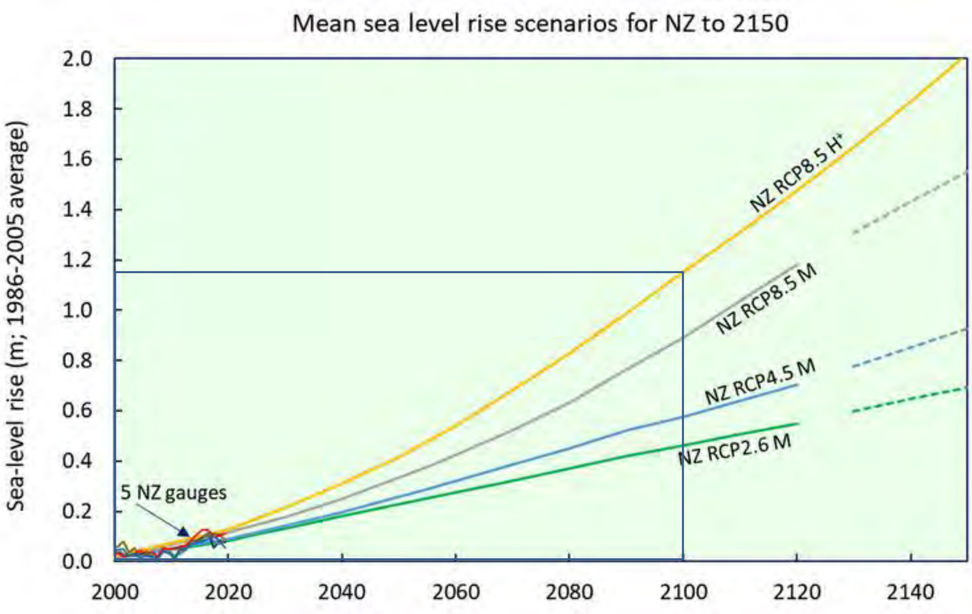


Figure 9: Sea level rise scenarios for New Zealand (after NIWA, 2021)

4.0 Methodology to assess changes in the saline-freshwater interface

Rises in sea level can result in several situations where the risk of saline intrusion into a freshwater aquifer is increased, including:

- increased sea water level at the coast,
- migration of surface sea water in a landwards direction and

- a lower and flatter groundwater gradient towards the coast.

The effects of these different situations on the location of the saline-freshwater interface will vary depending on the hydrogeological setting of the aquifer. There are two extreme end cases that can be considered:

- A constant flux scenario, where freshwater recharge into the aquifer remains constant under sea level rise and discharge from the aquifer to the coast also remains constant. Under this scenario, groundwater levels will rise in sympathy with the rise in sea level.
- A constant head scenario, where the fresh groundwater head (i.e., groundwater level) remains fixed at some point inland and does not rise in sympathy with sea level rise. As a result, the groundwater gradient flattens and the aquifer throughflow (flux) reduces. This could occur in a setting where groundwater intersects a fixed surface water drainage network inland of the coast.

The Rarangi Shallow Aquifer is an unconfined aquifer which is recharged via a combination of rainfall infiltration and runoff recharge from the inland hills. Discharge from the aquifer is to the coast and two surface water bodies (the Pukaka Drain and the Wairau Diversion channel), as well as to wetlands and agricultural drains that occur across the aquifer and to abstraction bores. The elevation of wetlands and agricultural drains is likely to be fixed, and therefore the RSA hydrogeological setting is likely to be similar to the constant head scenario described above.

Estimating the effect of sea level rise under a constant head scenario is generally more conservative compared to a constant flux scenario. This is because in a constant head scenario the reduced groundwater flux enables greater sea water intrusion into the aquifer, whereas the scenario where the flux remain constant restricts significant inland movement of the saline-freshwater interface.

