Mohaka catchment Characterisation

A physical characterisation of the Mohaka catchment

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Environmental Science - Land Science

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Executive summary

The Mohaka catchment is 1 of the 7 major water management zones in the Hawke's Bay Region. This report is intended to describe the current environmental state and condition of the catchment through an investigation of different aspects of its environment. The report is divided into 6 chapters covering;

- Climate
- Hydrology
- Land
- Groundwater and geology
- Terrestrial ecology and
- Wetlands

Climate.

The Mohaka catchment tends to be wetter and colder than the regional average, and snow on higher parts of the catchment is not uncommon during winter. Rainfall over at least the last 30 years does not appear to have exhibited any particular trends that are strong or consistent across the catchment, except perhaps that easterly storms have increased in frequency or intensity. Based on warm air temperatures alone, eastern areas of the catchment could provide the minimum number of Growing Degree Days (GDDs) required for crops such as grapes and kiwifruit. Gusty north westerly winds feature in the catchment as they do elsewhere in the region and assist with drying out the catchment during the spring and summer period, so that a soil moisture deficit typically exists for up to 60 days in eastern parts of the catchment where PET exceeds rainfall by up to 400 mm.

Over the next 50 years, climate change is predicted to result in a marginal increase in annual rainfall over the catchment, based on the median value of an ensemble of climate models, and a more marked increase in the occurrence of heavy rainfall events and droughts. Predicted decreases in rain during spring, together with rising temperatures, will increase the need for irrigation by median values of 15 to 25 mm during the growing season. The variations in rainfall predictions between individual climate models are large and the outcomes less certain than the predicted rise in air temperature, which is expected to be 1-2°C by 2065. This is expected to result in higher water temperatures throughout the catchment. The anticipated warming, and more specifically the associated increase in GDDs, may mean that growing crops such as grapes and kiwifruit becomes easier or more feasible over a broader area of the catchment, provided other conditions are suitable. The Mohaka catchment is unlikely to change from a temperate to a sub-tropical climate within the next 50 years.

Hydrology

River flow summary statistics for sites located within the Mohaka River Catchment show the variation in flows that occur within the Mohaka River and its tributaries. Statistics show that river flows increase downstream throughout the Mohaka River. The Taharua Stream contributes a large proportion of the flow in the upper Mohaka River through a wide range of flow conditions. Taharua Stream flows are more stable, with a higher baseflow component by comparison with flows at most sites on the Mohaka River and its other tributaries. Mean monthly river flows in the catchment are lowest during February and March.

At the Mohaka River at Raupunga site mean annual flows increasingly deviate from long-term average annual river flows until about 1980, then subsequently this trend decreases. This relates to long-term climate variability, particularly the positive and negative phases of the Interdecadal Pacific Oscillation (IPO). Analyses of annual low flows and annual maximum flows showed no apparent trends.

An assessment of consent information and river flows indicates that the current and historical consented water abstraction demand in the catchment is low and that total potential abstraction effects on river flows are minor, even at low flows.

Concurrent gauging data for the Taharua Stream Catchment show that flow in the Taharua Stream increases downstream through the catchment. The increase in flow between sites is most likely related to the increase in surface water catchment area. Flow data indicates that the interaction between surface water and groundwater is reasonably consistent throughout the surface water catchment.

Land

Land in the Mohaka catchment is generally in a very healthy state. Most of the catchment is in native bush, with the next largest land use being commercial forestry. There is scope for land-use intensification in the catchment, but large scale intensification is unlikely due to the high relief and difficulty of access to land in the catchment. It is possible that commercial forestry could expand within the region. However, forestry is generally considered one of the 'less intensive' land-use systems, and expansion of forestry should not detrimentally affect the ecological 'health' of Mohaka catchment. There are areas of concern in the upper catchment where nutrient losses from dairy farms have affected water quality and ecosystem health in both the Taharua River and the upper Mohaka River. This issue is currently being addressed with the help of the farmers concerned and other stakeholders.

Geology and Groundwater

The geology of the Mohaka catchment consists of mostly soft sedimentary rock in the mid to lower catchment and hard greywacke basement rock, volcanic ignimbrite rock and unconsolidated pumice in the upper catchment. The volcanic ignimbrite rock and unconsolidated pumice are sourced from the Taupo Volcanic Zone.

The known groundwater resource in the Mohaka catchment is mostly confined to the volcanic ignimbrite in the upper catchment of the Taharua valley. The remainder of the Mohaka catchment is dominated by greywacke rock, which is unlikely to yield a productive groundwater resource. In the lower Mohaka catchment a number of bores have been drilled into the sedimentary mudstone, sandstone and limestone rock formations, but there is little known about the groundwater resource in these rock formations.

The focus of groundwater investigation has been on the Taharua sub-catchment to support water quality investigations. From available geological bore logs, 3 water bearing formations are found in this sub-catchment:

1. Gravels eroded from the nearby greywacke ranges, 30 m to 100 m deep
2. Ignimbrite rock sourced from the eruptions in the northern Taupo Volcanic Zone, also 30 m to 100 m deep.
3. A shallow Taupo Pumice aquifer up to 20 m thick

Assessment of groundwater quality in shallow investigation bores and private water supply bores in the Taharua Catchment indicates the groundwater in both the shallow Taupo pumice aquifer and the deeper Ignimbrite/gravel aquifer can be used for drinking without treatment, meeting the Maximum Allowable Value (MAV).

The Taupo pumice aquifer is impacted by nitrate-N in the upper Taharua sub-catchment and some sites have high nitrate-N, which is half the MAV. The most likely sources of nitrate-N are from intensive dairying in this area. Some sites in the shallow pumice aquifer are also elevated in iron and manganese and do not meet the guideline values for aesthetics. Most sites also comply with the ANZECC irrigation guidelines, although some have low hardness. The low hardness may cause corrosion of metal pipework.

Trend analyses of data from shallow bores and Taharua spring indicates that nitrate-N in groundwater has decreased in 2 bores and increased in 1 monitoring bore, and phosphorus levels have increased in 1 monitoring bore and the Taharua spring. The sites with both increasing and decreasing trends are located in the vicinity of dairy farms. All 3 monitoring sites are located on a dairy farm which has undergone a significant decrease in stocking rate and associated reduction in nitrogen inputs after a change in farm ownership in 2009[1]. Further monitoring is needed to confirm the validity of these trends.

Results from water age assessment indicate that the groundwater from the deep ignimbrite/gravel aquifer has a mean residence time greater than 90 years, suggesting that the groundwater in the deeper ignimbrite aquifer is very old and has a long residence time. This indicates that active groundwater flows do not reach this depth. Groundwater in the shallower Taupo Pumice aquifer groundwater has a mean residence time of less than 5 years, which suggests that recharge is derived from local rainfall.

The age of Taharua River water increases down the catchment from 1 year at the spring to 8 years at the confluence with the Mohaka River. This steady increase in water age downstream in the Taharua River indicates a downstream increasing contribution of water from longer flow paths from deeper parts of the groundwater system. The presence of significant amounts of old water in the stream is probably related to larger water storage capacity of the volcanic pumice aquifer material. Good hydraulic conductivity of the volcanic material in the Taupo Pumice aquifer is indicated because streams sourced from the greywacke rock hill country run dry where they meet volcanic pumice infilling the valley (Morgenstern, 2014).

Biodiversity

The pattern of indigenous habitat loss since pre-Māori times – as defined by vegetation – in the Mohaka catchment is similar to the regional and national situation, where these habitats have been lost from lowlands and remained on mountain ranges. However, the catchment is characterised by a higher proportion of indigenous forest and scrub than the region. Most of the catchment is part of, or adjacent to, key public and privately-owned conservation areas where conservation efforts have been made. The catchment is also home to two of the few remnants of frost flats left in New Zealand. Although there is no quantitative framework, the Mohaka catchment has high values of terrestrial biodiversity.

Wetlands

The catchment has lost most of its wetlands. Determining the condition of remaining wetlands requires targeted investigation and an examination of causes of loss in order to halt further decline. There is very low representation of wetlands in the existing protected areas. This, and the degree of loss, leave wetlands as one of the most acutely threatened ecosystems in the Mohaka catchment.

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[1] personal communication with B Powell, Hawke's Bay Regional Council, 2014

1 Introduction

This characterisation report provides an overview of Hawke's Bay Regional Council's (HBRC) scientific understanding of the natural resources of the Mohaka catchment and its river system (

Figure **1-1**). Other reports summarising tangata whenua and socio-economic perspectives will provide a fuller catchment overview. For more detail on any specific topic in this report a range of HBRC documents is listed in the References section.

The purpose of the report is to provide an overview of Mohaka catchment characteristics. This information will assist informed, transparent debate on the future management of the catchment's fresh water and land. More specifically the report aims to inform the development of a proposed plan change to the *Hawke's Bay Regional Resource Management Plan*, addressing the Mohaka catchment.

A high-level Mohaka Consultation Group (MCG) will be formed as part of this process. HBRC will undertake a consultation process to enable the MCG and public to consider future Mohaka management options. This report will help inform the scenarios, which will need to be supported by an assessment of their environmental, social, cultural and economic consequences (based on current knowledge) and an understanding of resources.

The Mohaka catchment plan change is part of HBRC's rolling programme of catchment-specific plan changes, which will help give effect to the *National Policy Statement for Freshwater Management* (NPS-FM). Public notification of the proposed plan change is targeted for end of 2017. The plan will include freshwater objectives, freshwater quality and quantity limits and targets, timeframes and methods to meet them where these are exceeded (e.g. for the headwater Taharua sub-catchment).

The characterisation report draws on HBRC's State of the Environment monitoring, an intensive Taharua-Upper Mohaka investigations programme ongoing since 2006, and recent wider Mohaka investigations. It pulls together several existing science reports. It aims to highlight key trends and gives a snapshot of current state and risks. It should assist discussion of Mohaka issues, policy needs and provide a baseline for plan effectiveness monitoring. However, it does not claim to be definitive, and knowledge gaps and weaknesses are stated where known. It is anticipated that by mid-2017 the science will be robust enough to support the plan change. However, ongoing science monitoring and investigations will continue to clarify the picture over time.

Science is only one of the pillars needed to support policy discussions. This report needs to be considered in conjunction with mātauranga Māori and social and economic understanding. Work in these areas is also being undertaken.

Nitrogen loss from land, particularly from 3 large dairy farms, has degraded the quality of the Taharua and upper Mohaka rivers in recent years. The Taharua and the upper Mohaka River have been the focus of detailed science investigations since 2006, triggered by monthly Taharua water quality monitoring since 1999. In this report Taharua knowledge is detailed under the various section headings rather than in a stand-alone section.

For the purpose of summary analysis, this report often divides the Mohaka catchment into three proposed management zones: "upper", "mid" and "lower" (Figure 1-2), based primarily on water quality characteristics, river uses and geology. While these management zones could form the basis of Mohaka freshwater management units, this is a discussion still to be had with the MCG and alternatives will be considered.

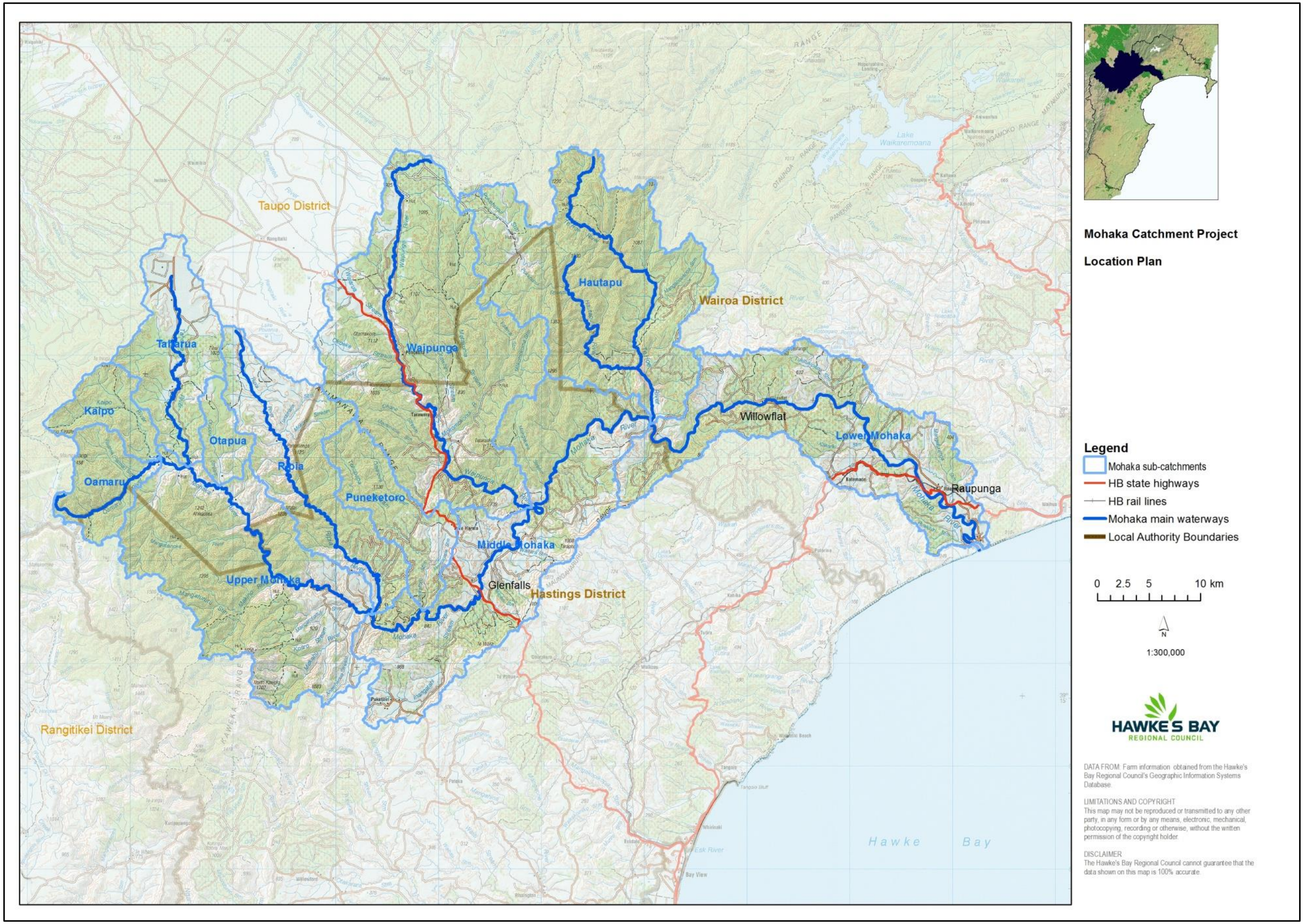


Figure 1-1: **Mohaka catchment and 11 surface water sub-catchments.**

The 3 proposed management zones include the following sub-catchments:

Upper zone: Oamru, Kaipo, Otapua, Upper Mohaka and Taharua

Mid zone: Ripia, Puneketoro and Middle Mohaka (part)

Lower zone: Middle Mohaka (part), Waipunga, Te Hoe/Hautapu and Lower Mohaka

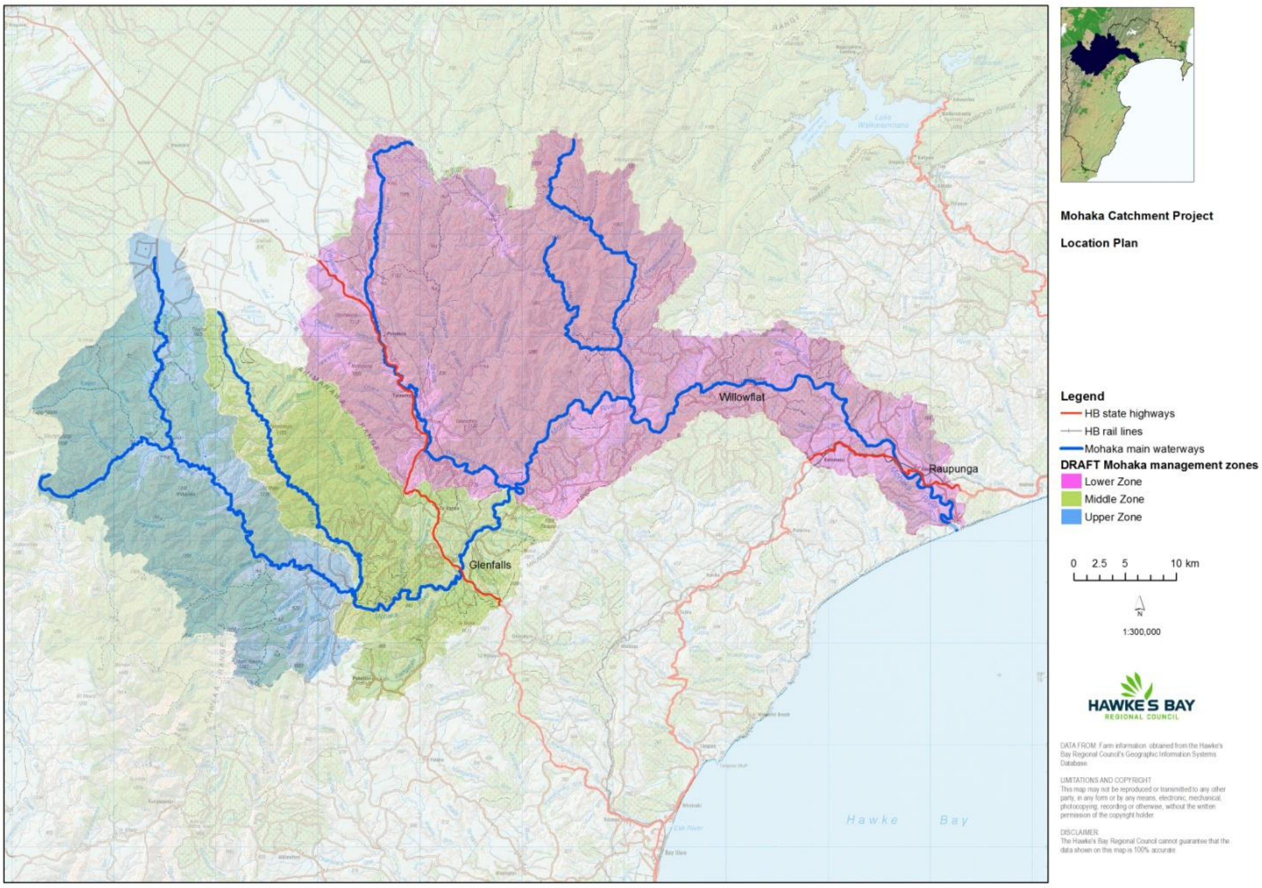


Figure 1-2: Proposed Mohaka "upper", mid and "lower zones used for catchment characterisation.

2 Mohaka catchment Climate

The effective management of water resources within the Mohaka catchment requires knowledge of the area's climate, its trends, extremes and predicted future changes. Climate influences supply of and demand for water, and affects land-use and plant growth through climate-related stresses and hazards. This is particularly important if land-use intensification and increased irrigation demand feature as prospects for the catchment.

The following section describes patterns of rainfall, temperature and wind in the Mohaka catchment and includes information about potential evapotranspiration and soil moisture deficits which ultimately influence irrigation demand. Scenarios of climate change are presented and the impacts discussed in terms of changes in mean conditions and extreme events.

2.1 Current Climate

2.1.1 Rainfall

Annual rainfall in the Mohaka catchment averages approximately 1620 mm (compared to a regional average of 1475 mm), ranging from about 1200 mm in sheltered valleys towards the eastern edge of the Middle Zone to 2430 mm around North Kaweka in the Upper Zone (Figure 2-1). The 3 zones all have similar mean annual rainfall, as shown in Table 2-1, but the Middle Zone does not experience the high rainfalls observed in parts of the Upper and Lower zones.

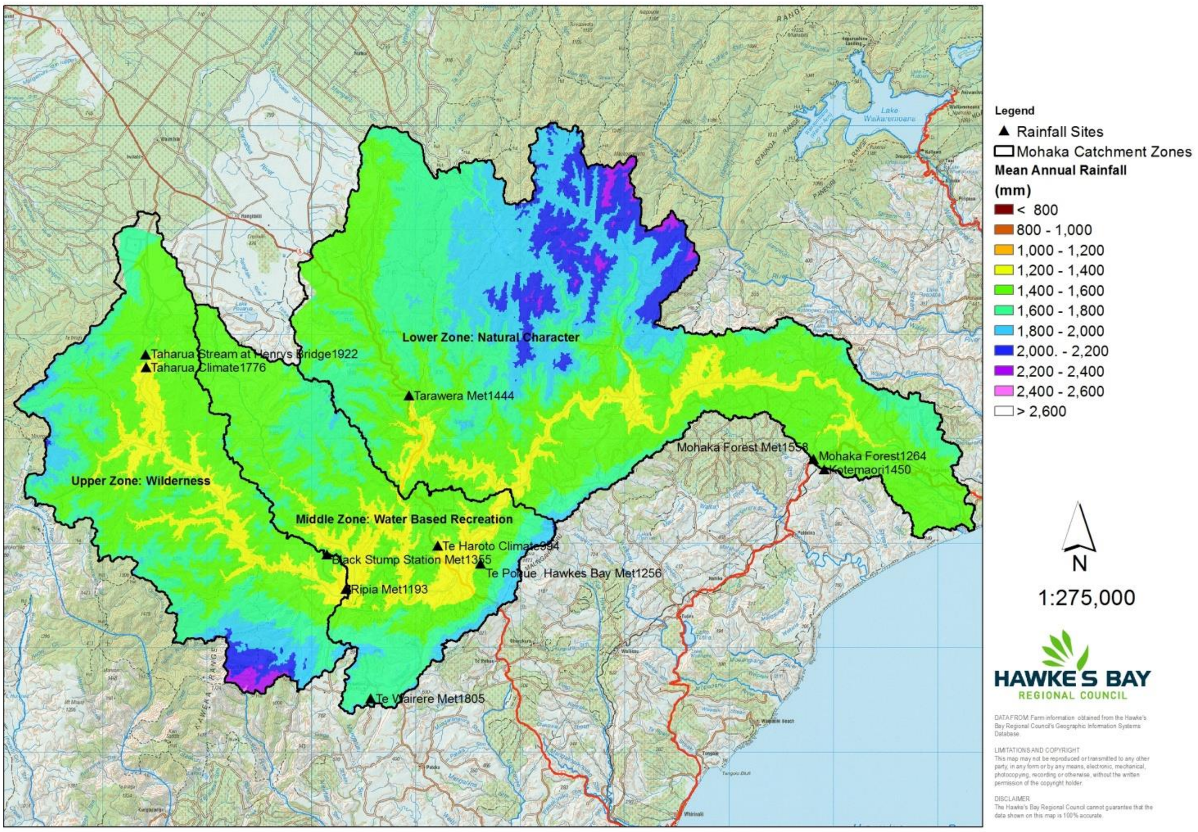


Figure 2-1: Mean Annual Rainfall Surface (mm) for the period 1950-1980 (Leathwick et al, 2002) and rainfall sites in the Mohaka catchment. Each rainfall site is labelled with its mean annual rainfall (mm) calculated using all observations.

