From Rain through River Catchment to Aquifer: The Flow of Water through the Wairau Hydrologic System

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BIBLIOGRAPHIC REFERENCE

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Groundwaters in the Wairau Fan near the Wairau River have low NO_3-N concentrations, similar to those of the river, indicating the river is their recharge source. Increasing NO_3-N concentrations with increasing distance from the Wairau River towards the southeast indicate an increasing contribution of local rain-recharged groundwater, loaded with NO_3-N from land-use activities. At the boundary between the Holocene and the Pleistocene deposits, NO_3-N is significantly higher, between approximately 1 and 2 mg/L. These groundwaters are older than those in the fan (Figure 4.8), indicating lower flow rates and therefore lower dilution by river water as the reason for the elevated nitrate. A few shallow groundwaters in the Wairau Plain have NO_3-N concentrations above 2 mg/L, indicating local sources.

4.2.4.3 Bicarbonate

The main sources of bicarbonate (HCO_3) in groundwater are uptake of CO_2 from the atmosphere, uptake of CO_2 in the soil zone from microbial and plant root respiration, reduction reactions of organic matter and sulphate in the groundwater system, and dissolution of carbonate rocks. Absence of a correlation between HCO_3 and sulphate in the Wairau Aquifer groundwater indicates that the main sources of elevated HCO_3 in groundwater are reduction reactions of organic matter and dissolution of carbonate rocks in the groundwater system.