Werner and Simmons (2009) developed a set of equations that can be used to describe the response of the saline-freshwater interface to a rise in sea level under a constant head scenario. Figure 10 shows the conceptual model that these equations are based on. The results of the equations determine the extent of the movement of the toe of the saline-freshwater interface (X_T) in Figure 10.

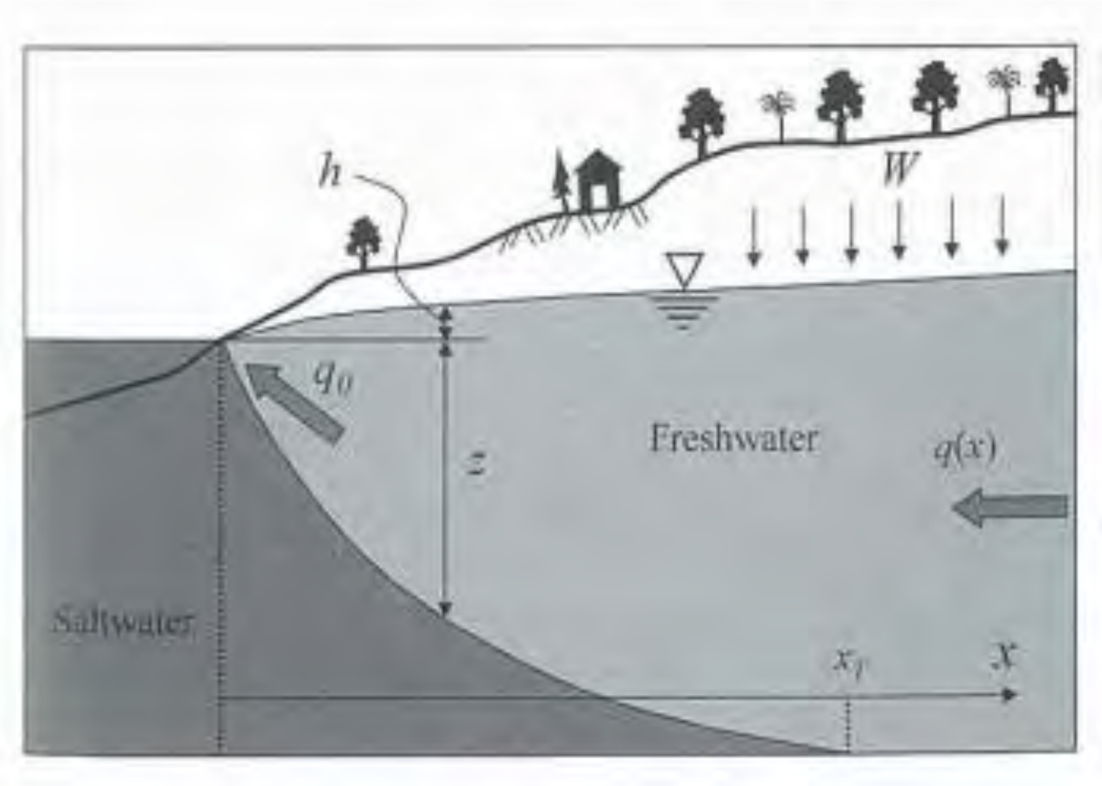


Figure 10: Conceptual model for the Werner and Simmons solution

The equations require various input parameters which are summarised in Table 1, together with comments regarding the derivation of the respective values of each parameter. Note that the assessment has been applied to each of the three cross sections / resistivity surveys (Rarangi 1, 2 and 3) discussed in Section 2.3 and 2.4 so that a representative set of effects along the Rarangi coast is considered.