Table 2-1: Mean Annual Rainfall for the Lower, Middle and Upper Zones of the Mohaka catchment.

	Upper Zone	Middle Zone	Lower Zone
Mean Annual Rainfall averaged across the zone (mm)	1581	1538	1663
Upper bound of average annual rainfall (mm)	2424	2054	2362
Lower bound of annual average rainfall (mm)	1261	1243	1273

There are 11 sites within the Mohaka catchment with daily rainfall records (Figure 2-1), although only 6 remain in use (Table 2-2). The observed mean annual rainfall at sites with records extending for at least 30 years aligns more closely with the rainfall surface presented in Figure 2-1 than those with shorter records. For example, rainfall totals at the Te Haroto site suggest that this part of the catchment may experience less than 1000 mm on average per year however the record consists of only eight complete years and cannot be considered representative of long-term averages. For all sites July is the wettest month in the catchment (typically between 120-200 mm), while the driest month (50-150 mm) varies between November, January and February depending on the site.

Table 2-2: Sites with daily rainfall data in the Mohaka catchment.

Rainfall Site	Zone	Status	Time of record	Mean Annual Rainfall (mm)
Taharua Stream at Henry's Bridge	Upper	Closed	25th Jan 2008 – 11 Mar 2013	1922
Taharua Climate	Upper	Open	16th Dec 2008 - present	1776
Ripia Met	Upper	Open	1 Jan 1967 – 30 Sep 2013	1193
Te Haroto Climate	Middle	Open	16 Dec 1998 - present	994
Black Stump Station Met	Middle	Open	1 Oct 1965 – 28 Feb 2013	1355
Te Pohue Hawke's Bay Met	Middle	Open	2 Jan 1983 – 30 Sep 2013	1256
Te Wairere Met	Middle	Closed	1 Apr 1932 – 31 Dec 2007	1805
Kotemaori	Lower	Open	12 Jan 1999 - present	1450
Mohaka Forest Met	Lower	Closed	1 Jul 1967 – 30 Apr 1996	1558
Mohaka Forest	Lower	Closed	1 May 1996 – 1 March 2003	1264
Tarawera Met	Lower	Closed	2 July 1908 – 1 September 1975	1444

Extreme events and trends in rainfall were examined for long term sites Ripia Met, Black Stump Station Met, and Te Pohue Hawke's Bay Met. Te Wairere Met was another long-term site considered for inclusion in the trend analysis. However, tree growth around the gauge affects its recent record, so this site was excluded. Unfortunately no sites in the Lower Zone could be included because they either do not have a record of sufficient length (which is at least 25-30 years) or have been closed for 15 years or more.

While the Ripia, Black Stump and Te Pohue rainfall sites have similar mean annual rainfall, Te Pohue experiences periods of heavy rainfall more frequently than the others. At Ripia and Black Stump, the return period of storms delivering 100 mm of rain in 24 hours is 4-5 years, compared to just 2 years at Te Pohue. Storms producing 300 mm of rain over 3 days can be expected approximately every 7 years at Te Pohue but every 90-100 years at the other 2 sites.

The heaviest 1, 2 and 3 day rainfall accumulations in the area occurred during an event that started on 14th March 1985 and resulted in large slips along the Napier to Taupo highway. The event contributed to the wettest month in the records of all three sites due to the “exceptional” predominance of southeasterly winds (Thompson, C.S., 1985). The monthly mean sea level pressure for March 1985 indicates a pattern of anticyclones in the Tasman Sea steering a southeast flow over central New Zealand (Figure 2-2).

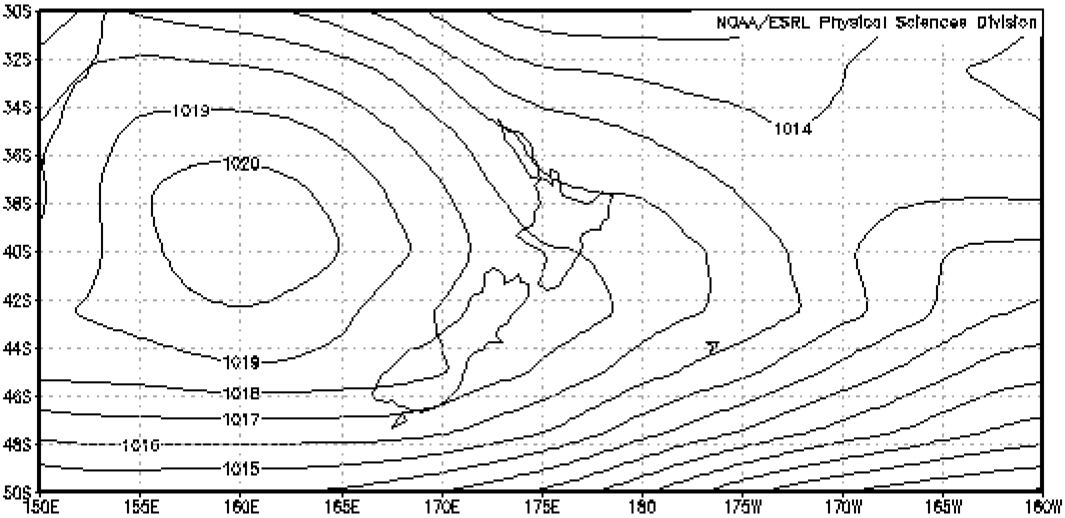


Figure 2-2: NCEP Reanalysis showing mean sea level pressure (hectopascals) for March 1985.

During the event on the 14-16th March, the southeast flow was strengthened as a ridge of high pressure covered the South Island and a low approached the North Island (Figure 2-3). The highest daily totals were 181 mm, 180 mm and 372 mm at Ripia, Black Stump and Te Pohue respectively. Over 3 days, rainfall accumulations reached 300 mm at Ripia, 333 mm at Black Stump and 510 mm at Te Pohue (where the total rainfall for the month was 610 mm). These totals appear to exceed the highest rainfall accumulations recorded at the Tarawera site, which dates from 1908 to 1975, where the highest one day total was 162 mm in June 1935 and the highest three day total was 238 mm in April 1938.

Parts of the Hawke’s Bay region, including the Mohaka catchment, experienced their worst droughts since 1940 during the spring and summer of 1997/98 and 2012/13 (Porteous and Mullan, 2013). The rainfall totals for the period from October 2012 through to March 2013 were the lowest recorded at Ripia (201.5 mm) and Te Pohue (213.7 mm), while the 1997/98 totals were a close second (Figure 2-4). Unfortunately Black Stump has data missing through the 2012/13 period and could not be included for comparison.

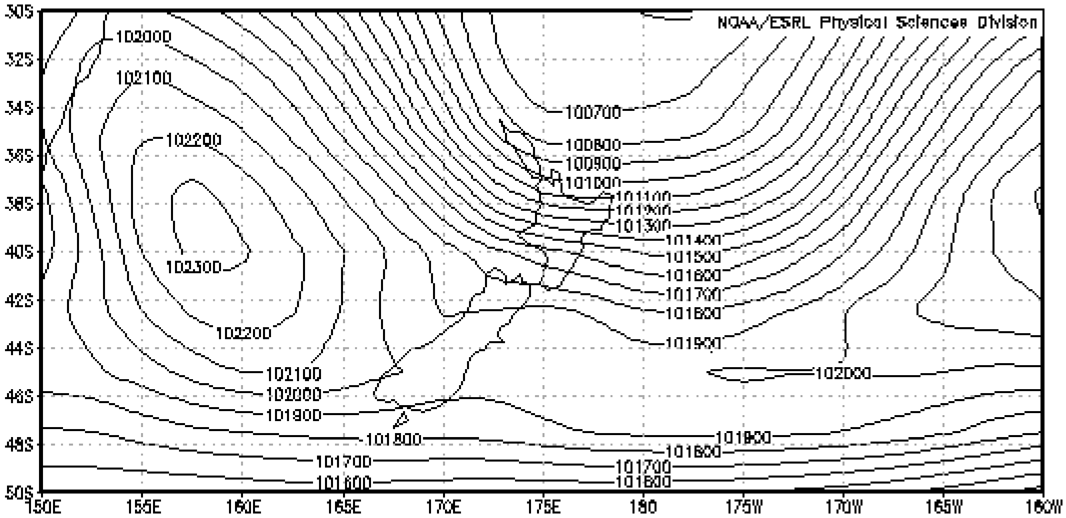


Figure 2-3: NCEP Reanalysis showing mean sea level pressure (Pascals) during 14th-16th March 1985.

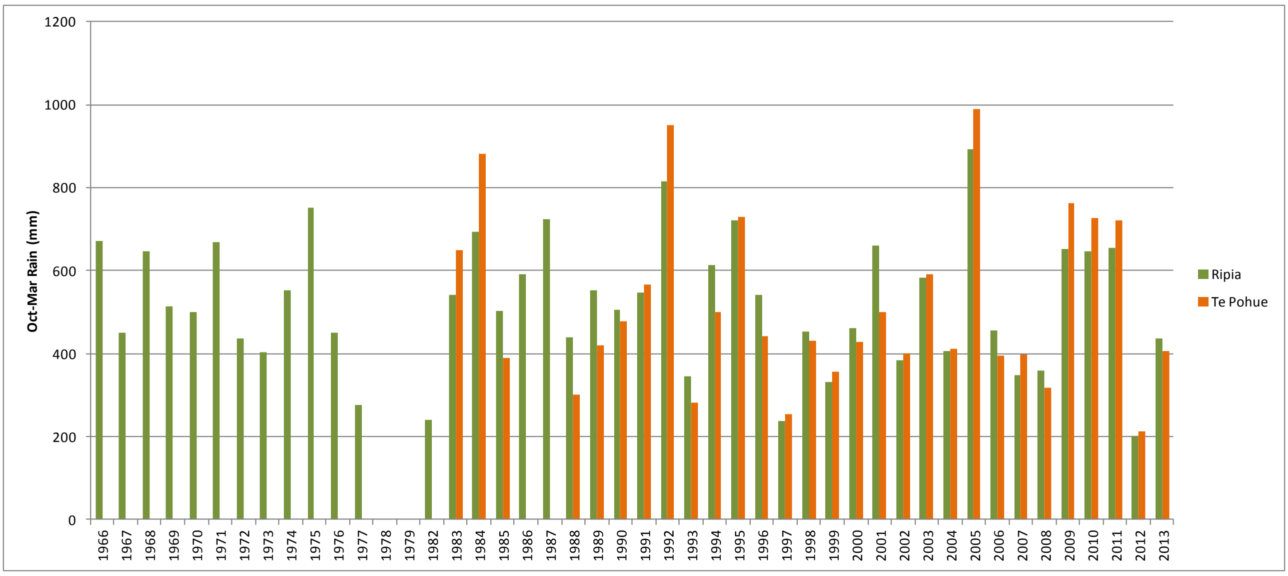


Figure 2-4: October to March rainfall totals (in millimetres) at the Ripia and Te Pohue sites. If a site appears to have zero rainfall for any particular year, totals for the period could not be calculated due to missing data. The rainfall totals are matched with the year that the October to March period starts.

Rclimdex was used to analyse long term trends in rainfall (Table 2-3). At each site only 1 or 2 indices showed a statistically significant trend through time. For example, Ripia Met, in the Upper Zone, showed a small decrease in the number of consecutive wet days through time. Black Stump Station Met, in the Middle Zone, showed small decreases in the simple daily intensity index (SDII) and the number of heavy precipitation days (R10) through time. Te Pohue Hawke's Bay Met, also in the Middle Zone but perhaps less sheltered from moist easterlies, showed increases in both the monthly maximum 1-day precipitation and the monthly maximum consecutive 5 day precipitation through time.

Table 2-3: List of core rainfall related climate indices in the Rclimdex software package.

RX1day	Maximum 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Rx5day	Maximum 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as precipitation ≥1.0mm) in the year	mm/day
R10	Number of heavy precipitation days	Annual count of days when precipitation >=10mm	Days
R20	Number of very heavy precipitation days	Annual count of days when precipitation >=20mm	Days
Rnn	Number of days above nn mm	Annual count of days when precipitation >=nn mm, nn is user defined threshold	Days
CDD	Consecutive dry days	Maximum number of consecutive days when precipitation <1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days when precipitation ≥1mm	Days
R95p	Very wet days	Annual total precipitation from days >95th percentile	mm
R99p	Extremely wet days	Annual total precipitation from days >99th percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total precipitation from days >=1mm	mm

2.1.2 Temperature

The Mohaka catchment has a temperate climate (Belda et al, 2014), with 6 months of the year having a mean temperature greater than 10°C. The annual average of daily mean temperature in the Mohaka catchment is about 10°C, which is cooler than the figure of 11°C for the Hawke's Bay region as a whole. The warmest part of the catchment is the coastal area of the Lower Zone, where the annual average temperature is closer to 14°C, while the south western edge of the Upper Zone is the coldest at approximately 5°C (Figure 2-5).

Temperature is measured at the Taharua and Te Haroto climate sites but the records are fairly short. In particular Taharua dates back only to 2008 and Te Haroto to December 1998. The Taharua Climate site is at an elevation of 710 m and although it is not the highest climate station in the region (Ngamatea is located at 980 m between the Kaweka and Ruahine Ranges), it is typically the coldest, with screen frosts - measured 1.3 m above the ground – occurring in all months except February. Snowfall is not uncommon at Taharua during winter months. Closer to the coast, frosts at Te Haroto typically may occur from April until October, but can occasionally occur in November. Figure 2-6 shows the number of frosts per week that might be expected during November in the Mohaka catchment on average 20% of the years (Porteous and Tait, 2008).

Temperature affects plant growth because plants need temperature to be sustained above a particular level (or base temperature) to grow. For example, pasture has a base temperature of 4°C and a base temperature of 10°C is required for some temperate and subtropical crops.

A measure used to assess whether an area will be warm enough for growth of particular crops is Growing Degree Days (GDDs). GDDs represent the number of degrees by which the daily average temperature exceeds the specific plant's base temperature. The annual total of GDDs is calculated by summing daily GDDs for a single year. For example, 1000 annual GDDs (using a base temperature of 10°C) are typically sufficient for growing grapes (Tait, 2008) and 1100 annual GDDs for growing kiwifruit (Salinger, 1986). Sweetcorn, cherries and apricots need more than 800 GDDs (Smallfield and Douglas, 2005) and apples need a minimum of 700 GDDs (Paterson, 2003).

In the Mohaka catchment, there are about 690 GDDs on an annual basis but more than 1000 GDDs in eastern areas of the Middle and Lower Zones (Figure 2-7).

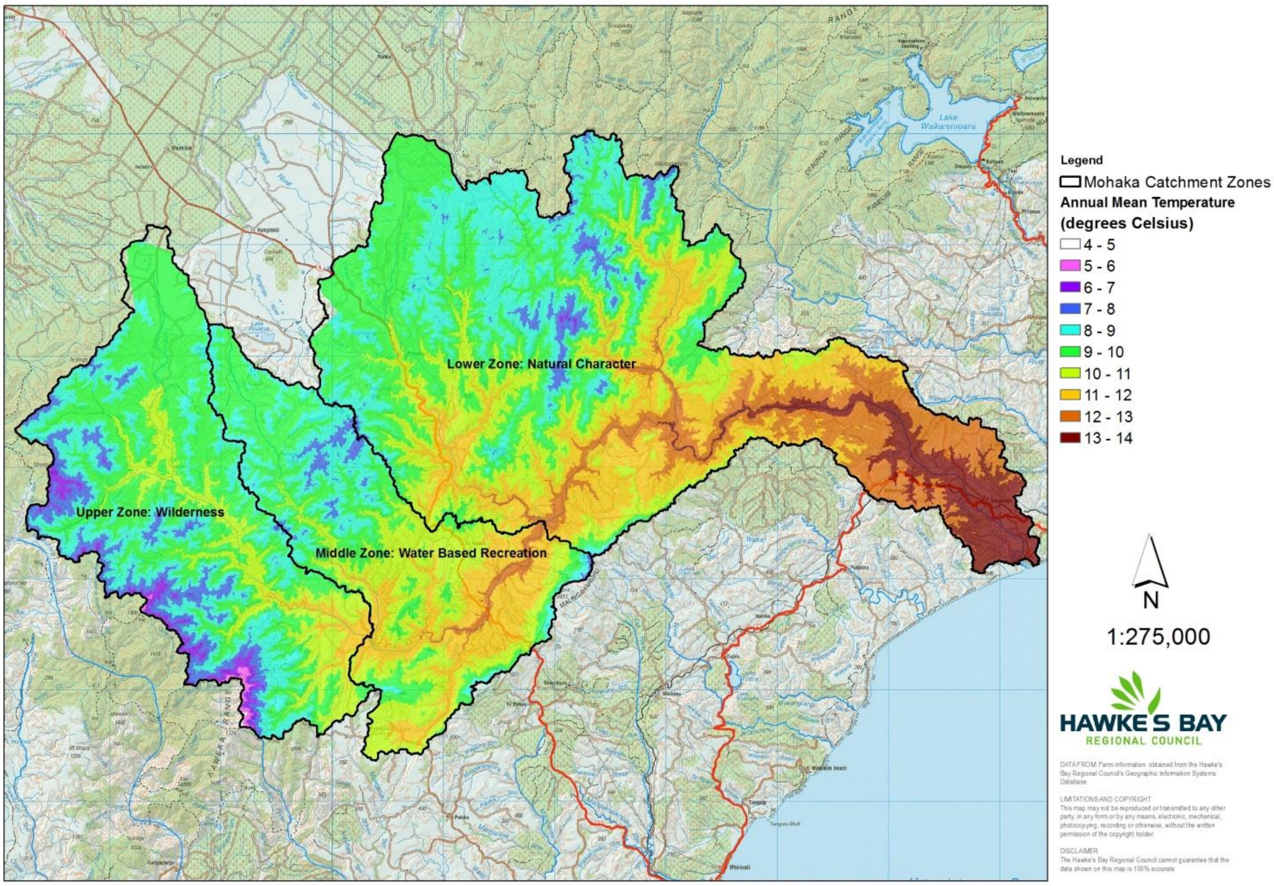
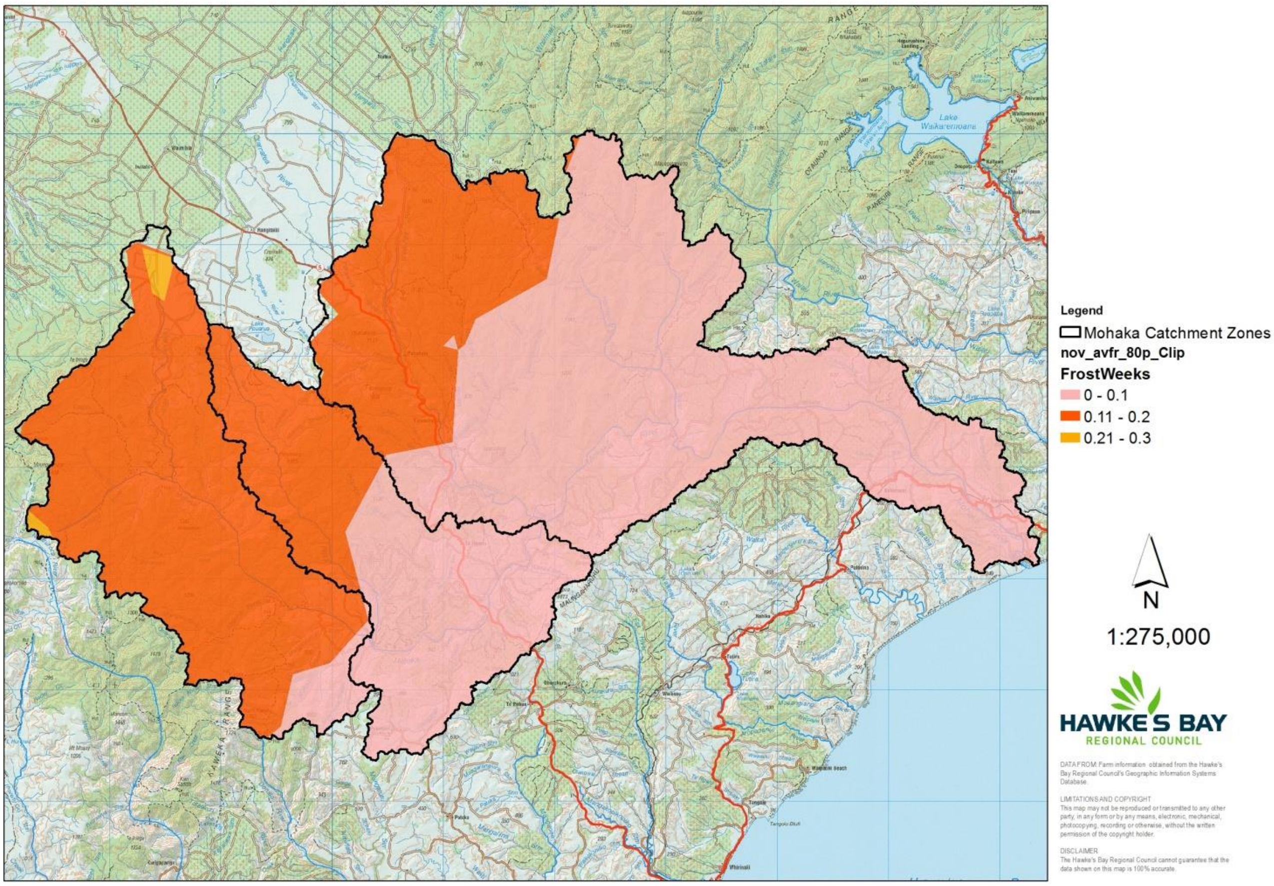


Figure 2-5: Annual average daily mean temperature in degrees Celsius for the period 1950-1980 (Leathwick et al, 2002).



DATAFROM: Farm information obtained from the Hawke's Bay Regional Council's Geographic Information Systems Database.