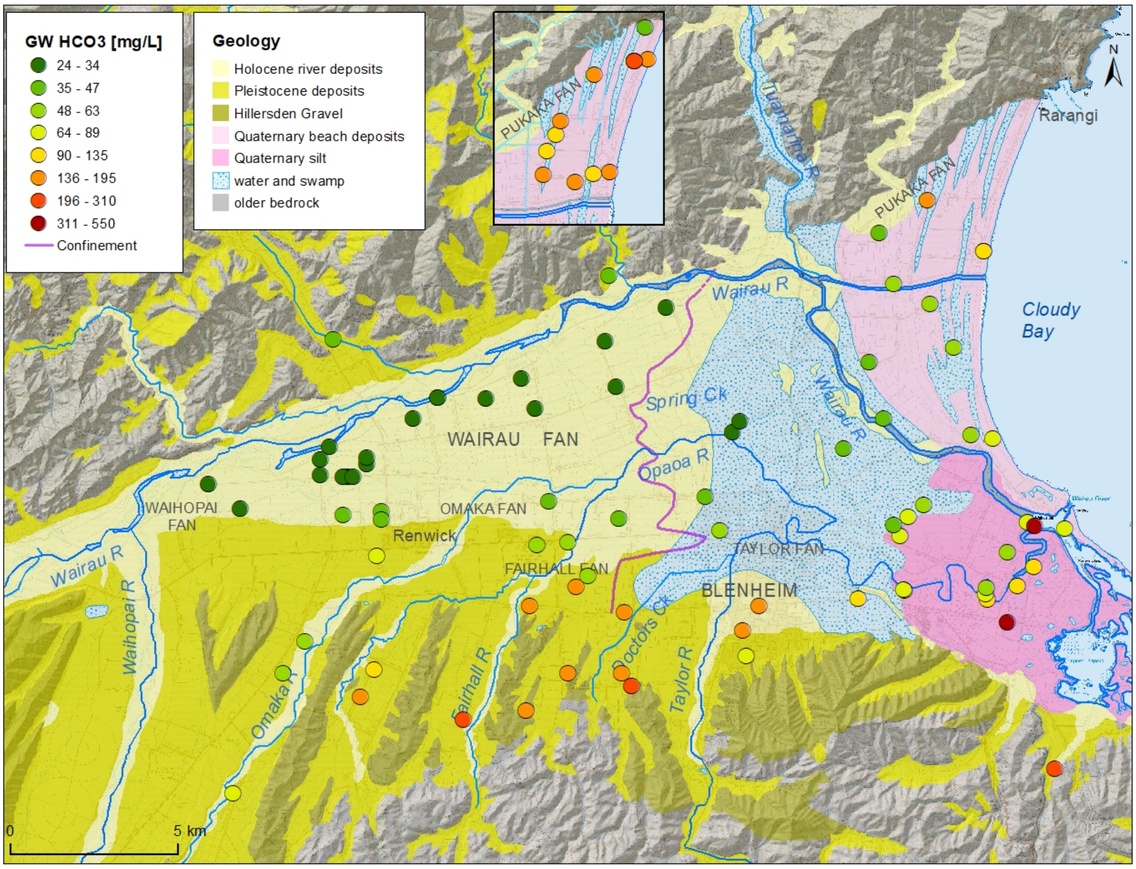

Figure 4.21 Spatial distribution of bicarbonate (HCO_3) in the Wairau Plain groundwaters. The insert on the top shows HCO_3 for the Rarangi Shallow Aquifer, while the main figure shows the HCO_3 only in the confined aquifer in this area.

Figure 4.21 shows the spatial distribution of HCO_3 in the Wairau Plain groundwater. In the Wairau Fan near the Wairau River, HCO_3 concentrations are very low (dark green symbols), representative of those of river water. Due to uptake of carbon in the aquifer, HCO_3 is slightly elevated (light green symbols) towards the coast and at the boundary between the Holocene and Pleistocene deposits, and further elevated in the northern and southern part of the coastal confined aquifer due to stagnant conditions.

High HCO_3 concentrations occur mainly in the old groundwater of the Pleistocene deposits, and in the coastal deposits of the Rarangi Shallow Aquifer (Figure 4.21 insert), with dissolution of carbonate rocks in the groundwater system being the main reason for these high HCO_3 concentrations. Figure 4.18f shows the molar ratios between Ca and HCO_3 for this data. About half of the Rarangi Shallow Aquifer data show equal molar ratios, indicating calcium-carbonate-dominated processes in agreement with the fossil shell bed nature of these deposits. The remaining HCO_3-enriched data indicate up to half of the HCO_3 being derived from reduction reactions of organic matter, in agreement with the coastal swamp nature of these deposits. In the Pleistocene deposits, groundwaters have less carbonate-rock-derived HCO_3, with all of them having a contribution of 40–50% derived from reduction reactions of organic matter.

4.2.5 Hierarchical Cluster Analysis

While individual hydrochemistry parameters in the Wairau Plain aquifer have enough contrast to distinguish between recharge sources via local rain or pristine rivers from higher altitudes, HCA (Section 3.3) was performed on the hydrochemistry dataset to obtain a combined picture of a larger number of chemical parameters.

HCA results are displayed as a dendrogram (Figure 4.22). Each vertical blue line ends at a single sample site. Horizontal blue lines join hydrochemical groups. The similarity between sites and groups of sites is indicated by the height up the y-axis (distance) of the respective connecting horizontal line. Low horizontal lines join sites with the most similar chemistry. Selection of appropriate threshold lines divides the sites into clusters with similar chemistry.

At the highest threshold the data is divided into two clusters, A and B (Figure 4.22). The main difference between the two clusters is that Cluster A has very low electrical conductivity, and accordingly low solute concentrations (Figure 4.23). With $\delta^{18}O$ values ranging between -8‰ and -8.5‰, these sites are likely to contain very young (un-evolved) groundwater recharged from the Wairau River.

At the second threshold, cluster B is divided into three sub-clusters, B1, B2 and B3. Cluster B1 has higher electrical conductivity and solute loadings than Cluster A (Figure 4.23), indicating that these groundwaters are more evolved and therefore older. These sites have slightly less negative $\delta^{18}O$ values than Cluster A, indicating predominantly river recharge, but also contribution from local land-surface recharge, which is also confirmed by the highest NO_3-N concentrations of all clusters. Cluster B2 has the highest electrical conductivity and solute loadings, indicating highly evolved old groundwater. $\delta^{18}O$ covers the whole range, indicating that this cluster includes water recharged from the river, from local rain, and a mixture of the two. NO_3-N is lower than in Cluster B2, due to mainly anoxic conditions. Cluster B3 is highly evolved and has undergone ion-exchange processes, such as replacement of Ca and Mg with Na, as have some sites in Cluster B2, but not to the same extent. Descriptions of each cluster are given in Table 4.3.