Table 1: Input parameters

Parameter	Value used	Source of value
Hydraulic conductivity of aquifer (K) (m/day)	30	Based on an average transmissivity of 300 m²/day and an aquifer thickness of 10 m
Depth to base of aquifer pre-sea level rise (Z_0) (m below sea level)	6 (Rarangi 1) 4 (Rarangi 2 and 3)	Based on a saturated aquifer thickness of 7 m (Rarangi 1) and 5 m (Rarangi 2 and 3) and groundwater levels that are around 1 m above sea level
Distance to inland boundary (L) (m)	1200 (Rarangi 1)	For Rarangi 1, the distance is based on the distance to the

Table 1: Input parameters

Parameter	Value used	Source of value
	1650 (Rarangi 2 and 3)	inland hill range. For Rarangi 2 and 3, the distance is based on the distance to the groundwater divide along the central aquifer axis.
Recharge rate (W) (m/day)	0.0009	Based on mean annual recharge of 322 m/year (Davidson, 2011)
Constant head at inland boundary (h_i) (m)	2.5 (Rarangi 1) 1.5 (Rarangi 2 and 3)	Based on summer elevations for piezometric contours in Davidson (2011)
Sea level rise (DZ_0)	1.15	Based on total rise by 2100

5.0 Results of calculations

The results of the calculations are shown graphically in Figure 11. In general, they indicate that there would be limited movement of the saline-freshwater interface due to 1.15 m of sea level rise. The greatest effect occurs around the Rarangi 1 area where the aquifer is thicker and the saline-freshwater interface could move inland by up to 11 m. In the Rarangi 2 and 3 areas, which are further south and closer to the Wairau Diversion, the model predicts that the interface could move inland by up to 6 m due to 1.15 m of sea level rise.

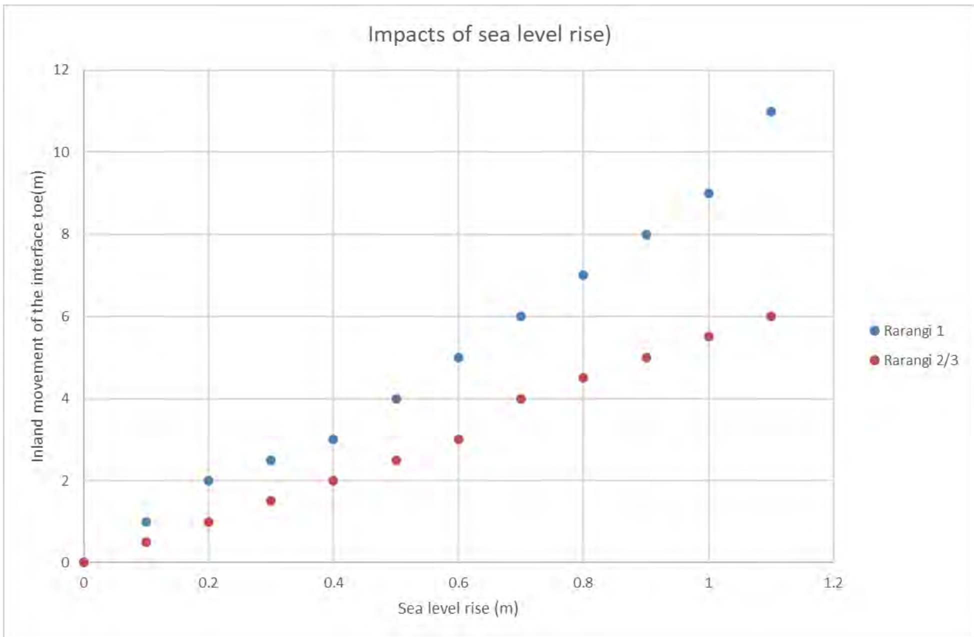


Figure 11: Movement of the inland toe of the saline-freshwater interface (X_T) under different sea level rises

This relatively small change is because of the thin nature of the aquifer, where the recharge from inland is effectively pushed through a small volume of strata, resulting in a relatively substantial discharge to the coast per unit thickness of strata, which limits the potential for saline intrusion. If the saturated thickness of the aquifer were much greater, then greater effects due to sea level rise may occur.