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Figure 2-6: Number of frosts occurring per week in November, on average 20% of the years (information sourced from Porteous and Tait, 2008)

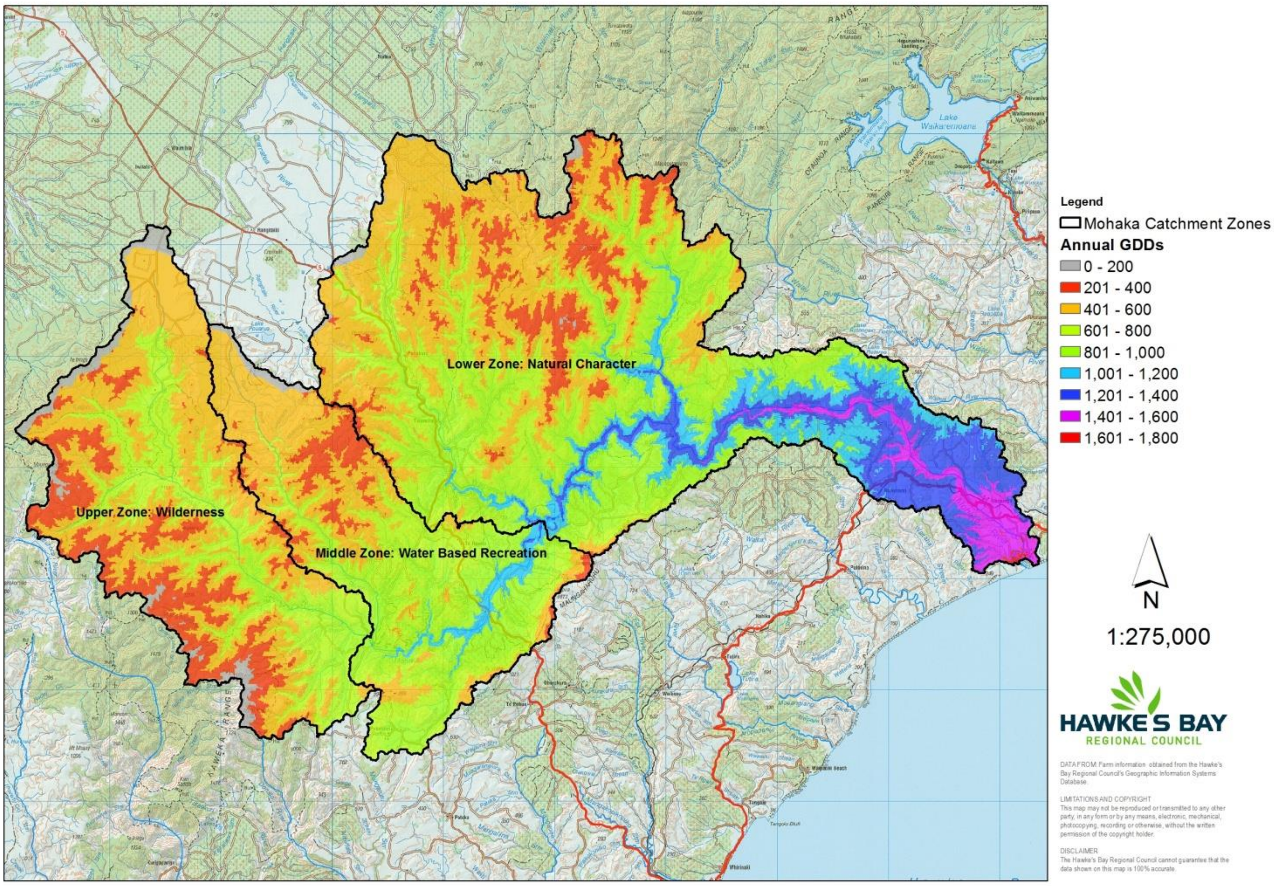

Figure 2-7: The average number of annual Growing Degree Days in the Mohaka catchment using a base temperature of 10°C (information generated using SimCLIM 2013 software). The daily temperature data used for this analysis covers the period 1950-1980 (Leathwick et al, 2002).

2.1.3 Wind

Wind speed and direction have been recorded at Te Haroto Climate station since 1998 and Taharua Climate Station for the past 5 years. Te Haroto lies in the Middle Zone at an elevation of 460 m. Winds at Te Haroto are predominantly from northerly, northwest and southerly directions and tend to be strongest from the northwest (Figure 2-8). Gale-force winds have been recorded at Te Haroto station with the highest recorded hourly mean speed reaching 75 km/hr, with gusts up to 138 km/hr. Rain at Te Haroto most commonly occurs with southerly winds (Figure 2-9). By contrast, rain is predominantly associated with northerlies at Taharua Climate Station. This highlights the spatial variability in weather and how the predominance of a particular weather regime and wind direction for a period of time could produce marked differences in available water across the catchment.

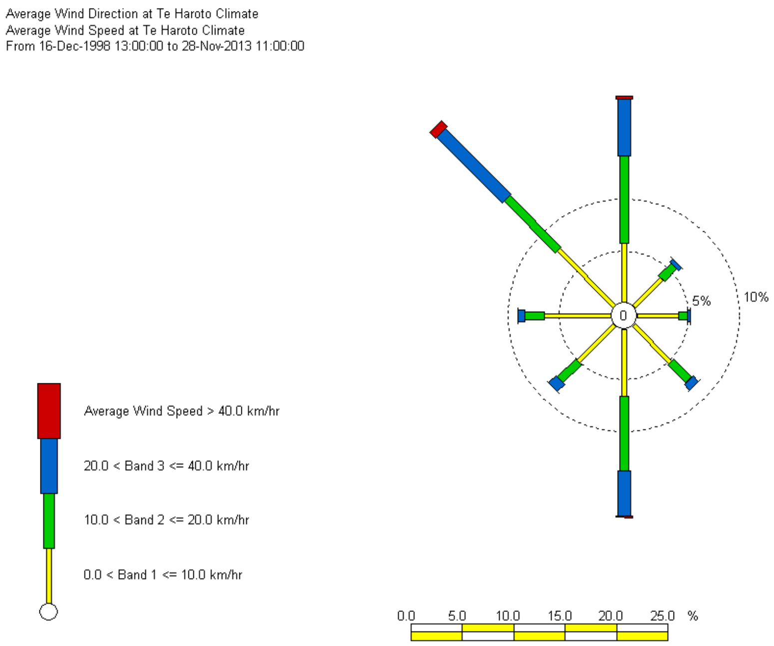

Figure 2-8: Wind rose for Te Haroto Climate Station showing average wind speed and direction from 1998 to 2013.

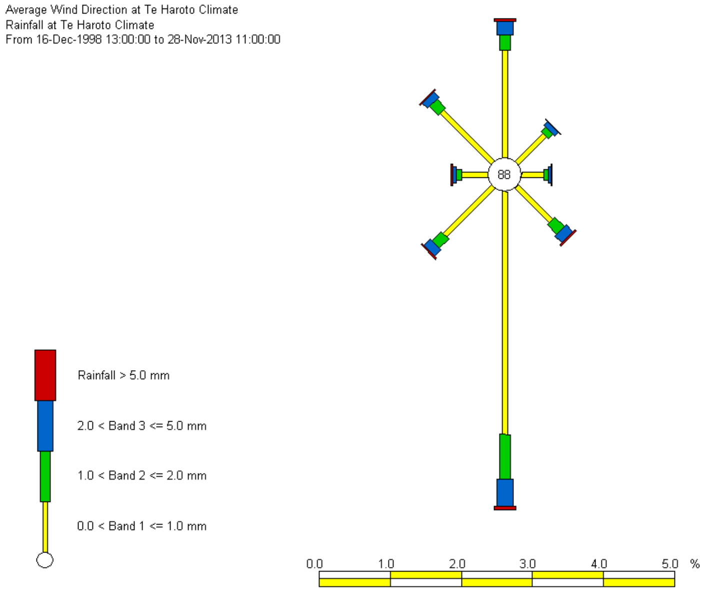

Figure 2-9: "Rain" rose for Te Haroto Climate Station showing hourly rainfall by wind direction for the period 1998 to 2013.

2.1.4 Potential Evapotranspiration and Soil Moisture Deficit

Rainfall exceeds potential evapotranspiration (PET) on an annual basis throughout the Mohaka catchment. During the growing season, a surplus of rainfall occurs at high elevations, but PET tends to exceed rainfall by up to 400 mm in coastal areas and river valleys. By comparison, PET exceeds rainfall by over 500 mm on average during the growing season on the Heretaunga and Ruataniwha Plains.

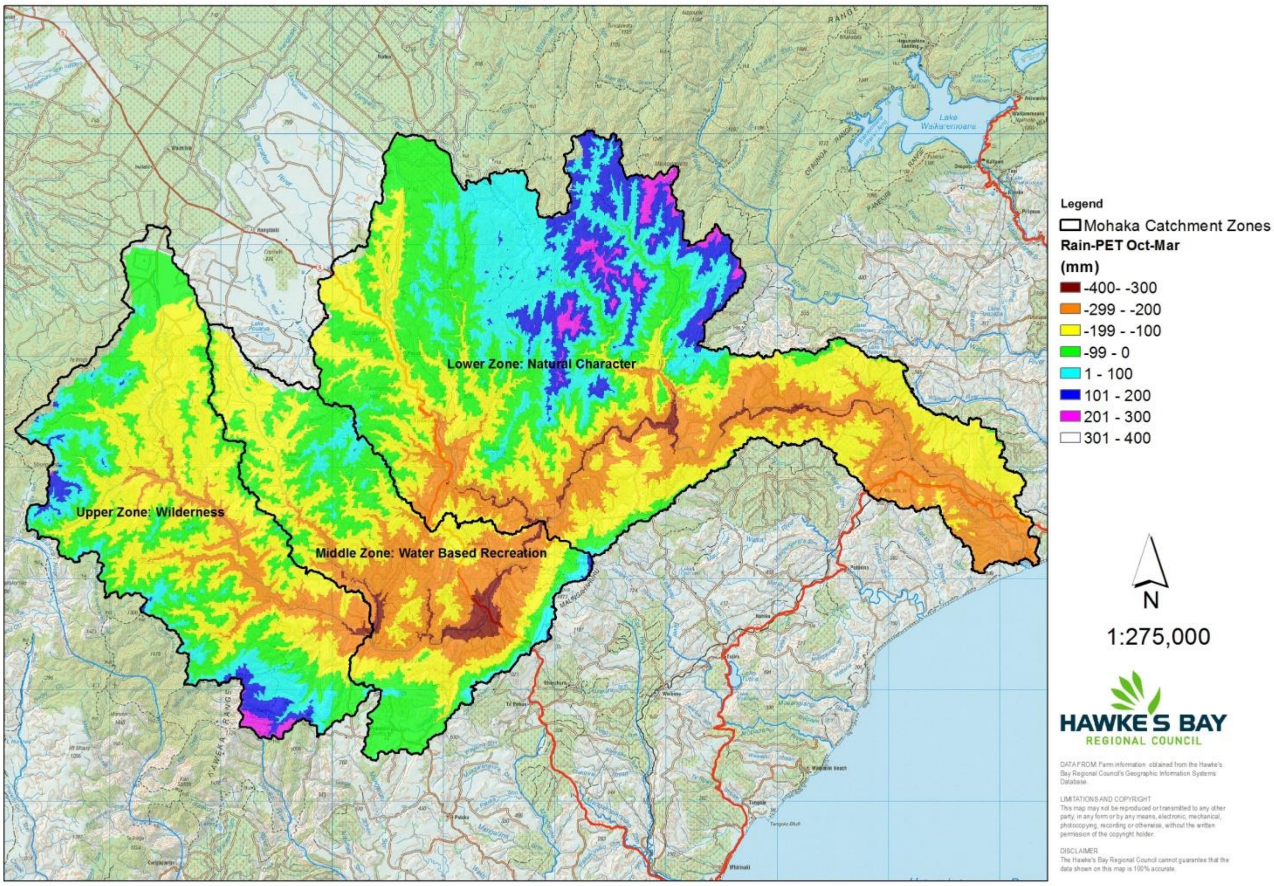

Figure 2-10: Rainfall minus PET (mm) for the October to March growing season in the Mohaka catchment (information generated using SimCLIM 2013 software and using data from 1950 to 1980 (Leathwick et al, 2002)).

The number of days that a soil moisture deficit (SMD) occurs during the growing season (October to March inclusive) indicates how frequently irrigation might be required. A SMD exists when plants are likely to become stressed due to insufficient readily available water in the soil profile. Figure 2-11 shows the average number of days of SMD during the growing season as calculated using a theoretical soil with an available water holding capacity of 150 mm (Tait, pers com, 2008). Although SMD is not common in higher parts of the catchment, eastern areas, particularly the coastal part of the Lower Zone, can have the equivalent of almost two months of SMD each year. More severe SMD occurs in other parts of the region such as the Heretaunga and Ruataniwha Plains, where in excess of 3 months SMD typically occurs.

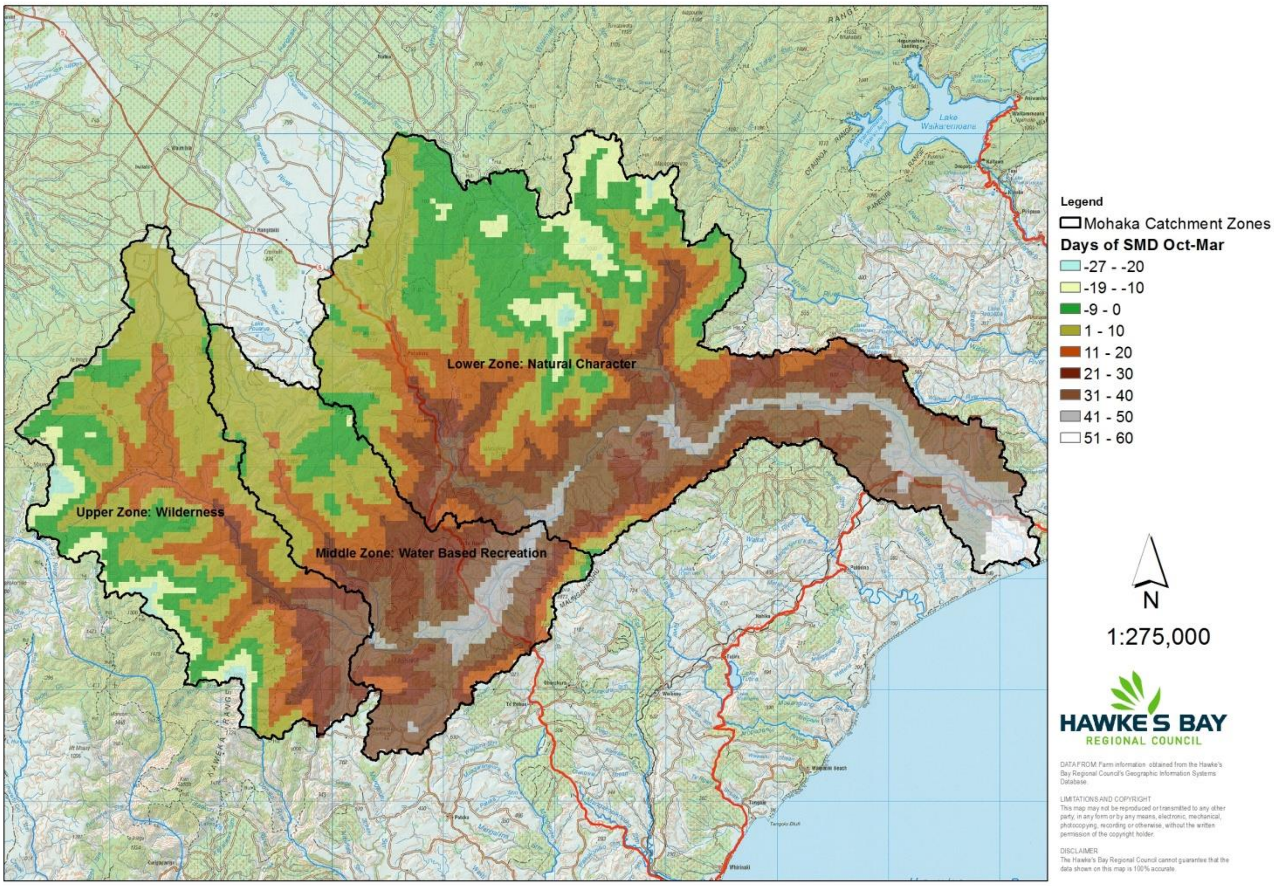

Figure 2-11: The average number of days of soil moisture deficit (SMD) in the Mohaka catchment for the months October to March inclusive. Data provided to HBRC by NIWA (Tait, pers. Com., 2008).

2.2 Climate change scenario over the next 50 years (2065)

The Intergovernmental Panel on Climate Change (IPCC) approved and accepted the Fifth Assessment Report on the physical scientific basis of climate change in 2013. The IPCC frames climate change projections in terms of four potential scenarios or Representative [greenhouse gas] Concentration Pathways (RCPs).

Each RCP assumes a relationship between particular CO_2 concentrations and the level of global warming. At present CO_2 concentrations are approximately 400 ppm. Various scenarios for what might happen have been assessed. By the year 2100, scenario RCP2.6 is expected to occur with CO_2 concentrations of 421 ppm (parts per million), RCP4.5 with 538 ppm, RCP6.0 with 670 ppm and RCP8.5 with 936 ppm. The terms RCP2.6, 4.5, 6.0 and 8.5 refer to the level of radiative forcing, in watts per square metre, assumed in these scenarios.

For both RCP6.0 and RCP8.5, warming would peak beyond 2100, while for RCP4.5 it would stabilise by 2100 and for RCP2.6 it would first peak then decline by 2100. RCP8.5 can be regarded as a "business as usual" scenario – it is what would happen if no reductions in greenhouse gas emissions took place. RCP2.6 would require stringent emissions reduction and RCP4.5 is probably a "best estimate" of achievable emissions reductions.

It is assumed here that, in future, either no change will take place in greenhouse gas emissions (scenario RCP8.5), or that the achievable emissions reductions are implemented internationally (RCP4.5). The following examination of climate change in the Mohaka catchment is focussed on the next 50 years (up to 2065) under RCP4.5 and RCP8.5 and is based on the median value of an ensemble of up to forty climate change models.

The projections are summarised in Table 2-4 and include the 10th and 90th percentile values of the ensemble's output in addition to the median. The projections are derived using the SimCLIM 2013 model developed by CLIMsystems Ltd (2014).

Mean annual rainfall is predicted to increase in the Mohaka catchment by about 1% by 2065 under RCP4.5, but differences between the models are large and range from drying the catchment by more than 10% to increasing rainfall by a similar magnitude. The median rainfall predictions indicate a near zero change in parts of the Lower Zone to an increase of slightly more than 1% along the western edge of the Upper Zone (Figure 2-12). The median ensemble results suggest the greatest increase in rainfall occurs during autumn, averaging 3%, followed by a 1% increase in summer. Winter rainfall increases by less than 1% on average but with eastern areas of the lower zone likely to see a small decrease, and south western parts an increase of approximately 1%. Spring rainfall is predicted to decrease in all parts of the catchment, averaging 1-2%.

Under RCP8.5 the pattern is similar but the magnitudes of change are greater and the magnitude of variation between the individual models is also greater. The median annual increase in rainfall is approximately 1% under RCP8.5; the spring decrease in rainfall is 2% on average; summer rainfall increases 1%; autumn increases by 5%; and winter increases 1%, although eastern parts could see a decrease of 1%. The more extreme ends of the model predictions would either dry the catchment by 15-20% through all seasons or increase rainfall by 15-30%.

Table 2-4: Climate Projections for the Mohaka catchment to 2065 under RCP4.5 and RCP8.5.

The projections are shown in the table as changes from 1995 values and are the average change across the Mohaka catchment. A (+) sign before a value indicates an increase and a (-) sign indicates a decrease compared to 1995. The median values of an ensemble of forty climate models are presented and underneath each one are the 10th and 90th percentiles in square brackets. With respect to rainfall-PET, negative values indicate a drying trend, i.e. that PET exceeds rainfall. The information was generated using SimCLIM 2013 software (CLIMsystems Ltd, 2014).

Projections to 2065	Mean Annual Rainfall	Mean Summer Rainfall	Mean Autumn Rainfall	Mean Winter Rainfall	Mean Spring Rainfall	Oct to Mar Rainfall - PET	Mean Annual Temp	Mean Annual GDDs (base 10°C)
RCP4.5	+0.8% [-11,+14]	+0.7% [-12,+15]	+3.3% [-10,+18]	+0.5% [-11,+12]	-1.4% [-12,+10]	-14 mm [+79,-98]	+1.1°C [+0.8,+1.5]	+241 [+160,+339]
RCP8.5	+1.3% [-18,+22]	+1.0% [-20,+24]	+5.3% [-16,+29]	+0.8% [-17,+19]	-2.3% [-18,+16]	-23 mm [+125,-155]	+1.8°C [+1.3,+2.4]	+396 [+262,+563]

The frequency and magnitude of extreme rainfall events are expected to increase over time. Under RCP4.5, a rainfall event which currently has a probability of occurrence of 1% each year (1 in 100 year return period) at the Te Pohue site would have a probability of occurrence of 1.3% each year (1 in 76 year return period) by 2065 and further increase in likelihood to 1.5% each year (1 in 66 year return period) under RCP8.5. These are however the median values of the ensemble of climate models and the range of results include increasing the likelihood from 1% each year to 7.2% each year (1 in 14 year return period) or decreasing it to 0.73% each year (1 in 137 year return period).

Table 2-5 shows several return periods and the associated 24 hour rainfall amounts at the Te Pohue site as they exist now and how they might change by 2065 under RCP4.5 and RCP8.5. Across New Zealand the occurrence of both flooding and droughts could double by 2100 under a mid-range scenario (Christensen et al, 2014).