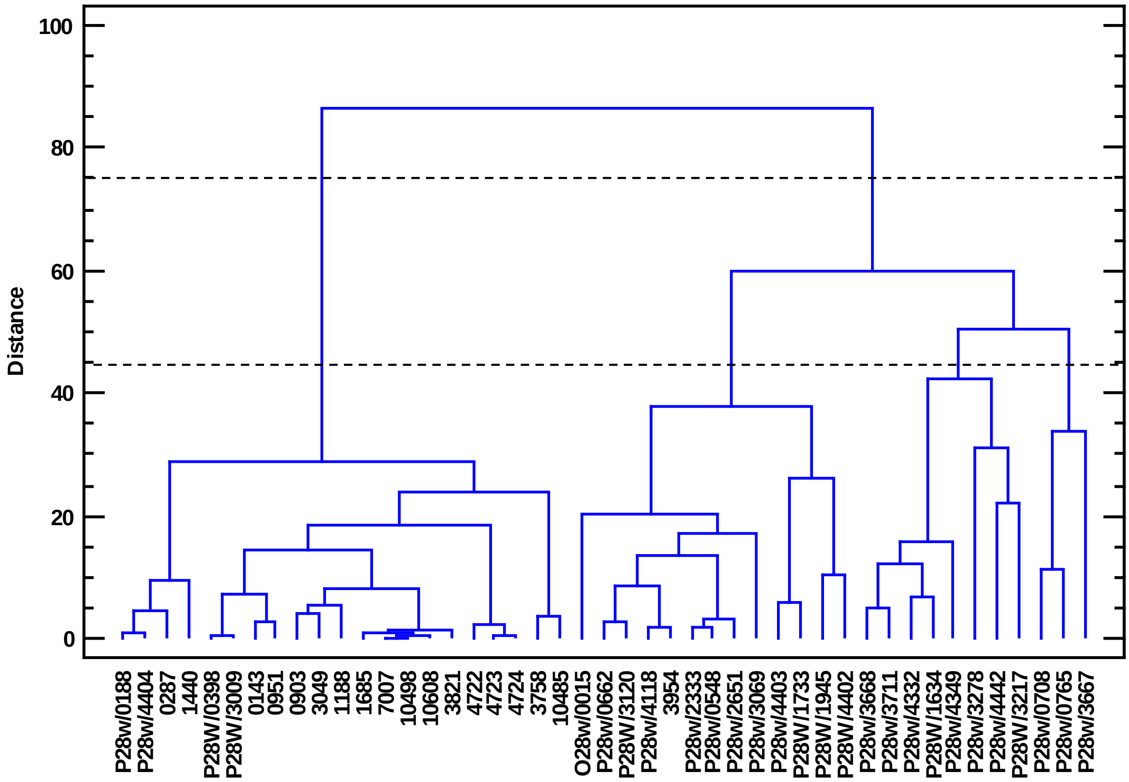

Figure 4.22 Dendrogram produced by Hierarchical Cluster Analysis (HCA).