However, the calculations are sensitive to the rate of recharge to the aquifer and if recharge to the aquifer were to fall, for example due to drier winters, then greater inland movement of the saline – freshwater interface could occur. Consequently, the calculations have also been carried out allowing for a dry year, where little recharge occurs. Based on information provided in Davidson (2011), recharge to the aquifer ranges from 180 mm/year to 630 mm/year. Using the lowest value in this range (180 mm/year), indicates that the saline-freshwater could move inland by up to around 38 m around Rarangi 1.

These calculations only consider the effect of a vertical movement of sea level. As discussed above, sea level rise will also result in an inland lateral movement of seawater. Based on LiDAR data for the area, a 1.15 m rise in sea level would result in sea water moving around 10 m inland along the coast (Figure 12). This is due to the relatively steep slope of the foreshore along the Rarangi coast, but should be considered in addition to the estimated effects due to vertical sea level rise i.e., the total landward movement of the interface around Rarangi 1 (in the north of the area) could be up to 21 m (under average recharge conditions), or up to around 48 m in a dry year. The total landward movement of the interface in the Rarangi 2 and 3 areas (to the south of the RSA area) could be up to 17 m under average recharge conditions.

These are generally conservative estimates because they do not allow for any discharge from the deeper Wairau Aquifer into the surface gravels of the RSA via the Dillons Point Formation. This discharge would restrict landward movement of the saline-freshwater interface.

6.0 Surface Inundation risks

Whilst not directly related to subsurface sea-water intrusion that is the focus of this assessment, it is worth noting that any surface inundation of the land by seawater will lead to infiltration of that surface seawater into the shallow aquifer. For example, whilst the estimates in this report allow for the long-term impact of coastal sea level rise via a subsurface migration pathway, there is also the potential effect of short-term storm surges, which could result in saline intrusion effects into the aquifer close to the coast due to downward infiltration of the surface storm surge water. This is an issue that would need to be assessed by coastal hydrologists.

It is also noted that the Pipitea Wetland is close to sea level, and according to the LiDAR data could be inundated under 1.15 m of sea level rise if protective flood gates and stop banks were not functioning along the Wairau Diversion channel.