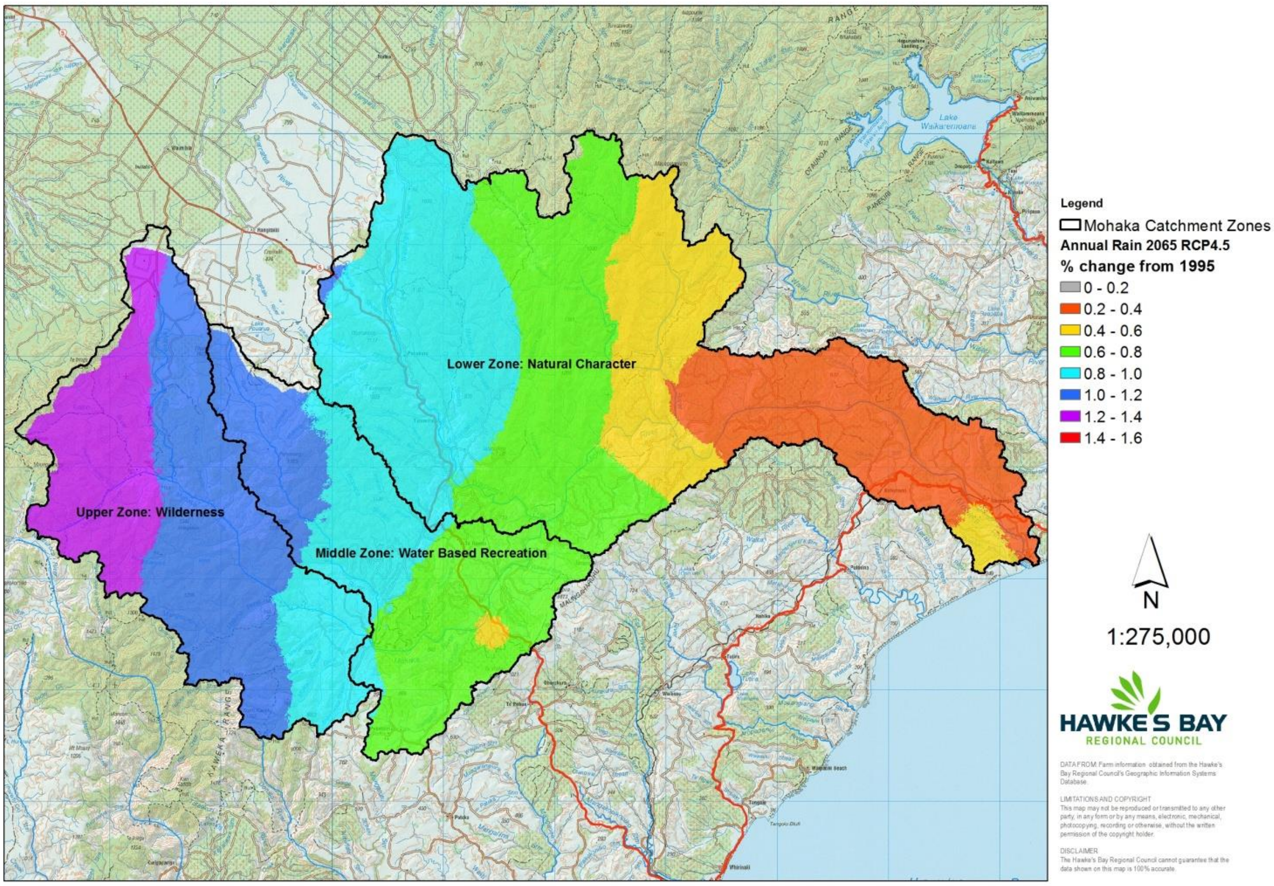

Figure 2-12: The projected percentage change in rainfall for the Mohaka catchment from 1995 to 2065 under RCP4.5. The information is generated using SimCLIM 2013 software (CLIMsystems Ltd (2014).

Table 2-5: 24 hour rainfall accumulations at the Te Pohue site associated with selected return periods. Rainfall totals are shown for present day conditions and the projections for 2065 under RCP4.5 and RCP8.5. Each result is the median value of an ensemble of 22 climate models, accompanied by 10th and 90th percentile values in square brackets. The information is generated using SimCLIM 2013 software (CLIMsystems Ltd, 2014).

Return Period (years)	Present Rainfall (mm)	2065 Rainfall (mm) RCP4.5	2065 Rainfall (mm) RCP8.5
2	96	111 [89, 152]	120 [85, 184]
5	150	167 [143, 225]	177 [139,270]
10	192	211 [184, 281]	221 [179,333]
20	238	258 [228, 339]	270 [223, 399]
50	307	329 [294, 424]	342 [286, 493]
100	366	390 [349, 495]	404 [339, 571]

Mean air temperatures are projected to increase by a little over 1°C by 2065 under RCP4.5 and closer to 2°C under RCP8.5. The magnitude of warming varies between individual models but the range is small and lies mostly within 1-2°C. This increase in temperature is likely to result in a lower incidence of frost, result in higher water temperatures in the catchment and increase the number of GDDs. GDDs could increase in the coastal areas of the lower zone to total more than 2000 under both RCP4.5 and RCP8.5 according to most of the climate models, with median predictions suggesting an increase of 400 GDDs and 600 GDDs respectively. The Mohaka catchment is unlikely to transition from a temperate to a sub-tropical climate (Belda et al, 2014), with only 4 models predicting the possibility and only under RCP8.5.

PET is likely to exceed rainfall during the growing season by an increasing amount over the next 50 years, due to PET rates increasing and under a scenario of lower spring rainfall. Averaged across the catchment, PET is estimated to exceed rainfall by 97 mm during the growing season and it could increase under RCP4.5 and RCP8.5 to about 110 mm and 120 mm respectively by 2065. Likewise the difference in the driest parts of the catchment could increase by 15 to 25 mm. The differences between the models are large though, and the range of predictions under RCP8.5 could mean the catchment has a surplus of rainfall of 30 mm or that PET exceeds rainfall by 250 mm.

2.3 Summary and conclusion

The Mohaka catchment tends to be wetter and colder than the regional average, and snow on higher parts of the catchment is not uncommon during winter. Rainfall over at least the last 30 years does not appear to have exhibited any particular trends that are strong or consistent across the catchment, except perhaps that easterly storms increased in frequency or intensity. Based on warm air temperatures alone, eastern areas of the catchment could provide the minimum number of GDDs required for crops such as grapes and kiwifruit. Gusty north westerly winds feature in the catchment as they do elsewhere in the region and assist with drying out the catchment during the spring and summer period, so that a soil moisture deficit typically exists for up to sixty days in eastern parts of the catchment and PET exceeds rainfall by up to 400 mm.

Over the next 50 years, climate change is predicted to result in a marginal increase in annual rainfall over the catchment, based on the median value of an ensemble of climate models, and a more marked increase in the occurrence of heavy rainfall events and droughts. Predicted decreases in rain during spring, together with rising temperatures, increase the need for irrigation by median values of 15 to 25 mm during the growing season. The variations in rainfall predictions between individual climate models are large and the outcomes less certain than the predicted rise in air temperature, which is expected to be 1-2°C by 2065. This is expected to result in higher water temperatures throughout the catchment. The anticipated warming, and more specifically the associated increase in GDDs, may mean that growing crops such as grapes and kiwifruit becomes easier or more feasible over a broader area of the catchment, provided other conditions are suitable. The Mohaka catchment is unlikely to change from a temperate to a sub-tropical climate within the next fifty years.

3 River Flows in the Upper, Middle and Lower Zones of the Mohaka catchment

The Mohaka River Catchment consists of 11 sub-catchments which are shown within the three proposed management zones in Figure 3-1. Within the catchment several hydrological instruments are installed at four sites, providing continuous rated flow records which differ in length between each site.

There are several other sites within the catchment which have been manually gauged to measure flow at a single point in time. These manually gauged flow sites are located on:

- The main stem of the Mohaka River upstream or downstream of a confluence with a significant tributary
- Significant tributaries close to the confluence with the main stem or with another significant tributary.

A range of hydrological techniques (which include the use of flow duration curves and regression analysis) have been used to derive synthetic flow records for the manually gauged flow sites and to synthetically extend flow records for rated flow sites which only have short-term flow records. The synthetic flow records used in this report have been derived using robust relationships between sites. The synthetic records provide a useful estimate of flow conditions where continuous measured data is unavailable.

Various sites for which continuous flow records (rated and synthetic) are available (from which summary flow statistics have been generated and presented in Section 3.1) were grouped based on the three proposed management zones (Figure 3-1, Table 3-1).

Rivers which are not modified by surface water or groundwater abstraction or discharges are often referred to as having a ‘natural’ flow regime. The flow record for a river which is modified by water abstraction or discharges can be modelled to simulate the ‘natural’ flow, resulting in the generation of a ‘naturalised’ flow record. The river flow records (rated and synthetic) referred to in this report have not been naturalised. This means they have not been modified to remove any influence from consented surface water or groundwater abstraction or discharges into a river. A summary of current and historically consented surface water and groundwater abstractions is presented in Section 3.4. A summary of current groundwater abstractions is also presented in Section 5.5. The summaries indicate that the current and historical water abstraction demand in the catchment is low and that the total potential abstraction effects on river flows are minor even at low flows. The river flow records referred to in this report are considered to be relatively close to ‘natural’ (pre-abstraction) conditions, on account of the minor current and historical abstraction effects on river flow.

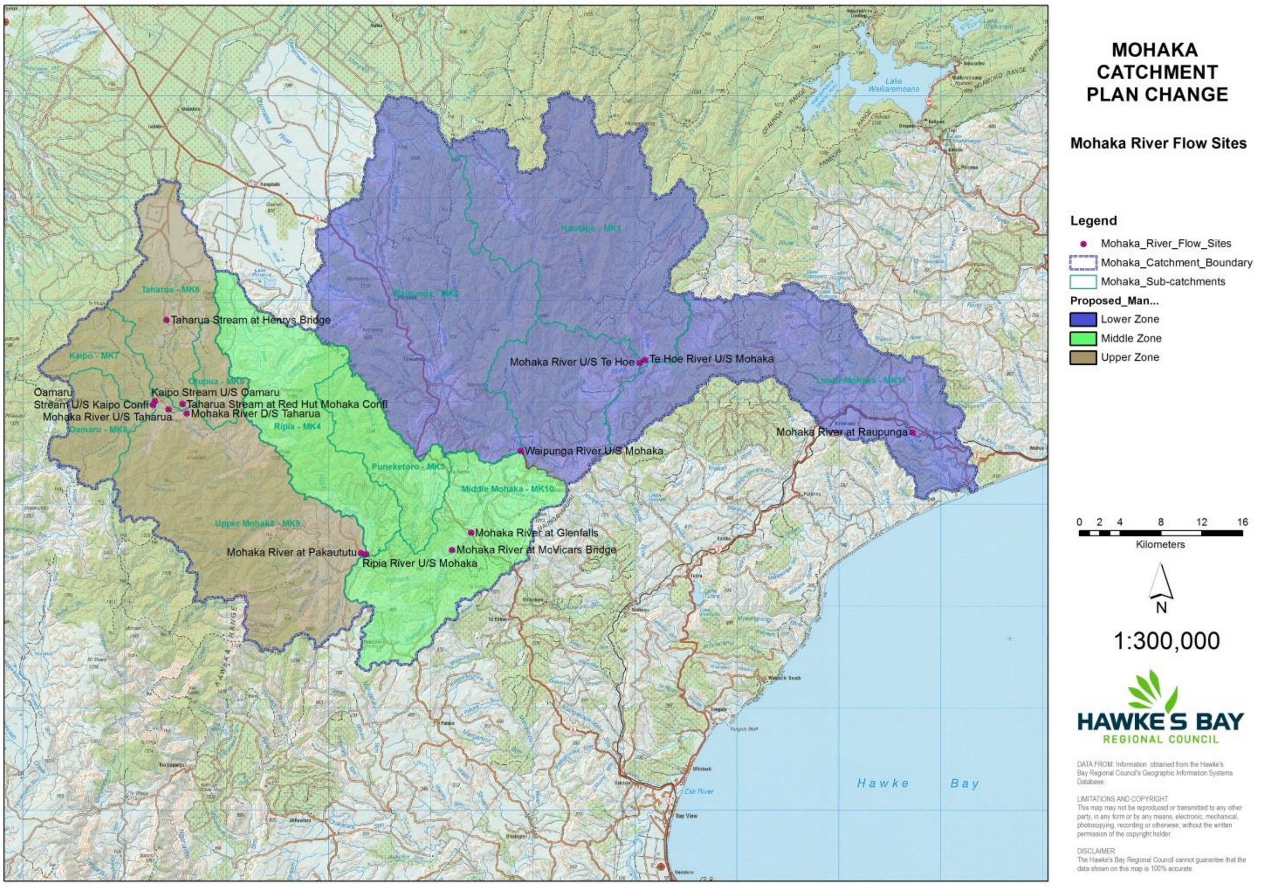

Figure 3-1: Map showing locations of river flow sites in the Mohaka catchment.

Table 3-1: Mohaka catchment river flow sites and record details.

Proposed Management Zones	Sub-catchment	Sub-catchment Code	Site	Record Type	Record Length	Catchment Area (km^2)
Upper Zone	Kaipo	MK7	Kaipo Stream U/S Oamaru	Synthetic Flow	1963-2013	54
	Oamaru	MK8	Oamaru Stream U/S Kaipo Confl	Synthetic Flow	1963-2013	66
	Upper Mohaka	MK9	Mohaka River U/S Taharua	Synthetic Flow	1963-2013	122
	Taharua	MK6	Taharua Stream at Henrys Bridge	Rated Flow	2008-2014	41
	Taharua	MK6	Taharua Stream at Red Hut Mohaka Confl	Synthetic Flow	2008-2014	133
	Upper Mohaka	MK9	Mohaka River D/S Taharua	Synthetic Flow	1963-2013	283
	Upper Mohaka	MK9	Mohaka River at Pakaututu	Synthetic Flow	1963-2013	605
Middle Zone	Ripia	MK4	Ripia River U/S Mohaka	Synthetic Flow	1963-2013	186
	Middle Mohaka	MK10	Mohaka River at Glenfalls	Rated Flow	1963-2013	997
	Middle Mohaka	MK10	Mohaka River at McVicars Bridge	Rated/Synthetic Flow	1963-2013	950
Lower Zone	Waipunga	MK2	Waipunga River U/S Mohaka	Synthetic Flow	1963-2013	474
	Middle Mohaka	MK10	Mohaka River U/S Te Hoe	Synthetic Flow	1957-2013	2127
	Hautapu	MK1	Te Hoe River U/S Mohaka	Synthetic Flow	1957-2013	337
	Lower Mohaka	MK11	Mohaka River at Raupunga	Rated Flow	1957-2013	2370

Note: All river flow records noted in the table above are un-naturalised (i.e. they have not been modified to remove any influence from consented groundwater or surface water abstraction or consented discharges into a river).

As shown in Figure 3-1, the Mohaka River at McVicars Bridge site is less than 5 km upstream from the Mohaka River at Glenfalls site. The McVicars site was installed in 2011 and has provided flow data since its installation. The McVicars site is operated and maintained by NIWA. The McVicars site was installed to replace the Glenfalls site (also operated by NIWA) which was decommissioned in 2014. The Glenfalls site was in operation since 1961 and provided flow data from 1963. The two sites were operated in parallel for over two years in order to establish a robust flow relationship between the two sites before Glenfalls was decommissioned.

The flow records from the 2 sites show that there is a minor increase in flow between the upstream and downstream site. This is attributed to the change in catchment area and contributions from a small tributary which joins the Mohaka River between the two sites. Synthetic flows have been derived to extend the rated flow record for McVicars back to 1963. Flow statistics have been generated for both sites and are presented in Table 3-2.

3.1 Summary river flow statistics

Summary river flow statistics have been calculated for each site and are presented in Table 3-2.

Table 3-2: Summary river flow statistics for sites in the Mohaka catchment.

Proposed Management Zones	Site	Record Length	Flow Statistic (l/s)								MALF/Mean Flow Index (%)
			Min	Max	Mean	Median	Q_{95}	Q_5	MALF	MAMF	
Upper Zone	Kaipo Stream U/S Oamaru	1963-2013	572	137850	3338	2662	1081	7273	1092	39267	33%
	Oamaru Stream U/S Kaipo Confl	1963-2013	486	154716	3593	2834	1057	8014	1070	43959	30%
	Mohaka River U/S Taharua	1963-2013	1053	332162	7723	6094	2280	17215	2308	94384	30%
	Taharua Stream at Henrys Bridge	2008-2014	1412	20307	2982	2630	1579	5526	1730	12799	58%
	Taharua Stream at Red Hut Mohaka Confl	2008-2014	1545	44397	5106	4310	1924	10877	2268	27369	44%
	Mohaka River D/S Taharua	1963-2013	3762	417611	12100	10063	5296	23963	5330	120415	44%
	Mohaka River at Pakaututu	1963-2013	5059	850755	22096	17935	8192	46340	8263	243438	37%
Middle Zone	Ripia River U/S Mohaka	1963-2013	962	265063	6283	4984	1941	13854	1963	75405	31%
	Mohaka River at Glenfalls	1963-2013	7867	1159372	37926	27572	11635	97233	12097	428210	32%
	Mohaka River at McVicars Bridge	1963-2013	6572	1519176	37045	29602	12177	80407	12304	432934	33%
Lower Zone	Waipunga River U/S Mohaka	1963-2013	2969	680162	16612	13280	5478	36025	5536	193852	33%
	Mohaka River U/S Te Hoe	1957-2013	11706	1726430	61605	44680	18198	154519	18500	684231	30%
	Te Hoe River U/S Mohaka	1957-2013	2518	558278	18690	13205	4622	48805	4720	220490	25%
	Mohaka River at Raupunga	1957-2013	15153	2201464	78775	57196	23430	197242	23815	872637	30%

Flow statistic and index definitions:

Minimum (Min) *- the lowest recorded/measured flow at a single point in time in the period of record.*

Maximum (Max) *- the highest recorded/measured flow at a single point in time in the period of record.*

Mean *- the average recorded/measured flow over the period of record.*

Median *- the flow that is equalled or exceeded 50% of the time over the period of record.*

Q_{95} *- the flow that is equalled or exceeded 95% of the time over the period of record. Q_{95} is used as a measure of the low flow of a river.*

Q_5 *- the flow that is equalled or exceeded 5% of the time over the period of record. Q_5 is used as a measure of the high flow of a river.*

Mean Annual Low Flow (MALF) *- this is the average of the lowest seven day period of flow recorded/measured in each year of the record. In this report MALF is calculated as 7-day moving average based on a hydrological year (Jul-Jun). Years with gaps in the record during which the annual minimum may have occurred are excluded. Hawke's Bay rivers regularly experience prolonged periods of low flow conditions over the summer months, during which the lowest flows typically occur. A hydrological year (Jul-Jun) is used to calculate the MALF rather than a calendar year (Jan-Dec) so that the lowest flow from each annual summer low flow event is used in the MALF calculation. If the calendar year was used, low flows from the same event could be selected as the lowest value in two different years which would bias the sample of annual low flows. A seven day averaging interval is considered the most relevant when taking into account ecological processes, as it smoothes out short term flow fluctuations which are less important to in-stream biota, focussing on longer low flow events that dry out parts of the river bed (Henderson & Diettrich 2007).*

Mean Annual Maximum Flow (MAMF) *- this is the average of the highest flow recorded/measured in each year of the record. In this report MAMF is calculated based on a calendar year (Jan-Dec) while excluding any years with gaps in record during which the annual maximum may have occurred.*

MALF/mean flow index *- this is a simple flow index which calculates the MALF as a proportion (percentage) of the mean flow. A higher percentage indicates more stable low flows and can indicate a higher baseflow component.*

The river flow statistics provided in Table 3-2 show that flows increase between all sites in a downstream direction through the Mohaka River. Mean flow increases from 7723 l/s at the Mohaka River U/S Taharua (located in the upper reaches of the Mohaka River) to 78775 l/s at Mohaka River at Raupunga (located at the most downstream point in the catchment). As with many rivers, the Mohaka River flow increases downstream as the catchment area upstream of the point being measured increases.

The Taharua Stream at Henry's Bridge has the greatest percentage of MALF/mean flow (58%), which indicates flows at this site are more stable and may have a higher baseflow component than other sites in the Mohaka catchment. The Taharua Stream at Red Hut Mohaka Confl and the Mohaka River D/S Taharua (both located downstream from the Henry's Bridge site) have the second highest percentage of MALF/mean flow (44%).

The Taharua Stream contributes a large proportion of the flow in the upper Mohaka River throughout a wide range of flow conditions. The mean annual low flow (MALF) for the Taharua Stream at Red Hut Mohaka Confl is 2268 l/s, which equates to 43% of the 5330 l/s MALF at the Mohaka River D/S Taharua. The Q_5 flow (a measure of high flow) at the Red Hut Mohaka Confl site is 45% of the Q_5 flow at the Mohaka River D/S Taharua. The large contribution of flow from the Taharua Stream is probably due to it having a higher baseflow component than other streams in the catchment. Comparing the MALF at Taharua Stream at Red Hut Mohaka Confl with Mohaka River flows further down the catchment, 2268 l/s is approximately only 10% of the 23815 l/s MALF at Mohaka River at Raupunga, due to the contribution of larger tributary flows into the main stem. The MALFs calculated for the Waipunga River U/S Mohaka (5336 l/s) and Te Hoe River U/S Mohaka (4720 l/s) are 23% and 20% respectively of the MALF at the Mohaka River at Raupunga.

3.2 Mean monthly river flows

Mean monthly river flows illustrate the general trends in flow at each site during the year (Table 3-3, Figure 3-2, Figure 3-3, Figure 3-4 and Figure 3-5).

At Henry’s Bridge the highest mean monthly river flow occurs in October, with the lowest occurring in April (Figure 3-2). The Mohaka River at Glenfalls has its highest mean monthly river flow in July and its lowest flow in February (Figure 3-3). Highest mean monthly river flows in the Mohaka River at McVicars occur in July, while the lowest occur in April (Figure 3-4). At the Mohaka River at Raupunga highest mean monthly river flows occur in July, and lowest flows occur in March (Figure 3-5).

Table 3-3: Mean monthly river flows for sites in the Mohaka catchment.