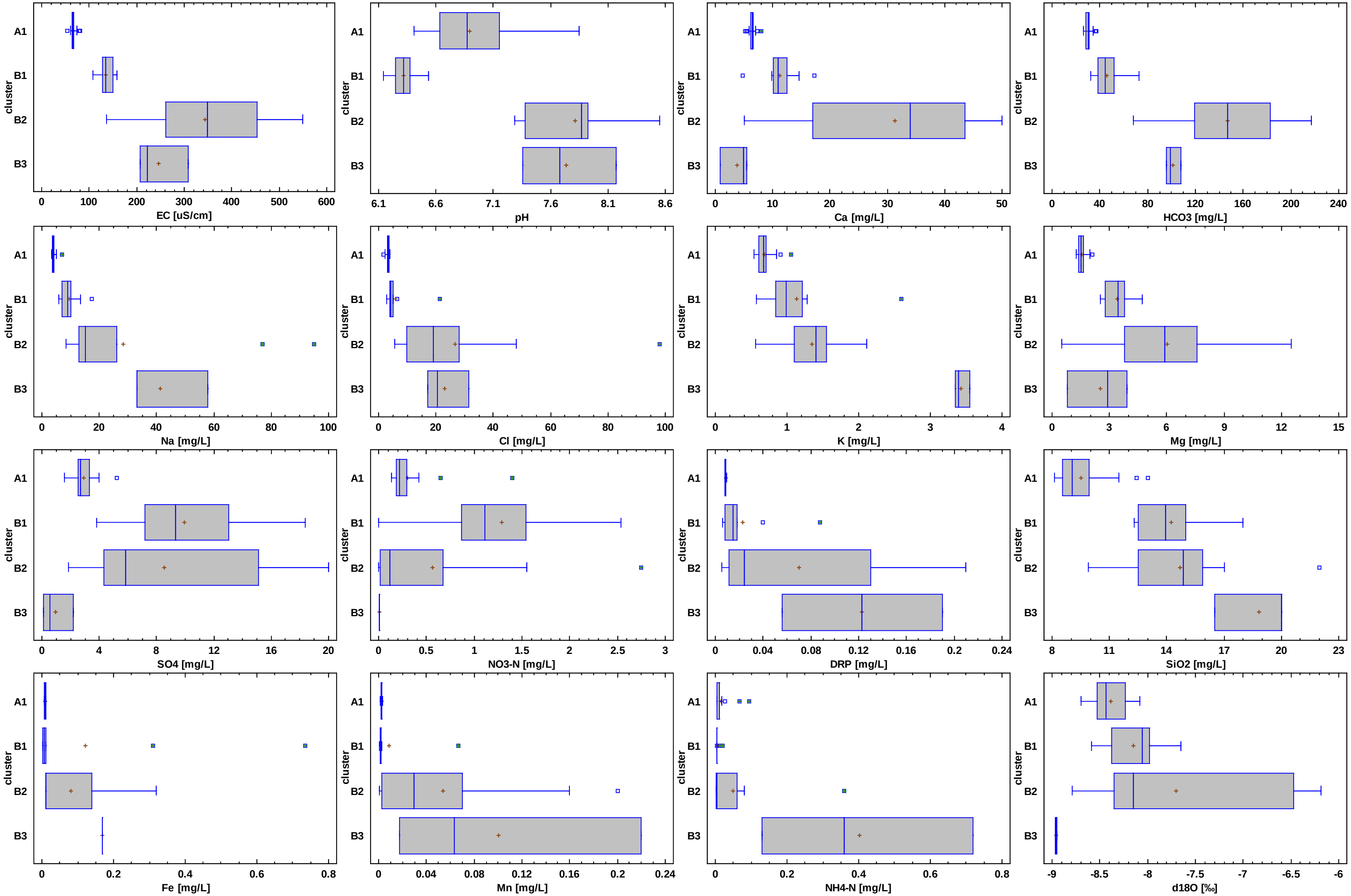

Figure 4.23 Box plots of hydrochemistry parameters organised by second threshold cluster.

Table 4.3 Hierarchical Cluster Analysis (HCA) clusters, showing water type and a general description of notable hydrochemistry and well depths from each cluster.