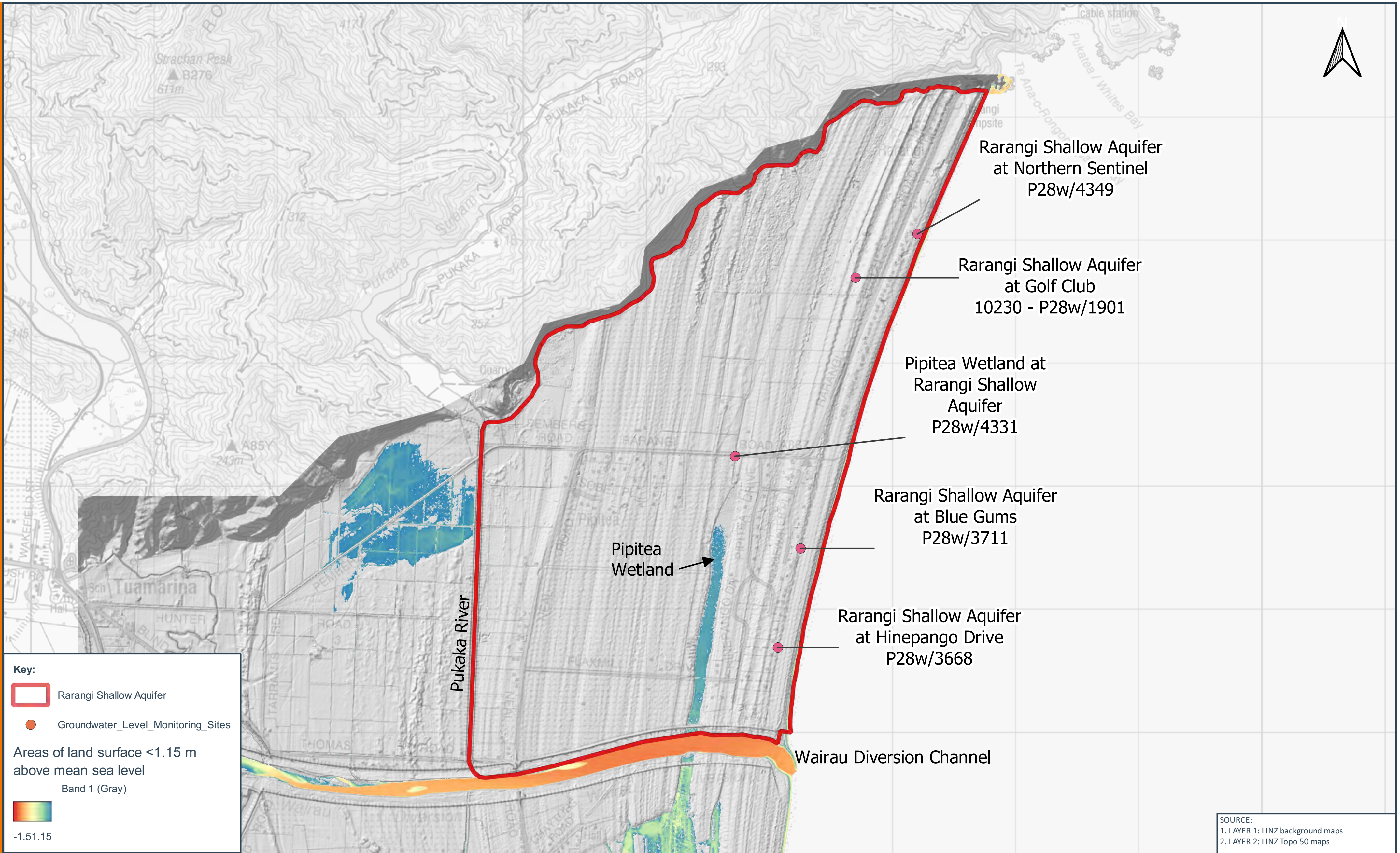


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FIGURE 12: AREAS OF LAND THAT ARE LESS THAN 1.15 M ABOVE SEA LEVEL

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If a higher sea level did allow sea-water to enter the Pipitea wetland that could significantly impact on the aquifer salinity utilised by water supply bores along Hinepango Drive. That would be an important risk to be managed and monitored.

7.0 Conclusions and recommendations

This review of the available data indicates that the shape of the saline-freshwater interface is likely to be somewhat variable along the Rarangi coast. The steepest interface is likely to occur in the north of the area, around the Golf Club, which may be due to slightly higher aquifer pressures in that area. The interface appears to become less steep further south, which may reflect lower groundwater pressures. However, it is important to note that these are relative differences; the saline freshwater interface appears to be located more than 100 m seawards from the monitoring bores along the coast, and existing electrical conductivity monitoring data does not indicate that any saline intrusion has occurred into those parts of the aquifer that are used to date.

Estimates of sea level rise for New Zealand indicate that by 2100, sea level rise could reach up to 1.15 m above the average sea level as measured between 1986 and 2005.

Conservative estimates of the effect of these sea level rise predictions indicate that the landward movement of the saline-freshwater interface could be up to around 50 m in the north of the area by 2100, allowing for both the vertical and lateral movement of sea level and for low recharge. Smaller movements of around 20 m could occur in the south and central part of the RSA coast line, which is largely due to the thinner nature of the RSA in those areas.

These movements of the saline – freshwater interface due to sea level rise are not expected to cause long term saline intrusion issues into the aquifer, and the interface is likely to be remain seawards of the location of the monitoring bores. However, whilst these estimates allow for the long-term impact of sea level rise, there is also a potential risk from short term storm surges, which could result in surface seawater infiltrating down into the aquifer close to the coast. Furthermore, the low lying Pipitea Drain could be at risk of surface seawater inundation if it is not adequately protected along its boundary with the Wairau Diversion channel. These potential surface sea-water inundation pathways may pose a greater risk to the shallow coastal aquifer than the subsurface movement of coastal seawater.

8.0 References

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