Proposed Management Zones	Site	Record Length	Mean Monthly Flow (l/s)												
			Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year
Upper Zone	Kaipo Stream U/S Oamaru	1963-2013	5213	4855	4370	3903	2992	2714	2440	2313	2293	2273	2787	3950	3368
	Oamaru Stream U/S Kaipo Confl	1963-2013	5699	5297	4752	4228	3205	2892	2584	2442	2419	2396	2974	4281	3626
	Mohaka River U/S Taharua	1963-2013	12245	11382	10212	9087	6890	6219	5558	5252	5202	5154	6395	9200	7796
	Taharua Stream at Henrys Bridge	2008-2014	3605	3972	4053	4186	3090	2880	2931	2217	2089	2036	2402	2849	3256
	Taharua Stream at Red Hut Mohaka Confl	2008-2014	6520	7352	7536	7837	5352	4875	4991	3372	3082	2961	3791	4805	5728
	Mohaka River D/S Taharua	1963-2013	17752	16673	15211	13804	11058	10219	9393	9011	8948	8889	10439	13945	12190
	Mohaka River at Pakaututu	1963-2013	33646	31441	28453	25580	19967	18254	16565	15784	15657	15534	18703	25867	22280
Middle Zone	Ripia River U/S Mohaka	1963-2013	9890	9201	8268	7371	5618	5083	4556	4312	4272	4234	5223	7461	6341
	Mohaka River at Glenfalls	1963-2013	62187	56794	50409	44211	32596	29750	26850	25406	25477	25412	30927	45611	38319
	Mohaka River at McVicars Bridge	1963-2013	57703	53760	48416	43276	33238	30173	27152	25756	25528	25309	30976	43790	37375
Lower Zone	Waipunga River U/S Mohaka	1963-2013	25861	24095	21703	19402	14908	13535	12183	11558	11456	11358	13895	19632	16760
	Mohaka River U/S Te Hoe	1957-2013	97632	90180	76388	71035	52426	49869	44818	40420	38697	44021	53172	72991	62506
	Te Hoe River U/S Mohaka	1957-2013	30367	27952	23482	21747	15716	14887	13250	11824	11266	12991	15957	22381	18982
	Mohaka River at Raupunga	1957-2013	124710	115209	97623	90798	67072	63811	57371	51764	49567	56355	68023	93292	79923

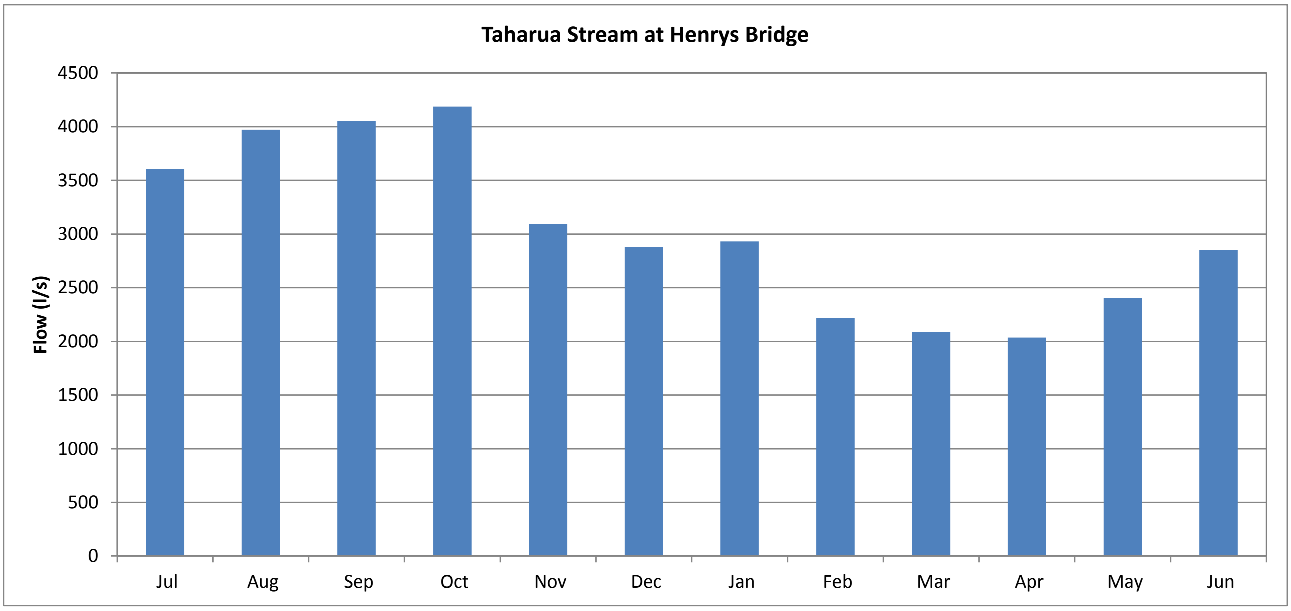

Figure 3-2: Plot of mean monthly river flows for the Taharua Stream at Henry’s Bridge.

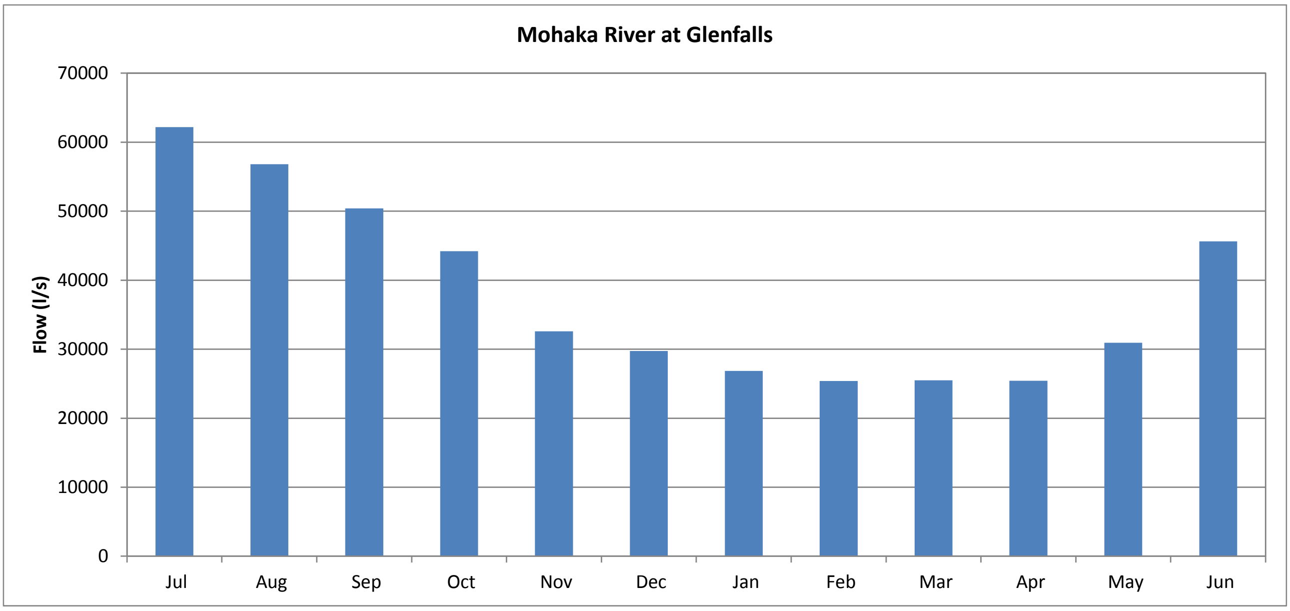

Figure 3-3: Plot of mean monthly river flows for the Mohaka River at Glenfalls.

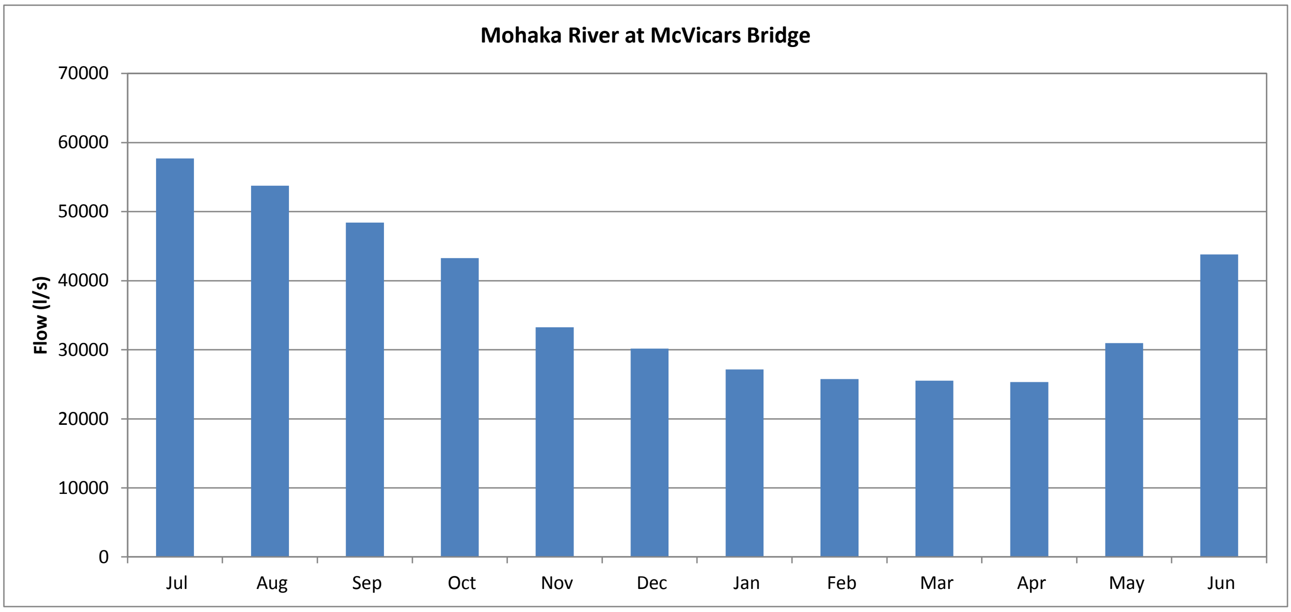

Figure 3-4: Plot of mean monthly river flows for the Mohaka River at McVicars Bridge.

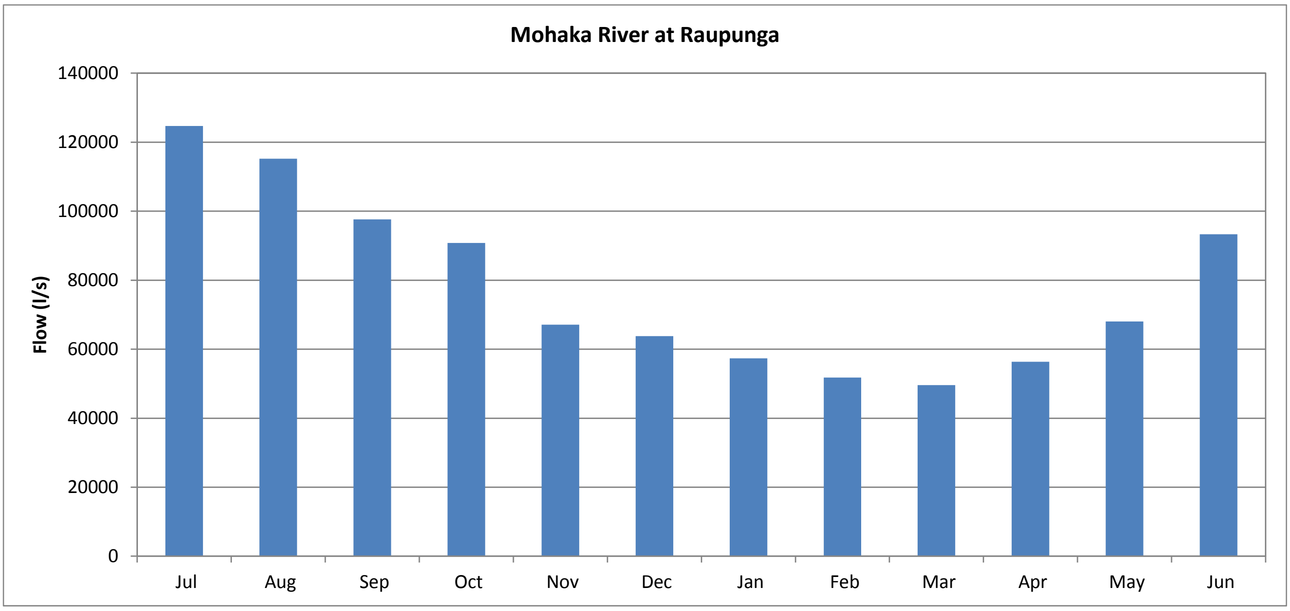

Figure 3-5: Plot of mean monthly river flows for the Mohaka River at Raupunga.

3.3 Trends and variability in river flows

River flow data for sites across the region (Harkness 2009) was analysed to identify long-term trends. Data from the Mohaka River at Raupunga site was used for trend analysis in the Mohaka catchment.

River flow data was analysed using three methods:

(1) The cumulative deviation of mean annual flows from the long-term average

(2) Annual low flows

(3) Annual maximum flows

Harkness (2009) investigated long-term climate variability, particularly the positive and negative phases of the Interdecadal Pacific Oscillation (IPO) when analysing river flow data.

The following excerpt from Harkness (2009) explains the climate cycles which have potential to influence rainfall and river flows in the Mohaka catchment:

> *New Zealand's climate varies naturally from year to year and from decade to decade. Much of this natural variation is apparently random, but there are two key natural cycles, operating over timescales of years, the El Niño-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO). Both these natural phenomena operate over the entire Pacific Ocean and beyond, and cause fluctuations in the prevailing Trade Winds and in the strength of the subtropical high-pressure belt.*
>
> *ENSO is a Pacific wide oscillation that affects pressure, winds, sea surface temperatures and rainfall that results from a cyclic warming and cooling of the surface of the central and eastern Pacific Ocean. It is a major influence on natural climate variability affecting rainfall in a two to seven year timescale.*
>
> *A measure of ENSO is the Southern Oscillation Index (SOI). The SOI is calculated from the monthly or seasonal variation in the air pressure difference between Tahiti and Darwin. When the SOI is positive it indicates a La Niña phase of ENSO. When the SOI is negative it indicates an El Niño phase. A neutral phase occurs with SOI values around zero.*
>
> *A description of La Niña and El Niño conditions in New Zealand is provided below by MfE (2008). During La Niña conditions New Zealand experiences:*
>
> - *more north-easterly winds*
> - *slightly higher wave conditions off the northeast coast of the North Island*
> - *higher sea levels*
> - *higher likelihood of ex-tropical cyclones affecting New Zealand.*

The tendency for easterly winds in summer months leads to increased rainfall and risk of ex-tropical cyclones in Hawkes Bay.

During El Niño conditions New Zealand experiences:

- *more westerly winds*
- *slightly high wave conditions off the southwest coast of the South Island*
- *depressed sea levels*
- *lower likelihood of ex-tropical cyclones affecting New Zealand.*

In summer stronger or more frequent than normal westerly winds lead to increased risk of drought in Hawkes Bay.

Figure 2-1 shows the SOI from 1900 to 2008. The extreme El Niño during the 1982/83 summer can be clearly seen with monthly SOI values reaching -3.6. This resulted in a severe drought for the Hawkes Bay region

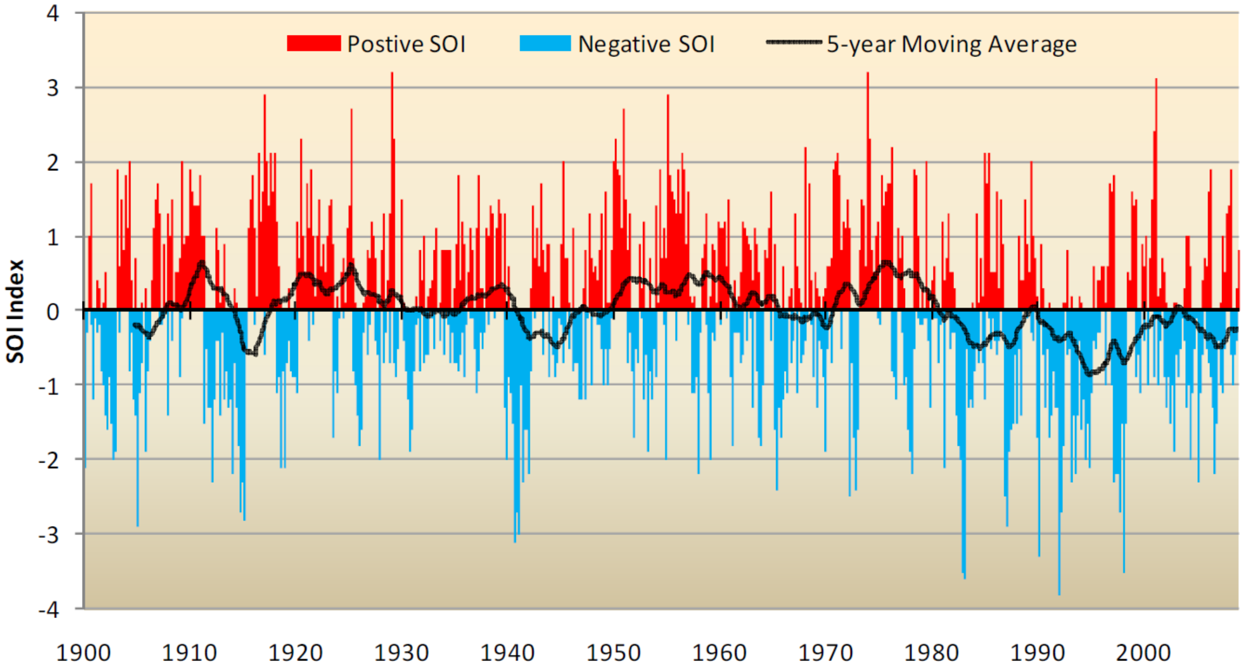

Figure 2-1: Monthly SOI values

The IPO is a long-lived Pacific-wide natural fluctuation that causes relatively abrupt 'shifts' in circulation patterns within the Pacific Ocean that can last for two to three decades (MfE 2008). It is strongest in the northern Pacific but affects New Zealand's climate. There are two phases of IPO, a negative phase and a positive phase. Phases have been identified as shown in Figure 2-2. The current phase is negative (beginning around 1999).

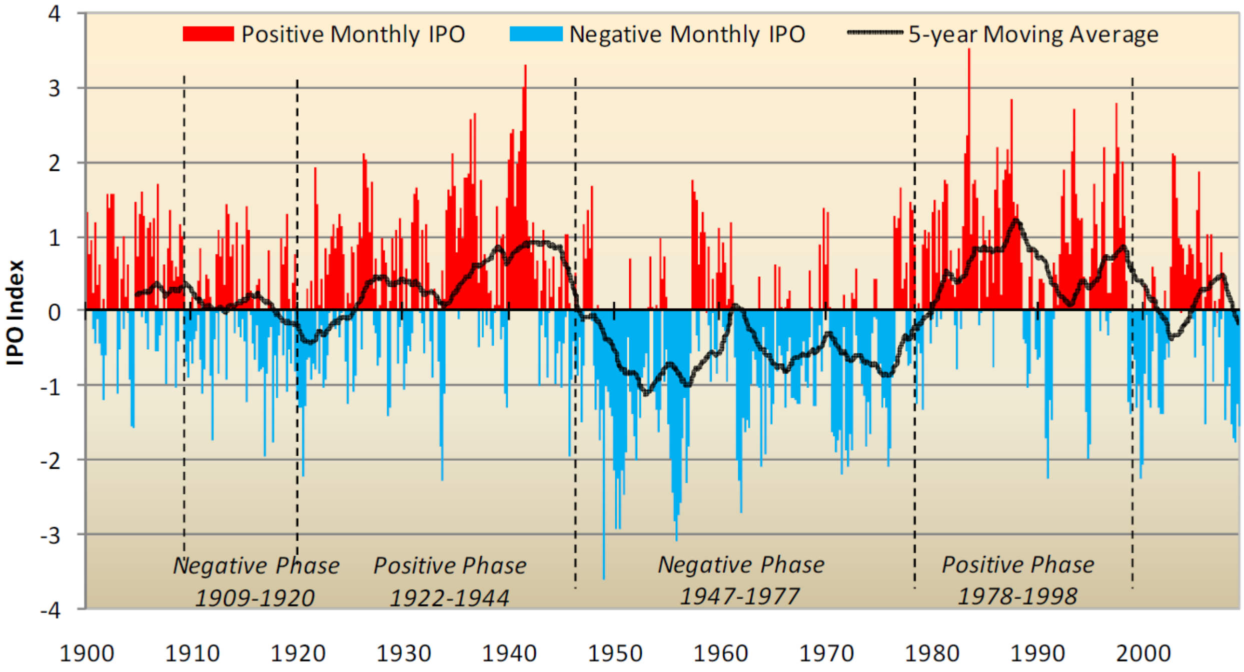

Figure 2-2: Monthly IPO Values

MfE (2008) describes IPO conditions over New Zealand as detailed below.

Positive IPO phases are characterised by:

- *an increased tendency for El Niño events*
- *a decreased rate of sea-level rise*
- *increased westerly winds and anticyclones in the north Tasman*
- *a tendency for beaches on the northeast coastline of the North Island to accrete*
- *possibly less frequent and smaller storm surge events*
- *drier conditions in the north and east.*

Negative phases of IPO are characterised by:

- *an increased tendency for La Niña events*
- *an increased rate of sea-level rise*
- *weaker westerly's, more easterlies and north-easterlies over northern New Zealand*
- *a tendency for beaches on the northeast coastline of the North Island to erode*
- *possibly more frequent and larger storm surge events.*

There is a tendency for more extreme El Niño events to occur during positive IPO phases and more extreme La Niña events to occur in a negative IPO phase. During the most recent positive IPO phase from 1978 to 1998 there were four significant drought events in Hawkes Bay associated with El Niño conditions.

(1) Cumulative Deviation of Mean Annual Flow

Harkness (2009) plotted the cumulative percentage deviation of mean annual flow for the Mohaka River at Raupunga which is shown in Figure 3-6. This type of graph highlights periods when mean annual flow is increasing or decreasing. An upward slope indicates a period of increasing annual flow, and a downward slope indicates decreasing annual flow. Negative and positive phases of the IPO cycle are plotted for comparison.

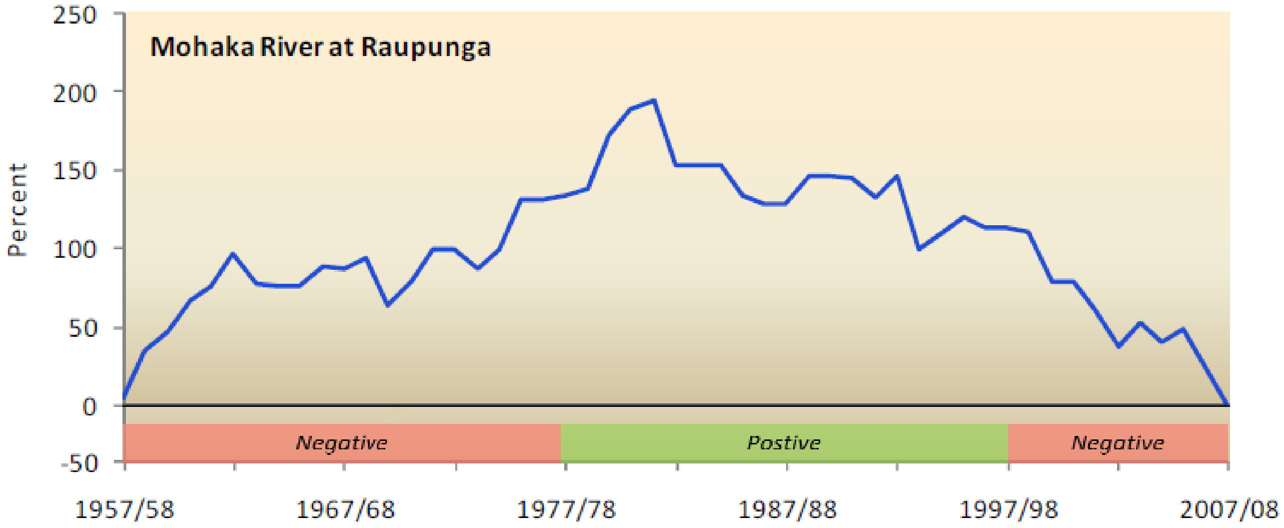

Figure 3-6: Mohaka River at Raupunga cumulative deviation of mean annual flow from average and IPO phases (Harkness 2009).