Cluster	Water Type	Description
A	Ca-Na- HCO_3; some Mg	Low EC, low solute loading; river recharge
B1	Ca-Na-Mg- HCO_3; some SO_4	Higher EC and solute loading than Cluster A; river recharge with some land surface recharge
B2	Mixed water types: Ca-Mg-Na- HCO_3 to Na-Ca- HCO_3-Cl	High EC and solute loading; mixed recharge sources but significant land surface recharge; more evolved groundwater
B3	Na- HCO_3-Cl	Highly evolved, high solute loading, reverse anion exchange; very old groundwater

Figure 4.24 shows the major ion composition of the four clusters, including the impact of ion-exchange processes, with replacement of Ca and Mg through Na and K. The clusters can also be divided into water types based on the relative prevalence of different ions (Table 4.3). Cluster A is mainly Ca-Na- HCO_3-type water, with Mg also present in significant proportions for some wells. Cluster B1 is distinguished from Cluster A1 by having overall higher proportions of Mg and SO_4. Cluster B2 has a range of water types, ranging from waters similar to Cluster B2 to much more evolved Na-Ca- HCO_3-Cl-type waters showing the influence of ion-exchange processes. Cluster B3 is similar to Cluster B2, with highly evolved Na- HCO_3 Cl-type water.

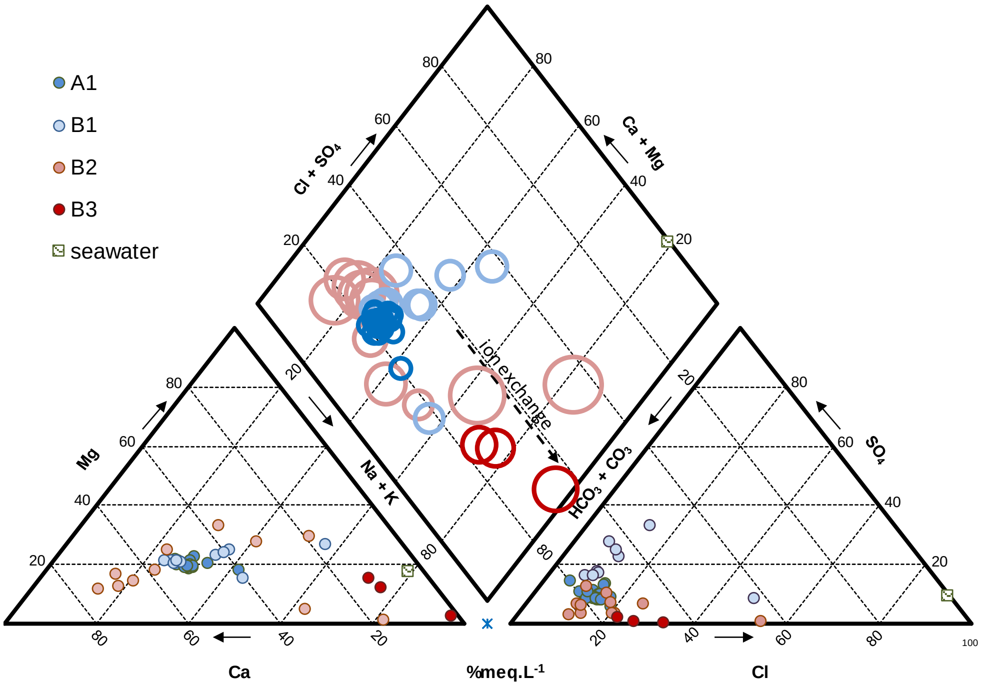

Figure 4.24 Piper diagram showing the variation of major ion chemistry by cluster. The left and right triangles show the major cation and anion ratios on an equivalence basis, respectively, and the centre diamond plots projections based on the two triangular plots. Sites are grouped into clusters assigned by Hierarchical Cluster Analysis (HCA). The size of the symbols in the centre diamond indicate the relative total dissolved solids (TDS) concentrations. The composition of seawater is shown for comparison but is not scaled by TDS.

The geographic distribution of the HCA clusters is shown in Figure 4.25. Groundwater in the Holocene gravels along the Wairau River is dominated by Cluster A, with the hydrochemistry of very young water, indicating the river as the recharge source. Cluster B1 groundwaters appear adjacent to the Cluster A groundwaters at the boundary of the Holocene gravel aquifer further from the river towards the south. Cluster B1 groundwaters are slightly more evolved and also have the Wairau River as the main recharge source, but with some contribution from local rain recharge, indicating that these represent the continued flow of Cluster A groundwater towards the sea.