For the Mohaka River at Raupunga, Harkness (2009) identified a pattern of increasing annual flows up to around 1980 followed by a decreasing trend. There is no clear relationship between increasing or decreasing mean annual flows and IPO phases.

(2) Annual low flows

Harkness (2009) extracted the annual 7-day (fixed average) low flow for each year of record (Figure 3-7) to see if any trends in changes to the magnitude of the flows over time occur. Negative and positive phases of the IPO cycle are plotted for comparison.

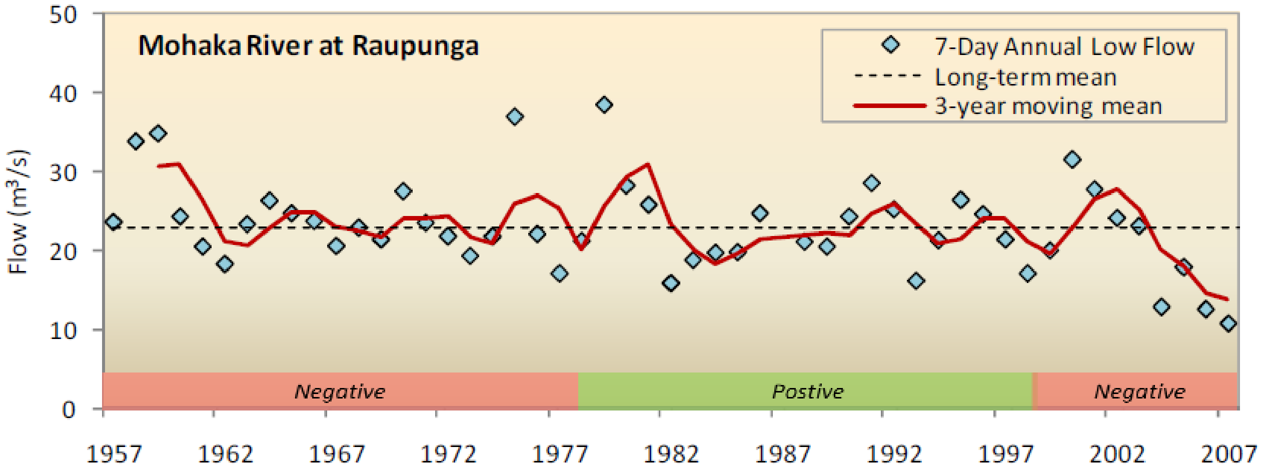

Figure 3-7: **Mohaka River at Raupunga annual 7-day low flows and IPO phases (Harkness 2009).**

For the Mohaka River at Raupunga, data for the Mohaka River show no apparent trend in 7-day annual low flows (Harkness 2009). There is no clear relationship between annual low flows and IPO phases.

(3) Annual maximum flows

The annual maximum floods recorded at the Mohaka River at Raupunga sites were examined (Harkness 2009) for any long-term trends (Figure 3-8). Phases of the IPO cycle are again plotted for comparison.

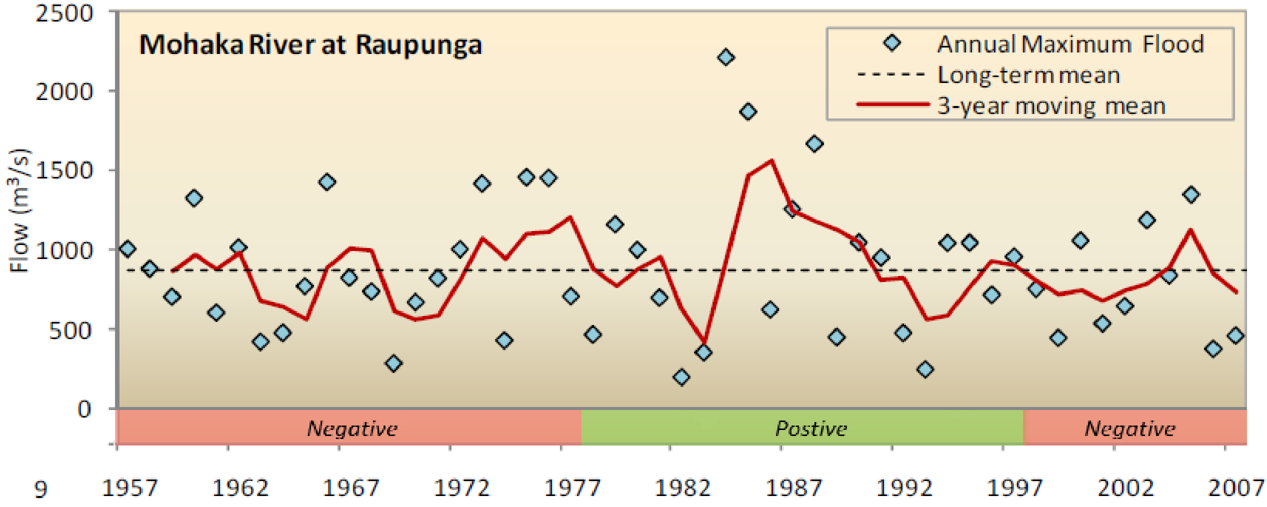

Figure 3-8: **Mohaka River at Raupunga annual maximum flows and IPO phases (Harkness 2009).**

For the Mohaka River at Raupunga, Harkness (2009) concluded that data for Mohaka River show no apparent trend in annual maximum flows. There is no clear relationship between annual maximum flows and IPO phases.

3.4 Consented surface water and groundwater abstractions

Surface water and groundwater is taken and has historically been taken from several sub-catchments of the Mohaka catchment (Table 3-4).

Table 3-4: Current and historical consented surface water and groundwater abstractions in the Mohaka catchment.

River Name	Status	Consent ID	Abstraction Category	Max rate of take (l/s)	Max weekly volume (m3/wk)	Min Flow Site	Min Flow (l/s)
Taharua Stream	Current	WP990321T	Surface Water	10	980	-	-
Taharua Stream	Current	WP990325T	Surface Water	10	980	-	-
Taharua Stream	Current	WP090093T	Surface Water	5	791	-	-
Inangatihi Stream	Current	WP080048T	Surface Water	1.1	325	-	-
Inangatihi Stream	Historic	HKB860218	Surface Water	1.1	162	-	-
Inangatihi Stream	Historic	WP951109T	Surface Water	1.1	325	-	-
Puneketoro Stream	Historic	HKB870148	Surface Water	0.45	105	-	-
Waipunga River	Historic	WP930324T	Surface Water	5	100	-	-
Mohaka River	Current	WP090641T	Surface Water	7.7	1400	-	-
Mohaka River	Current	WP080172T	Groundwater	50	10400	-	-
Mohaka River	Current	WP080196T	Stream Depleting Groundwater	54	21250	-	-
Mohaka River	Current	WP080027T	Surface Water	36	6480	-	-
Mohaka River	Current	WP080130T	Stream Depleting Groundwater	50	10400	-	-
Mohaka River	Historic	WP950388T	Surface Water	8	1260	-	-
Mohaka River	Historic	HKB870150	Groundwater	*0.78*	472	-	-
Mohaka River	Historic	WP960298T	Groundwater	0.75	*453.6*	-	-
Mohaka River	Historic	WP000595T	Stream Depleting Groundwater	54	21250	Mohaka River at Raupunga	18000
Mohaka River	Historic	WP000595Ta	Stream Depleting Groundwater	54	21250	Mohaka River at Raupunga	18000
Mohaka River	Historic	HKB850612	Surface Water	9.5	1400	-	-
Mohaka River	Historic	HKB900502	Surface Water	9.5	*5745.6*	-	-
Mohaka River	Historic	WP951141T	Surface Water	9.5	*5745.6*	-	-
Mohaka River	Historic	WP950166T	Stream Depleting Groundwater	50	10400	-	-
Mohaka River	Historic	HKB870061	Surface Water	4	1462	-	-
Mohaka River	Historic	WP951119T	Surface Water	36	*21772.8*	-	-
Mohaka River	Historic	HKB900500	Surface Water	3	*1814.4*	-	-
Mohaka River	Historic	HKB850602	Surface Water	7	1500	-	-
Mohaka River	Historic	WP950189T	Surface Water	5	650	-	-
Mohaka River	Historic	WP951099T	Surface Water	70	15000	-	-
Mohaka River	Historic	HKB830370	Surface Water	9	487	-	-

The total maximum rate of surface water and groundwater takes in the Mohaka catchment is 223.8 l/s. This represents the estimated maximum potential rate of abstraction from the Mohaka River if all consented abstractions were to operate at the maximum rate at the same time while assuming that all groundwater abstractions have a direct surface water depletion effect (although it is unlikely that all groundwater abstractions will have a direct effect, this assumption means the maximum potential rate of abstraction is probably over-estimated).

The Mohaka River at Raupunga is the site located at the most downstream point in the catchment. The MALF estimated for the Mohaka River at Raupunga is 23815 l/s (refer to Table 3-2). The estimated maximum potential rate of abstraction of 223.8 l/s equates to less than 1% of the MALF at the Mohaka River at Raupunga. This indicates that the estimated maximum potential rate of abstraction would have a relatively minor effect on river flow when flow is close to the MALF at the Mohaka River at Raupunga.

3.5 Taharua River Catchment

In the Taharua Catchment, the Taharua Stream flows on the surface above the sub-surface Taharua Aquifer System. Flows in the Taharua Stream at the Henry’s Bridge site and Red Hut Mohaka Confl site are more stable and may have a higher baseflow component in comparison to most sites located on the Mohaka River and its other tributaries (see Section 3.1). Concurrent gauging surveys are often undertaken to help understand the interaction between groundwater and surface water along river/stream reaches. Several concurrent gauging surveys have been undertaken at eight sites on the Taharua Stream (2009-2013). The locations of these gauging sites are shown in Figure 3-9.

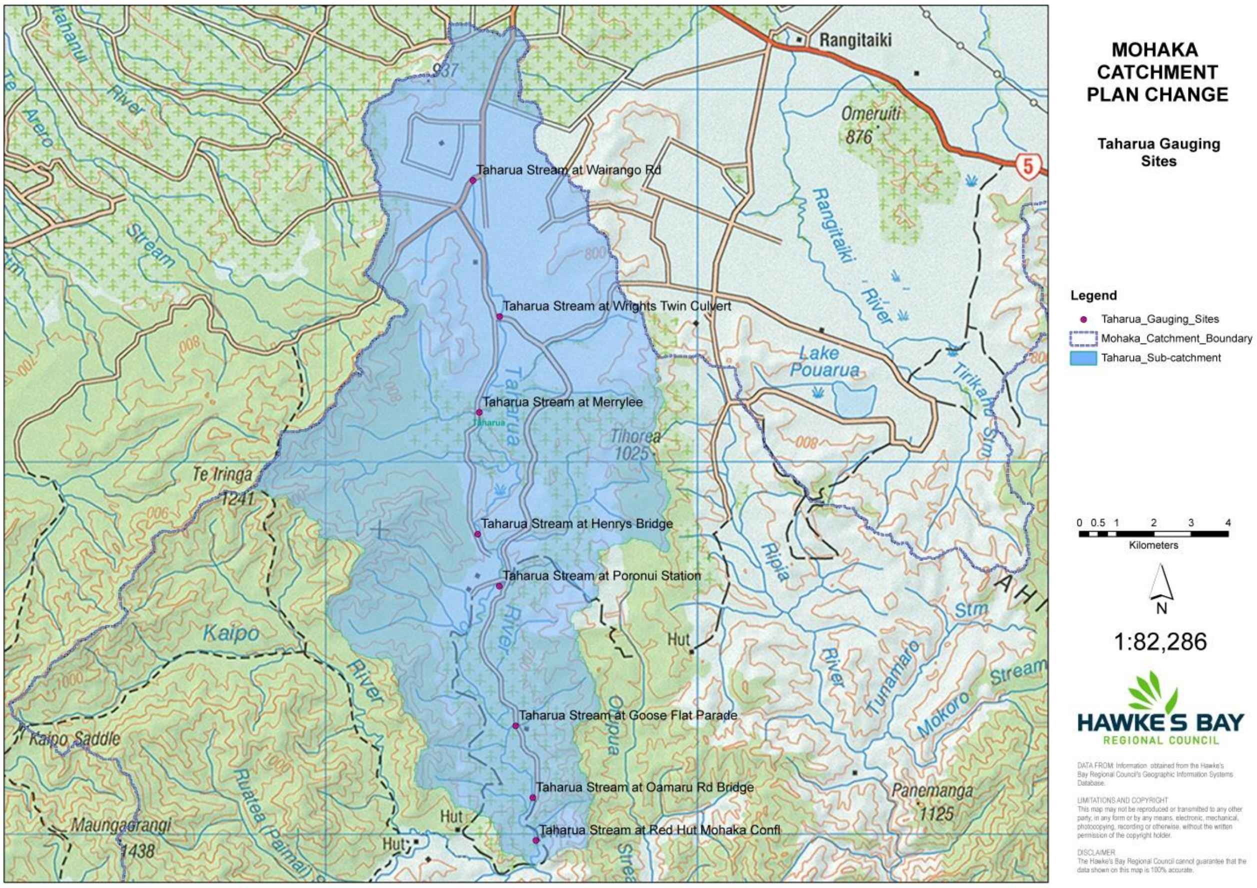

Figure 3-9: Map showing locations of Taharua gauging sites.

The concurrent gauging surveys do not cover all eight sites for each survey as not every survey was planned to target the whole catchment. In some cases environmental conditions limited the access to sites preventing gaugings being undertaken. The concurrent gauging data for each survey is presented in Table 3-5. Using the NIWA River Environment Classification (REC) system, estimates of mean annual low flow (MALF) and mean flow have been identified and included for comparison in Table 3-5. REC river flow estimates account for variations in rainfall, topography, catchment area, evapotranspiration, etc. but do not account for the interaction between surface water and groundwater resources. When comparing REC flow estimates with observed/measured flows, significant differences can indicate whether or not the interaction between surface water and groundwater (in terms of gaining from or losing to groundwater) varies within the surface water catchment.

Table 3-5: Taharua Stream concurrent gauging data and REC MALF and mean flow estimates.

Gauging site	Gauged flows (ls) for survey date													REC MALF (l/s)	REC mean flow (l/s)
	09-02-09	25-02-09	24-03-09	26-05-09	22-06-09	16-07-09	15-09-09	15-12-09	23-02-10	23-09-11	20-10-11	06-03-12	11-04-13		
Taharua Stream at Wairango Rd	343	272	302	203	104	171	300	398	237	517	514	353	198	252	624
Taharua Stream at Wrights Twin Culvert	763	858	611	455	554	564	748	1023	615	1335	1319	803	405	467	1223
Taharua Stream at Merrylee	1426	1575	1218										942	742	2021
Taharua Stream at Henrys Bridge	1909	2191	1953	2114*	1913*	2246*	2519*	2862*	1980*	2949*	3854*	2435*	1798	1248	3504
Taharua Stream at Poronui Station	2149	2412	2056	2700	2176	2659	2990	2963	2087	3364	4488	2812		1456	4127
Taharua Stream at Goose Flat Parade	2376	2718	2296											1819	5196
Taharua Stream at Oamaru Rd Bridge													2279	1964	5628
Taharua Stream at Red Hut Mohaka Confl	2734	3100	2481	3139**	2682**	3437**	4057**	4834**	2833**	5033**	7084**	3867**	2421**	2057	5899

*Notes: *Daily mean rated flow value, **Synthetic flow value*

Gauging data is also plotted in Figure 3-10 with the furthest upstream site (Taharua Stream at Wairango Rd) plotted on the left of the graph and the most downstream site (Taharua Stream at Red Hut Mohaka Confl) plotted on the right.

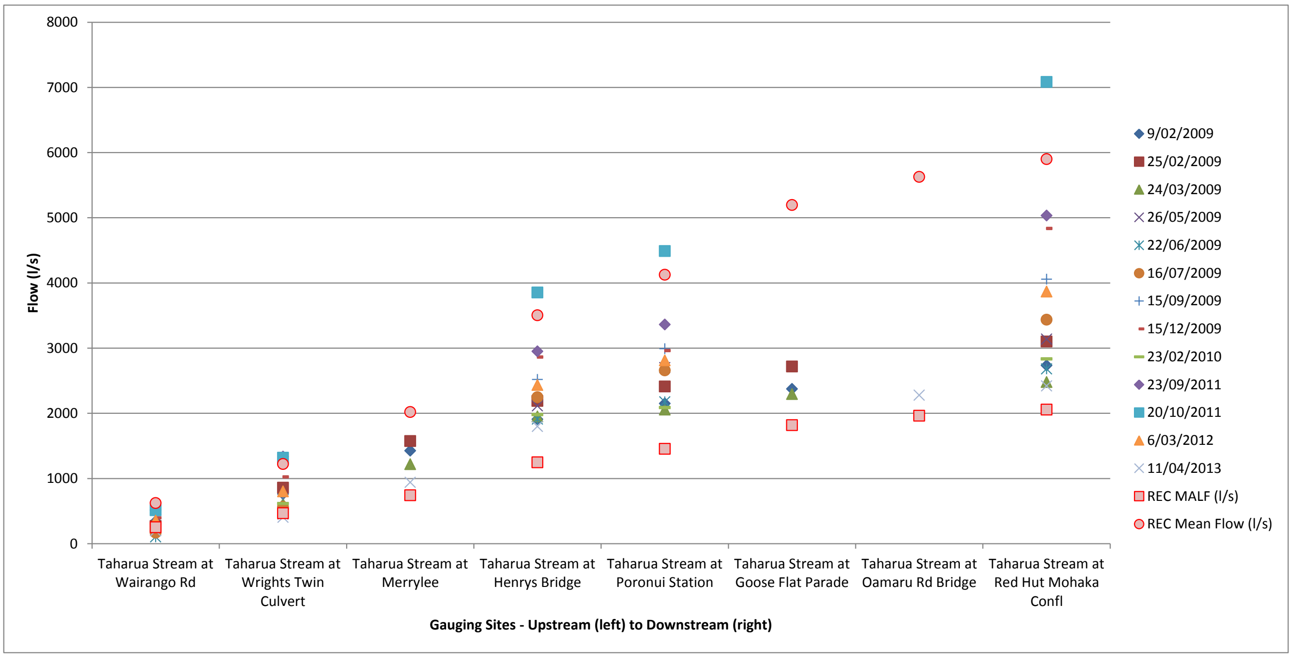

Figure 3-10: Taharua Stream concurrent gauging data and REC MALF and mean flow estimates.

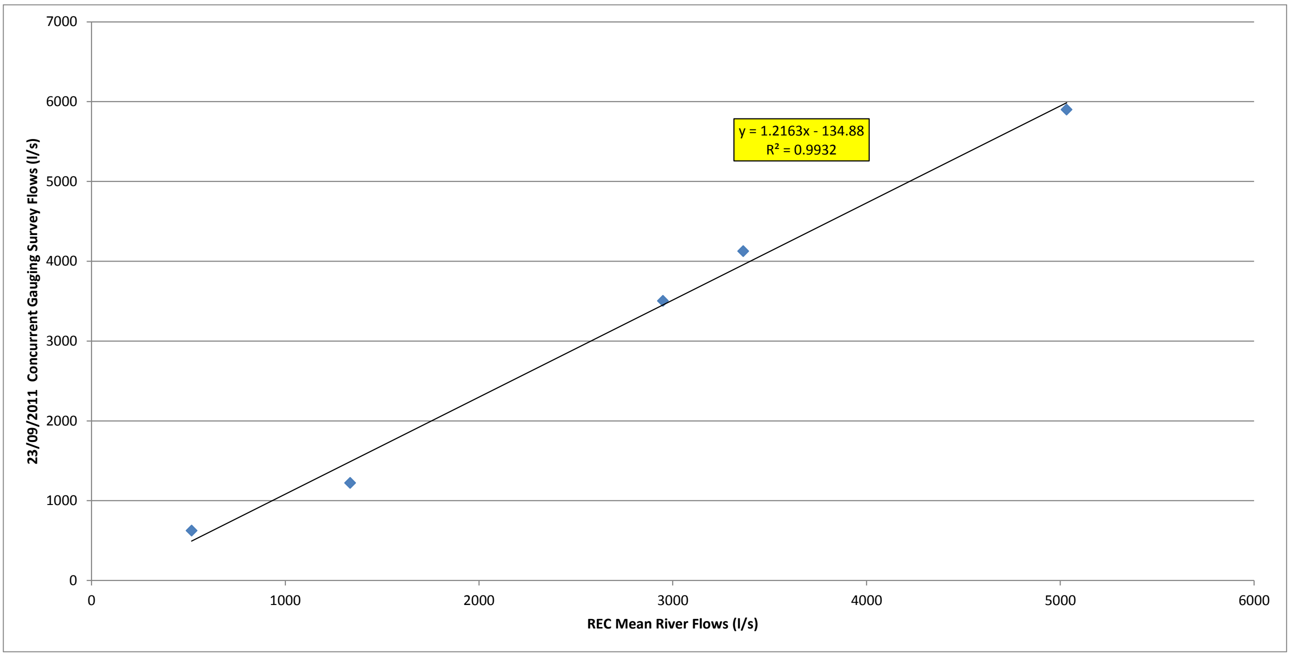

Figure 3-11: Taharua Stream 23/09/2011 concurrent gauging survey plotted against REC mean flow estimates.

The gauging data presented in Table 3-5 and Figure 3-10 shows that flow in the Taharua Stream increases downstream through the catchment. The pattern of increasing flow is consistent for each survey undertaken. The increase in flow between sites is most likely a consequence of the increase in surface water catchment area feeding each site.

Taharua Stream flows during the 23/09/2011 concurrent gauging survey are considered to be close to mean flow (the 23/09/2011 gauged flow for the Taharua Stream at Henry's Bridge site is 2949 l/s whereas the calculated mean flow for the site presented in Table 3-2 is 2982 l/s). Plotting 23/09/2011 concurrent gauging survey flows against REC mean flows (Figure 3-11) shows there is a strong correlation ($R^2 = 0.9932$) between the REC mean flows and survey flows.

As noted previously, REC river flow estimates do not account for the interaction between surface water and groundwater resources. The REC flow estimates show a similar pattern of flow increase between sites when compared to the concurrent gauging data, which is an indication that the interaction between surface water and groundwater is reasonably consistent throughout the surface water catchment. As noted in Section 5, further work is required to delineate the extent of the groundwater catchment.

3.6 Summary and conclusions

River flow summary statistics for sites located within the Mohaka River Catchment show the variation in flows that occur within the Mohaka River and its tributaries. Statistics show that river flows increase between all sites in a downstream direction through the Mohaka River. The Taharua Stream contributes a large proportion of the flow in the upper Mohaka River throughout a wide range of flow conditions. Taharua Stream flows are more stable with a higher baseflow component in comparison to flows at most sites on the Mohaka River and its other tributaries. Mean monthly river flows in the catchment are lowest during February and March.

The cumulative deviation of mean annual flows from long-term average annual river flows at the Mohaka River at Raupunga site increases up to around 1980, followed by a decreasing trend. This relates to long-term climate variability, particularly the positive and negative phases of the Interdecadal Pacific Oscillation (IPO). Analyses of annual low flows and annual maximum flows showed no apparent trends.

An assessment of consent information and river flows indicates that the current and historical consented water abstraction demand in the catchment is low and that the total potential abstraction effects on river flows are minor even at low flows.

Concurrent gauging data for the Taharua Stream Catchment showed that flow in the Taharua Stream increases downstream through the catchment. The increase in flow between sites is most likely related to the increase in surface water catchment area. Flow data indicates that the interaction between surface water and groundwater is reasonably consistent throughout the surface water catchment.

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4 The Land Resource of the Upper, Middle and Lower Zones of the Mohaka catchment

Much of the Mohaka catchment remains undeveloped including an area of more than 70,000 hectares of Department of Conservation (DoC) land. For the remaining land a prime reason for lack of development may be linked to the steep topography of the catchment and its inaccessibility. The following section describes the land resource of the catchment looking at its 'natural' condition and to what extent it has been altered by anthropogenic influences. It should be noted that there is some variation in the total area (hectares) that is quoted between sections. This is an artefact of geographic information system (GIS) mapping and is mainly caused by the way the different parameters are measured and overlaid. The estimated area of the Mohaka catchment is approximately 244,000 hectares.

4.1 Determining Current Land Use

The current land use in the Mohaka catchment was estimated using a combination of AgriBase ™ (Sanson & Pearson, 1997; Sanson, 2005; Agribase, 2012) the Land Cover Data Base Version 4.1 (LCDB 4.1; LRIS, 2016a) and local knowledge.

AgriBase™ is a national database compiled from the answers supplied voluntarily by farmers to questionnaires mailed to them on an annual basis by a company called AsureQuality. Originally developed in 1993 for the management of properties susceptible to foot and mouth disease, the database has been extended and now can be a used as a useful modelling input. The current questionnaire sent to land owners is very detailed and asks for information on all aspects of farm management. The LCDB 4.1 is a geographic information system (GIS) land use layer developed by Landcare Research and derived from 2012 satellite imagery and physical confirmation by visiting selected sites ("ground truthing").

Although AgriBase™ is an excellent data source it is incomplete. AgriBase™ records agricultural land use type and the extent in hectares of each agricultural land use but a small percentage of the land area within the catchment area has not been categorised. These 'gaps' in AgriBase™ information arise for several reasons but chiefly it is due to land owners not returning the questionnaires, the land in question not belonging to a specific land owner or the land not fitting into an identified category (e.g. roads, rivers, bare rock, urban areas etc). To fill in the missing data LCDB 4.1 is used. This is a land cover data base rather than a land use database but inferences can be made between land cover and what it can be used for. Derived maps in this section are therefore hybrid land use/land cover maps but are referred to as land use maps for simplicity.

Accurate and precise land use mapping can be difficult, labour intensive and expensive. The land use mapping carried out here is the most appropriate for use on a catchment the size of the Mohaka catchment. When mapping at this scale it is inevitable that some fine detail will be lost so it should be noted that data derived from this mapping will be a broad physical characterisation of the land use in the catchment and not a completely accurate portrayal of every farm paddock.

4.1.1 Current Land Use in the Mohaka catchment

The Mohaka catchment covers an area of approximately 244,000 hectares. Figure 4-1 presents the land use distribution across the catchment.

From both Figure 4-1 and Table 4-1 below it is clear that the main land use/cover in the Mohaka catchment is indigenous forest, followed by exotic forest (commercial forestry). Together these two types of forest cover account for nearly 82% of the Mohaka catchment. The pastoral farming in the catchment is mainly sheep and/or beef farming (12.4% of catchment) with a relatively small amount of dairy farming (1.3% of catchment). Most dairy farming is carried out at the northern end of the Taharua sub-catchment and in a small area in the lower catchment area (see Figure 4-1). Just outside the Mohaka catchment (and across the regional border) and immediately adjacent to the Ripia and Waipunga Rivers lies land that is currently being intensively farmed and where further intensification could occur. While the surface topography suggests that drains and streams flow away from the Mohaka catchment, it is conceivable (although not proven) that groundwater could enter the Waipunga and Ripia streams from this potentially intensified land area. If so then land use changes just outside the Mohaka catchment may need to be considered during the plan change process.

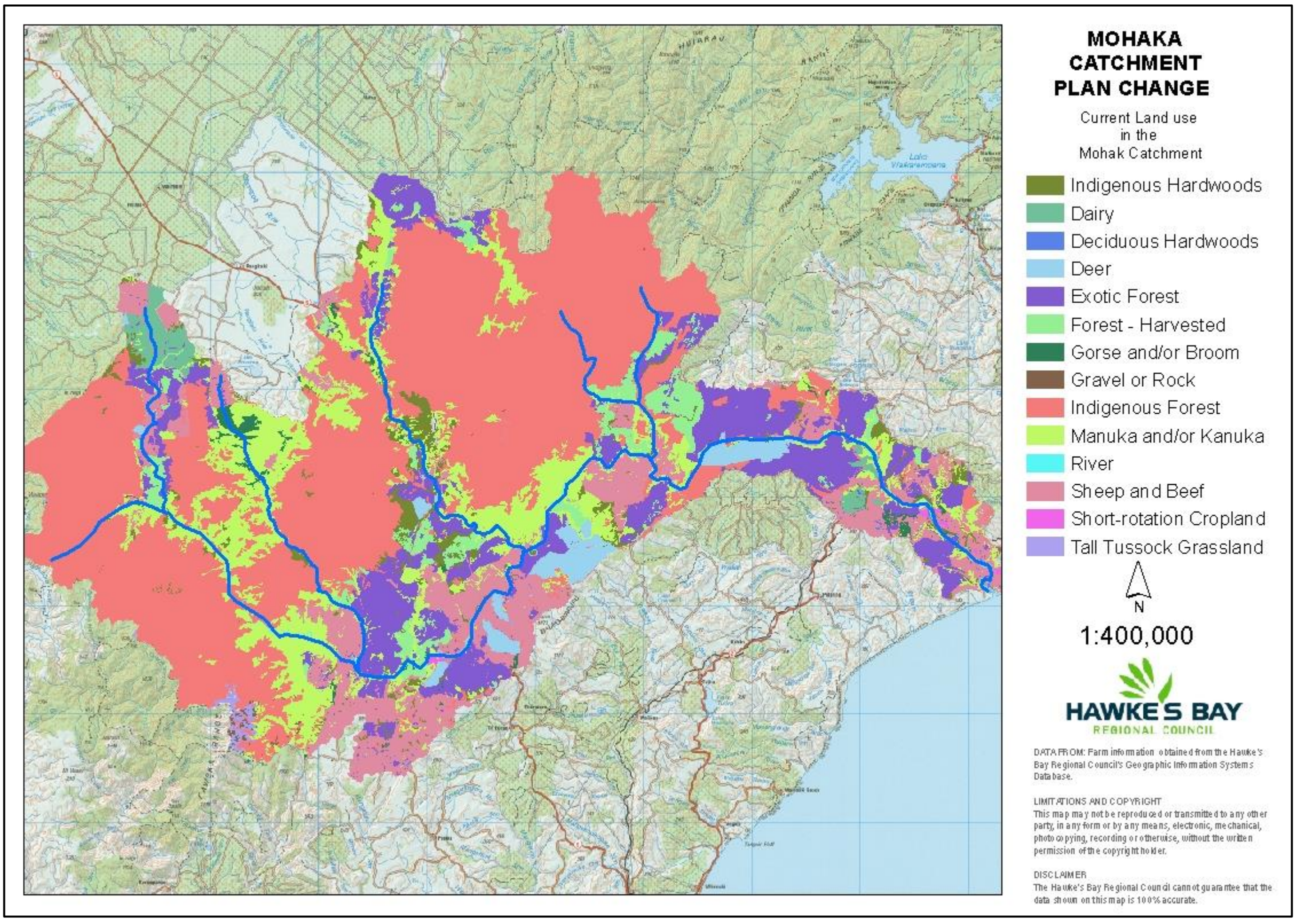


Figure 4-1: Current land use in the Mohaka catchment. Source: Agribase supplemented by LCDB 4.1

Table 4-1: Major land uses in the Mohaka catchment and their areas (Ha)

Land-use/cover	Ha	% of Catchment
Broadleaved Indigenous Hardwoods	6,408	2.6
Dairy	3,220	1.3
Deciduous Hardwoods	230	0.1
Deer	5,047	2.1
Exotic Forest	31,051	12.7
Forest - Harvested	8,910	3.7
Gorse and/or Broom	1,730	0.7
Gravel or Rock	495	0.2
Indigenous Forest	117,005	47.9
Manuka and/or Kanuka	36,220	14.8
Sheep and Beef	30,266	12.4
Short-rotation Cropland	287	0.1
Tall Tussock Grassland	725	0.3
Other land covers	2,500	1.0
Grand Total	244,092	100.0

4.2 Proposed management zones

It is proposed to categorise environmental issues within the Mohaka catchment in 3 zones – the Upper Zone: Wilderness; Middle Zone: Water Based Recreation; and Lower zone: Natural Character (Figure 4-2). This partitioning of areas may or may not be useful in future but for completeness, section 4.2 has been included in this report.

Some catchment land use is concentrated in specific Management Zones. For example, although dairy farming only covers 1.5% of the total catchment land area it covers 5.2% of the total Upper Zone: Wilderness land area.

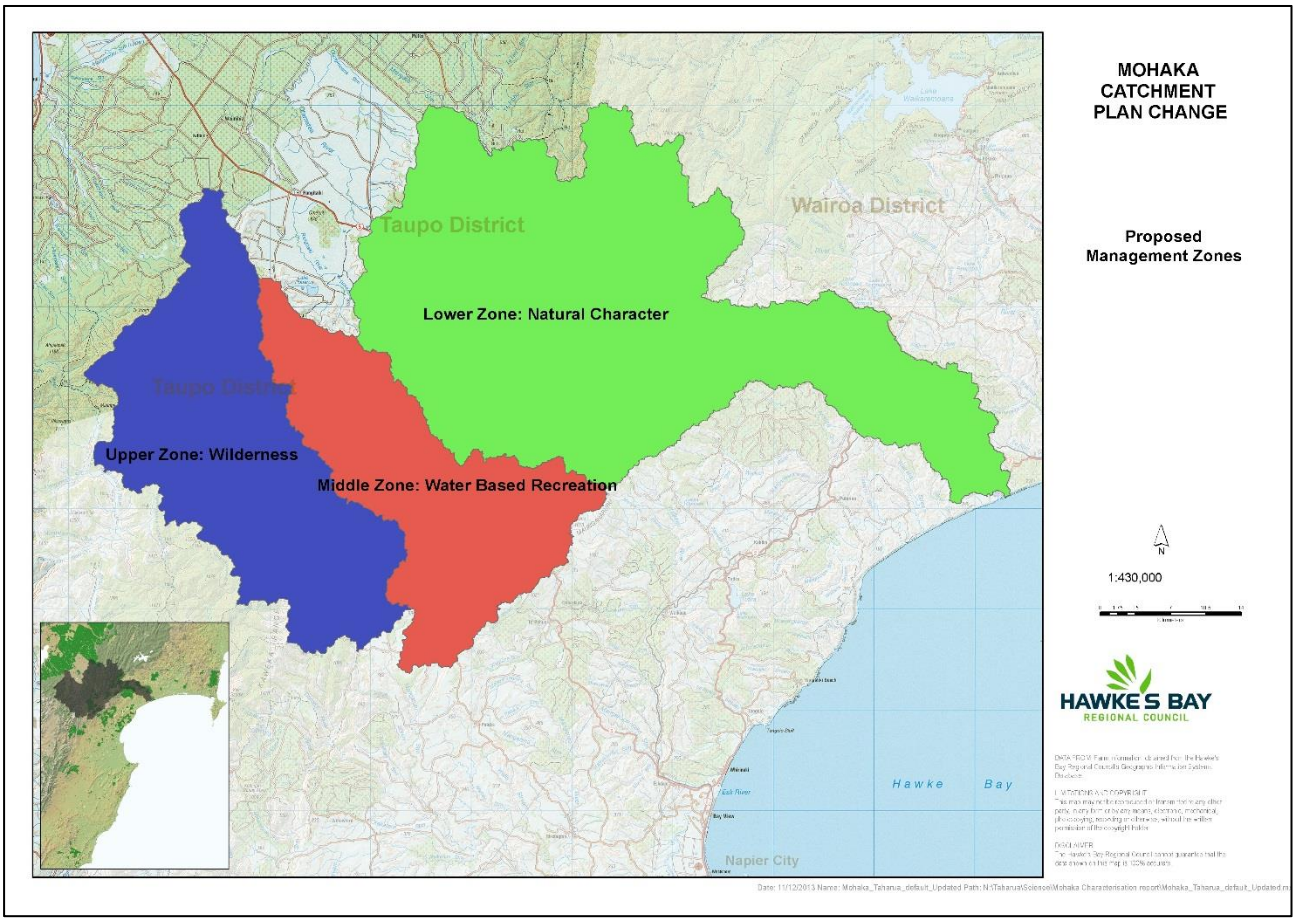


Figure 4-2: Suggested water management zones in the Mohaka catchment.

Table 4-2: Land Use in the Mohaka catchment divided by proposed Management Zones.

	Zone							
	Lower Zone: Natural Character		Middle Zone: Water Based Recreation		Upper Zone: Wilderness		Grand Total	
Land Use	Area (Ha)	% of Zone	Area (Ha)	% of Zone	Area (Ha)	% of Zone	Ha	% of Whole Catchment
Arable	233	0.2	113	0.2	0	0.0	347	0.1
Beef	2,052	1.6	75	0.2	846	1.4	2,973	1.2
Dairy	362	0.3	0	0.0	3,252	5.2	3,614	1.5
Deer	1,080	0.8	594	1.2	93	0.1	1,766	0.7
Forestry	28,674	21.9	11,940	24.2	3,596	5.7	44,210	18.2
Fruit	123	0.1	0	0.0	4	0.0	127	0.1
Native Bush	87,932	67.2	23,601	47.8	50,643	81.0	162,176	66.8
Non Productive Land	741	0.6	249	0.5	490	0.8	1,480	0.6
Sheep	611	0.5	336	0.7	0	0.0	947	0.4
Sheep & Beef	9,043	6.9	12,444	25.2	3,609	5.8	25,097	10.3
Grand Total	130,852	100.0	49,353	100.0	62,533	100.0	242,738	100.0

4.3 Determining Possible Future Land Use Intensification in the Mohaka catchment

To determine the potential for future land use intensification in the Mohaka catchment a system to identify the maximum sustainable level of intensification was required. The Land Resource Inventory/Land Use Capability index (LRI/LUC) was used (Lynn et al, 2009). This is a national database that covers every region in New Zealand and takes into account parameters such as:

- Slope
- Soil type
- Geology
- Vegetation cover
- Erosion

LUC class 1 land is versatile and able to be used in many ways. LUC class 8 land is very limited in its potential uses. By comparing the LUC against current land use, areas of land that are being used unsustainably (according to the LUC), or well within their capabilities can be identified. The LUC index is a coarse tool that does not consider how well areas of land are managed. This analysis also only predicts the area that could be intensified, but doesn't predict the degree of change that may be feasible. For example, an area of 'good quality' flat land (LUC class 1) currently in native bush could be converted either to cropping land (a substantial intensification), or to sheep and beef farming, which would be a lesser degree of intensification.

4.3.1 Possible Future Land Use Intensification in the Mohaka catchment

In section 4.1.1 the current land use in the Mohaka catchment was examined. In this section the possible future land use intensification of the catchment is investigated.

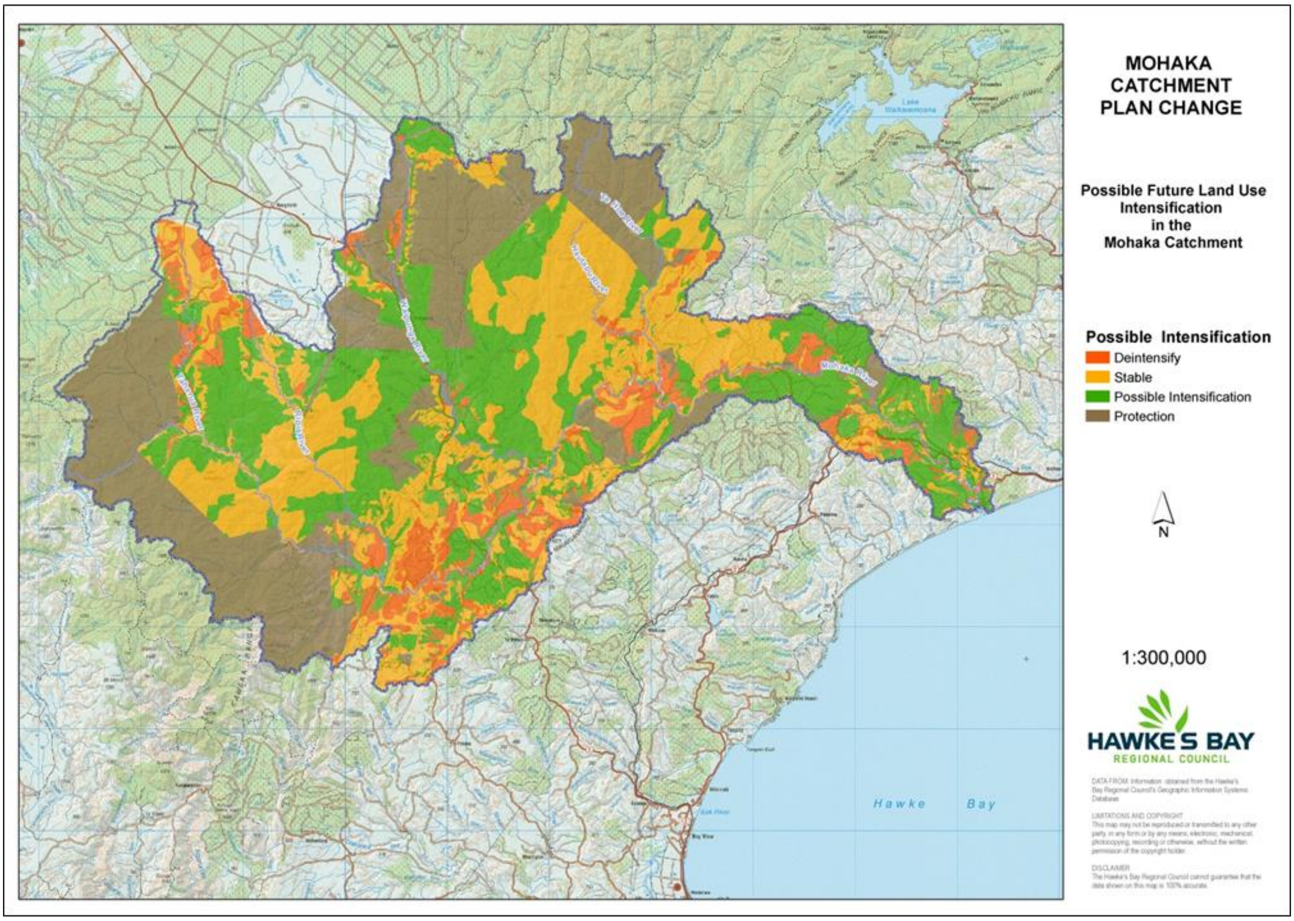


Figure 4-3: Possible future land use intensification in the Mohaka catchment as predicted by LUC.

Possible future land use intensification was estimated using the data derived from current land use and comparing it with what the land is capable of sustaining according to the LUC categorisation (see section 4.3). Figure 4-3 shows the Mohaka catchment divided up into four categories that can be described as follows;

- De-intensify: Land that according to its LUC classification is currently being used in an unsustainable way and should be de-intensified.
- Stable: Land that according to its LUC classification is currently being used in a sustainable way but land use should not be intensified.
- Possible Intensification: Land that according to its LUC classification is currently being used in a sustainable way but land use could be intensified.
- Protection: Land that is currently protected by the Department of Conservation or QEII covenants and will not change in the future.

Table 4-3 below shows the number of hectares of each classification and also the percentage of each classification on a catchment scale.

Table 4-3: Possible Land Use Intensification in the Mohaka catchment.

Current Land Use Status	Ha	% of Catchment
Too Intensive	27,326	11.1
Could be Intensified	74,666	30.3
At Maximum Intensification	73,473	29.8
Protected from Intensification	70,963	28.8
Total	246,428	100.0

From Figure 4-3 and Table 4-3 there are indications that it may be possible to introduce a more intensive land use into 30% of the catchment. However in reality this amount of intensification is unlikely to occur because most land that could be intensified is currently in native or commercial forest, and in most cases the steep terrain makes it impractical to change to alternative land uses. For example, 82% of land in the Mohaka catchment has a slope greater than 20 degrees and 61% of the land has a slope greater than 26 degrees (Figure **4-4** and Table 4-4) making it difficult to utilise for anything other than forestry.