Cluster B2 groundwaters occur in the southern part of the Wairau Valley in the Pleistocene deposits and in the Rarangi coastal deposits. Cluster B3 groundwaters are related to the Quaternary beach and silt deposits.

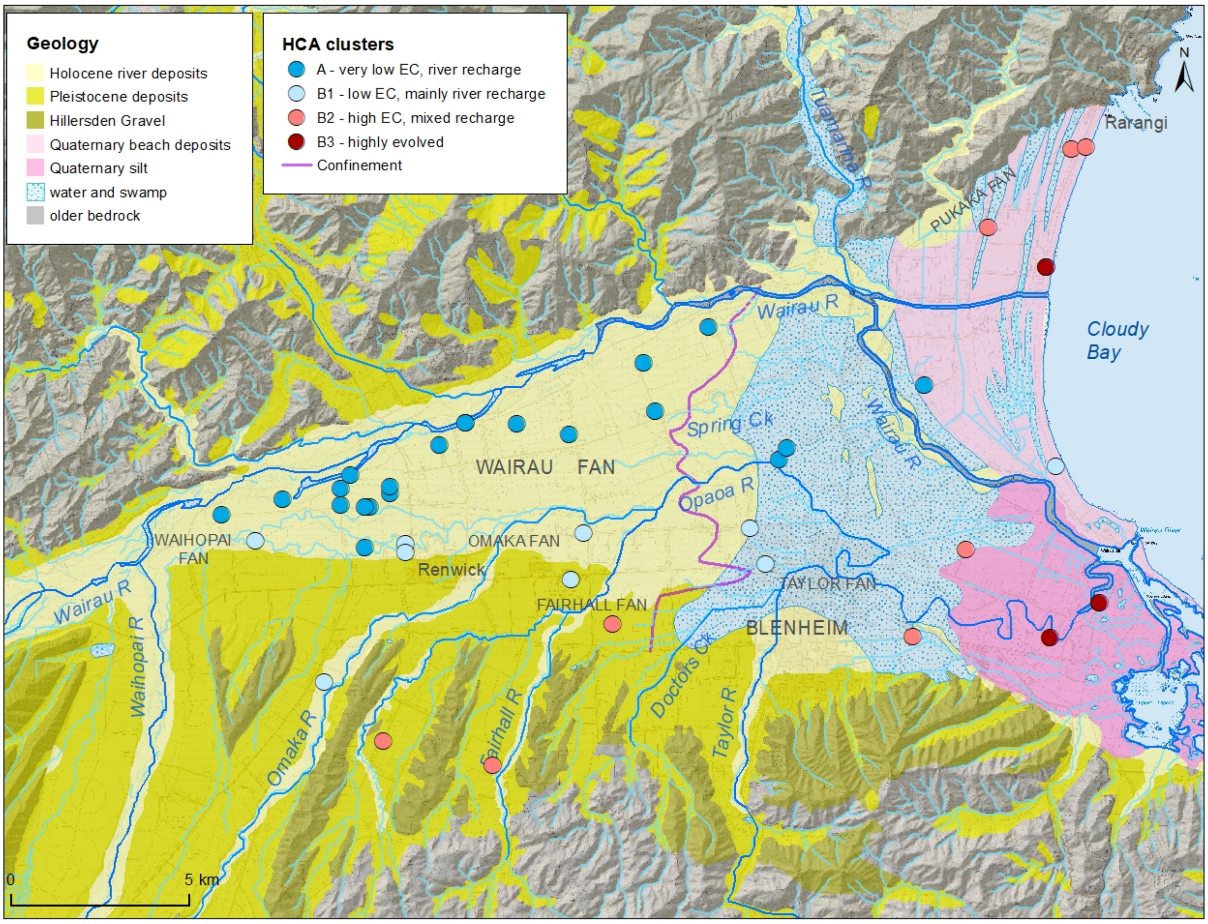

Figure 4.25 Geographic distribution of sites assigned to clusters using Hierarchical Cluster Analysis (HCA).