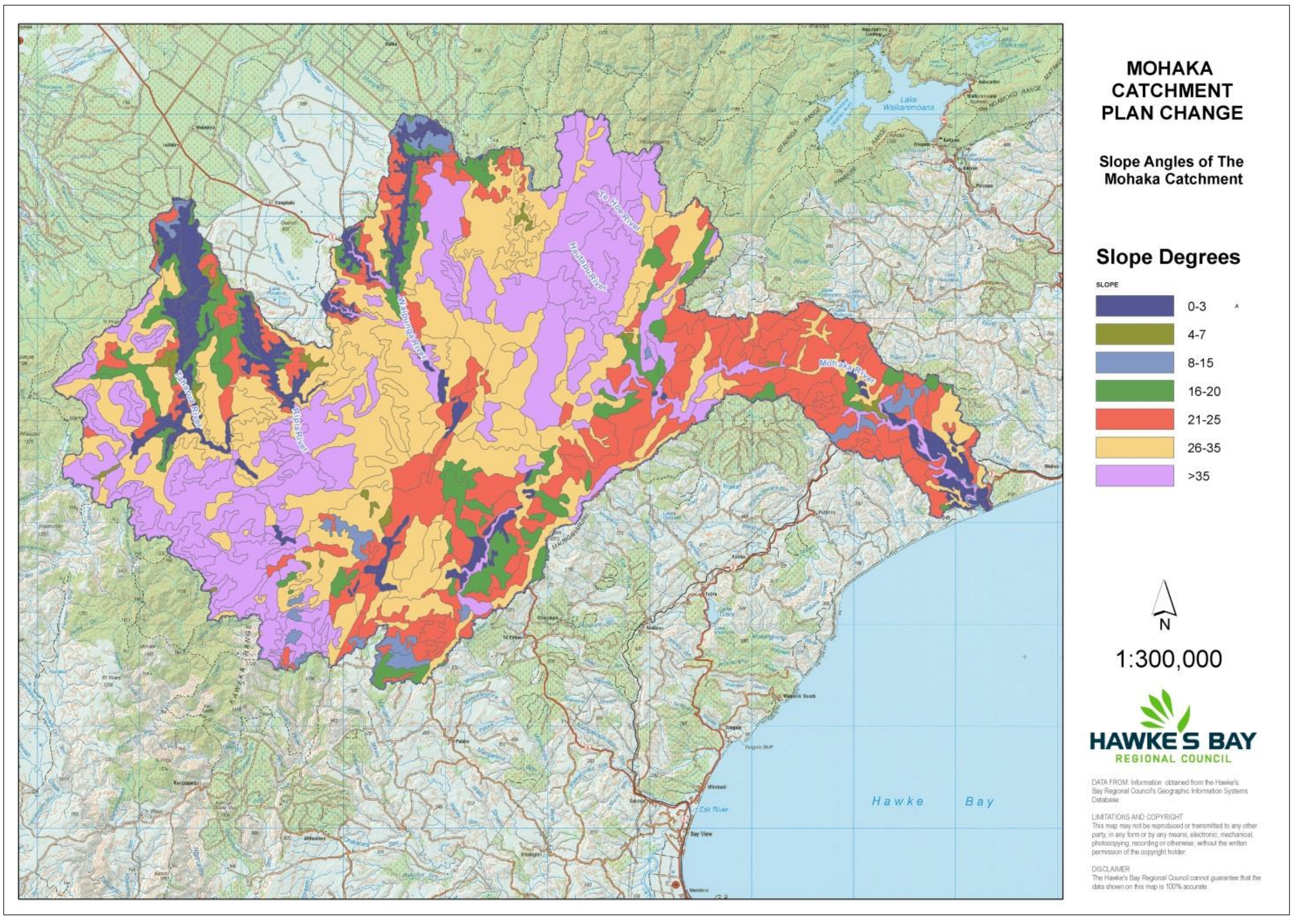


Figure 4-4: Land slope angles in the Mohaka catchment.

Table 4-4: Slope gradient break down in the Mohaka catchment.

Slope degrees	Total area (ha)	% of catchment
0-3	16,643	7
4-7	1,911	1
8-15	4,888	2
16-20	18,128	7
21-25	52,218	21
26-35	80,713	33
>35	69,344	28
	243,845	100

Approximately 11% of the Mohaka catchment is being used in an unsustainable manner (Table 4-3). Although this may not be ideal, this assessment does not reflect the degree to which the land is being used outside its suggested capability according to LUC. This issue needs further investigation to determine whether it is significant.

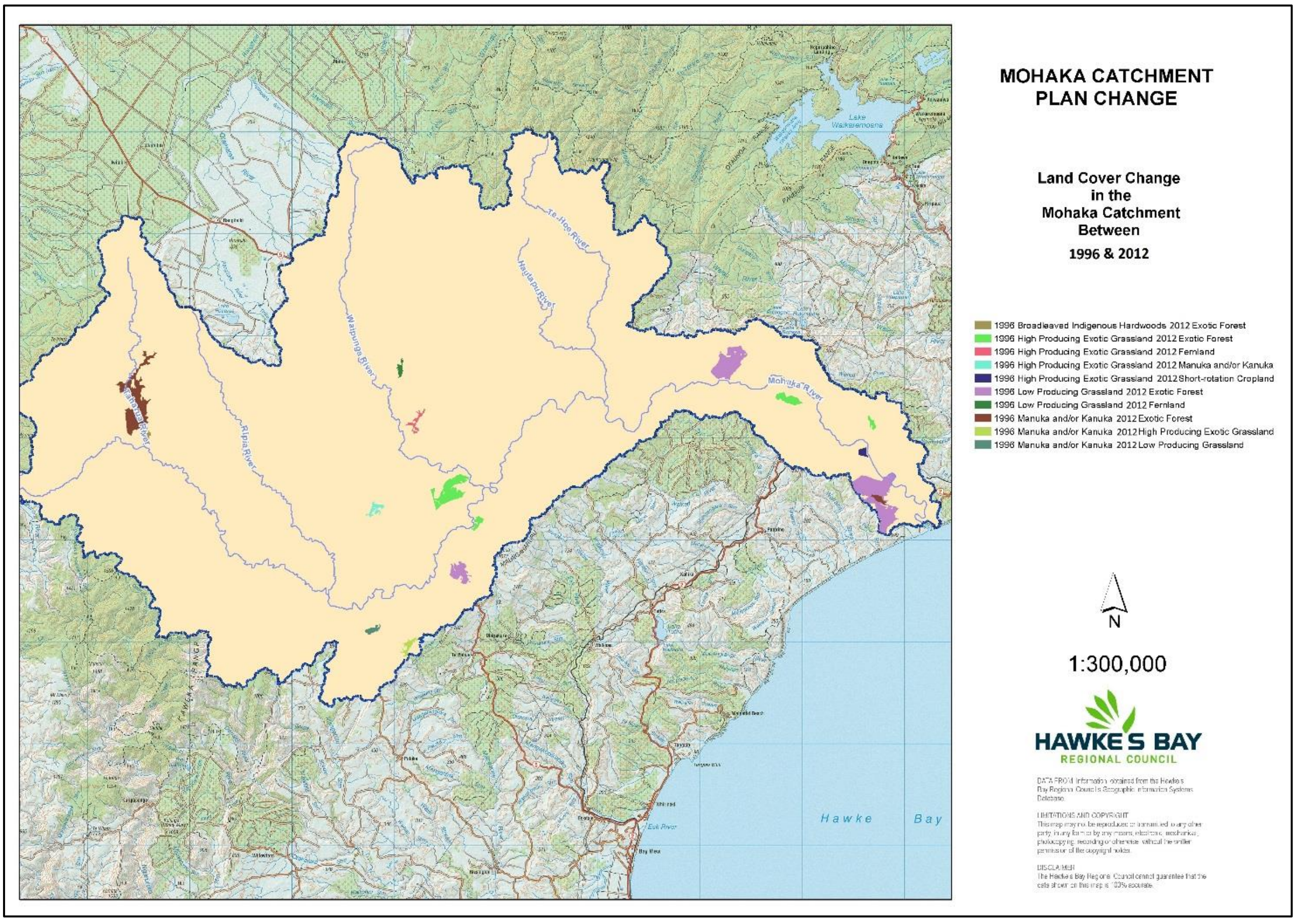
4.4 Land use change

Land use change in the Mohaka catchment has been negligible during the period covering 1996-2012 (Figure 4-5). This period has been chosen as this is the latest period that be covered using the LCDB databases (see section 4.1).

It is estimated that 4,391 ha of land changed land use between 1996 and 2012, with 90% of this change being conversion of land to commercial forestry (Table 4-5).

Table 4-5: How Land Cover has Changed in the Mohaka catchment Between 1996 and 2012.

Land Cover Change in the Mohaka catchment between 1996-2012			
1996	2012	Total (Ha)	% Change
Broadleaved Indigenous Hardwoods	Exotic Forest	71	1.6
High Producing Exotic Grassland	Exotic Forest	790	18.0
High Producing Exotic Grassland	Fernland	91	2.1
High Producing Exotic Grassland	Manuka and/or Kanuka	94	2.1
High Producing Exotic Grassland	Short-rotation Cropland	59	1.4
Low Producing Grassland	Exotic Forest	2,000	45.5
Low Producing Grassland	Fernland	63	1.4
Manuka and/or Kanuka	Exotic Forest	1,058	24.1
Manuka and/or Kanuka	High Producing Exotic Grassland	95	2.2
Manuka and/or Kanuka	Low Producing Grassland	70	1.6
Grand Total		4,391	100.0



Note: Beige colour signifies no land use change

Figure 4-5: Land Cover Change between 1996 and 2012 in the Mohaka catchment.

The data used to identify land use change in the Mohaka catchment are derived from aerial imagery and from ground truthing carried out between 1996 and 2012. Other land cover changes in the catchment since 2012 include 2000 ha of eucalyptus trees being cleared from the Poronui Station in the Taharua sub-catchment. These data need to be updated and it is anticipated that HBRC will undertake this work in the near future.

4.5 Topography

The topography of the Mohaka catchment restricts the amount of intensification that can take place. The terrain of the upper and middle Mohaka catchment is heavily incised by river channels making access to many areas difficult (Figure **4-6**).

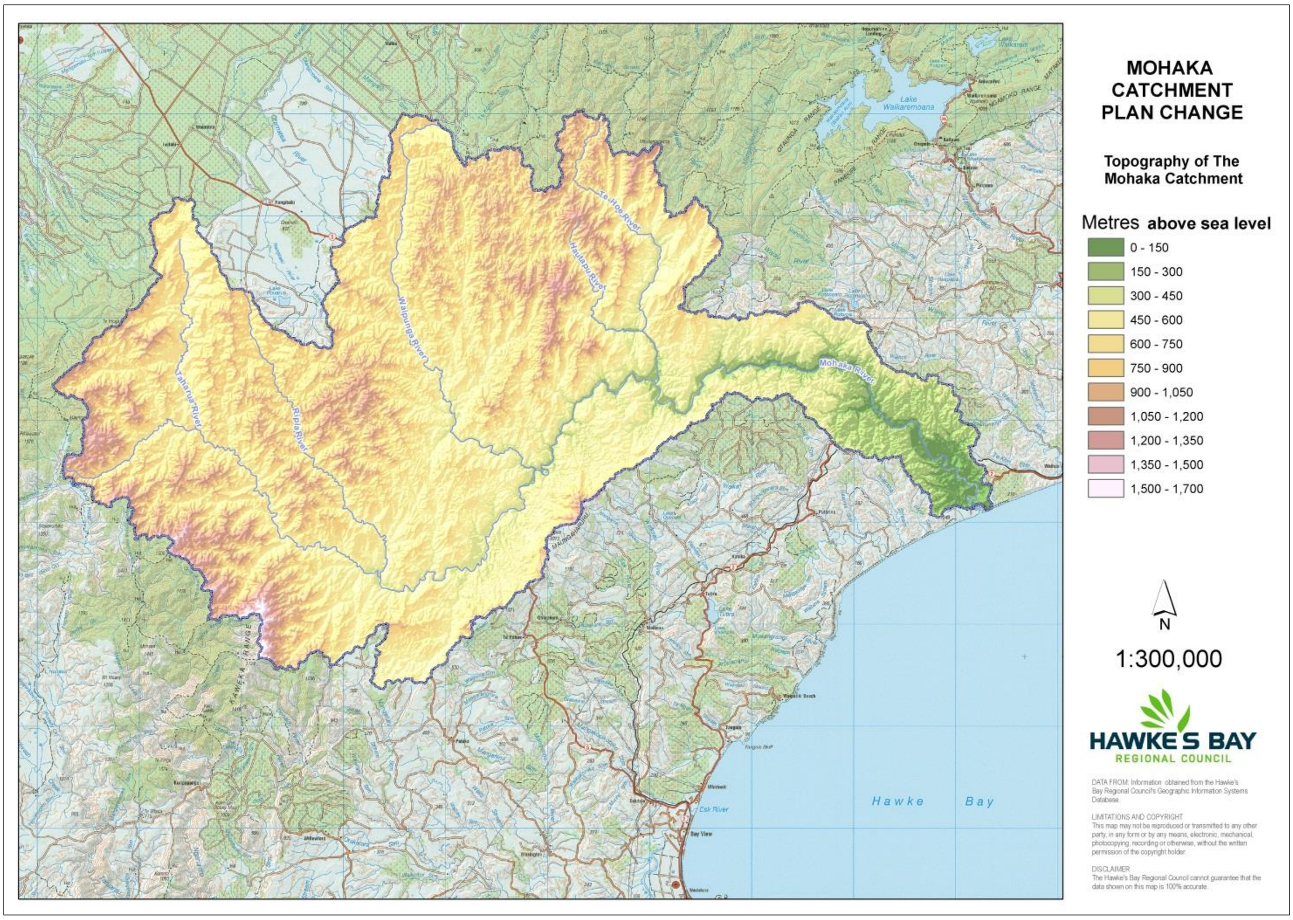


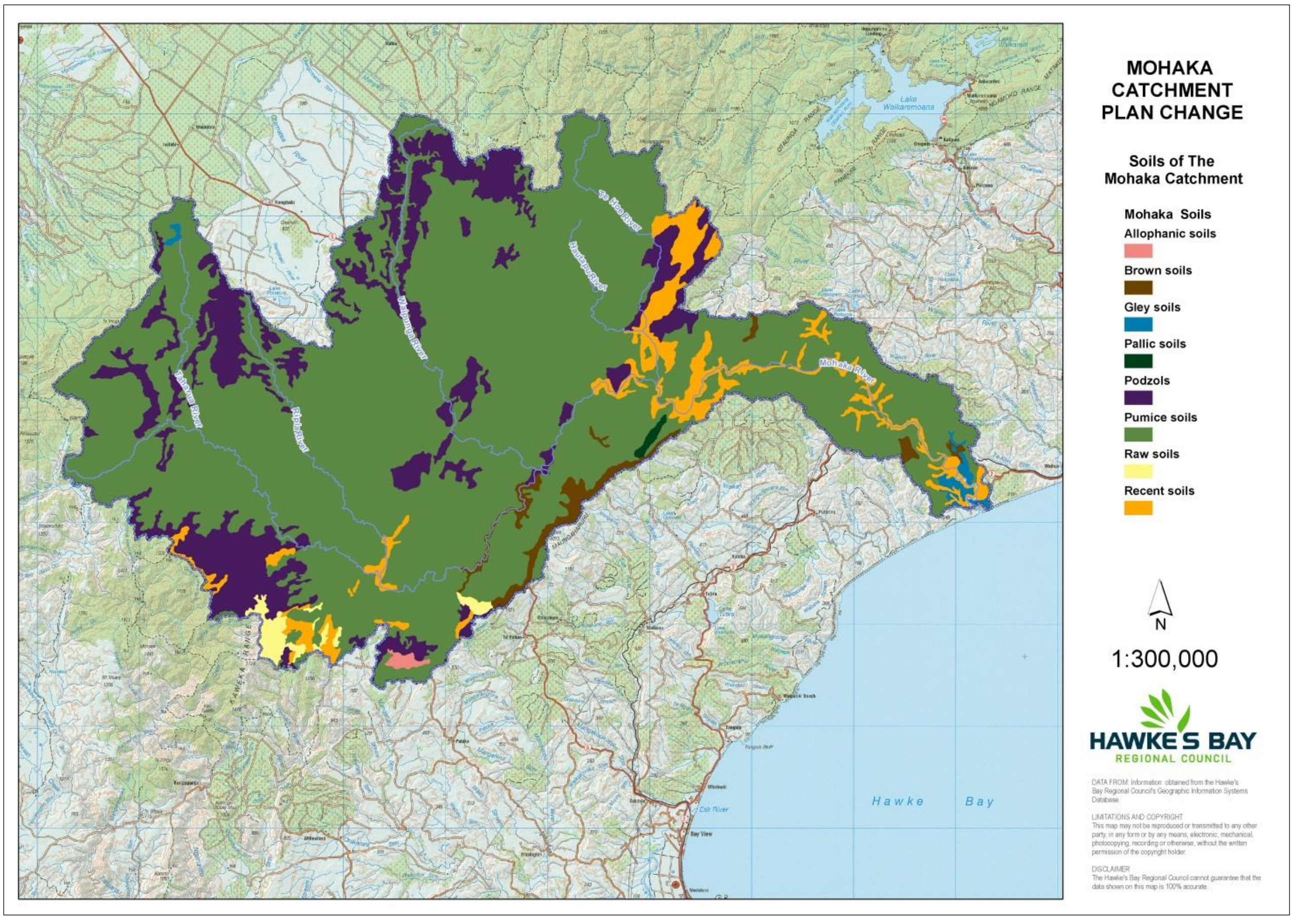
Figure 4-6: Topography of the Mohaka catchment.

4.6 Soils of the Mohaka catchment

The Mohaka catchment is dominated by pumice soil, which comprises more than 77% of the catchment soils (Table 4-6). The pumice soil is derived from two volcanic eruptions from the ancient Taupo volcano (now marked by Lake Taupo). The first eruption occurred approximately 26,500 years ago while the second occurred much more recently, approximately 1,800 years ago. These eruptions ejected millions of tonnes of rock and ash that covered the Mohaka catchment region and beyond.

There are two other significant soil orders in the catchment area (Table 4-6 and Figure 4-7). These are podzols and recent soils. Podzols are strongly acidic soils usually associated with areas of high rainfall and forests that produce acid litter. Recent soils, as the name would suggest are young soils, usually not more than 1000-2000 years old. They form on new land surfaces such as alluvial plains, unstable slopes or soils mantled with young volcanic ash.

A description of the other soil orders can be found on the Landcare Research soils classification web page.[2] Soil information presented below is taken from the Fundamental Soils Layer (LRIS, 2016a).



DATA FROM: Information obtained from the Hawke's Bay Regional Council's Geographic Information Systems Database.

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The Hawke's Bay Regional Council cannot guarantee that the data shown on this map is 100% accurate.

Figure 4-7: Soil Orders of the Mohaka catchment.

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[2] https://soils.landcareresearch.co.nz/describing-soils/nzsc/soil-order/recent-soils/

Table 4-6: Soil Orders by land area in the Mohaka catchment.

Soil Type	Area (ha)	% of Catchment
Allophanic	444	0.2
Brown	3,857	1.6
Gley	1,118	0.5
Pallic	367	0.2
Podzols	34,656	14.3
Pumice	187,877	77.3
Raw	1,396	0.6
Recent	13,457	5.5
Total	243,172	100.0

4.7 Estimated Nitrogen loss from the Mohaka catchment

Nitrogen loss from land is one of the most important issues currently facing farming. This is not just a local issue but a national issue and one that is of concern in some areas of the Mohaka catchment.

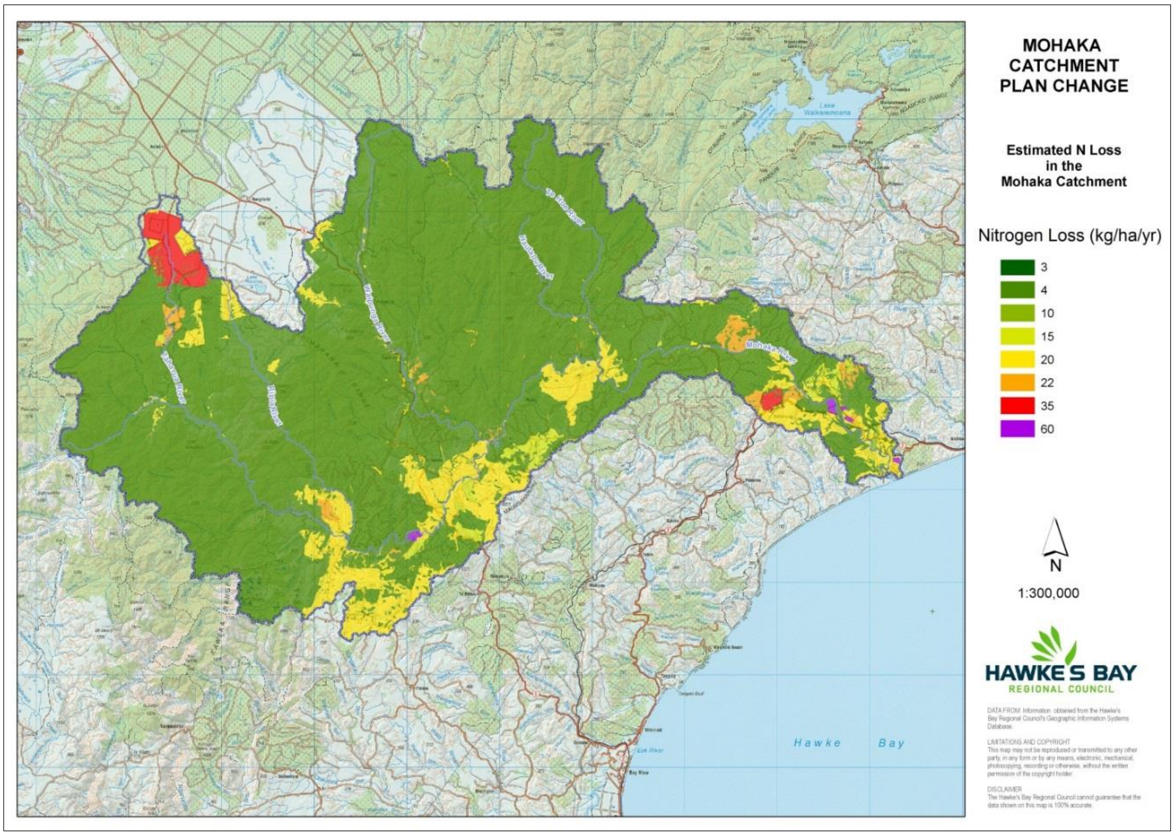

Figure 4-8: Estimated Total Nitrogen Loss from the Mohaka catchment (kg/ha/yr).

By using the land use map (Figure 4-1) a generic nitrogen loss coefficient can be applied to each land use found in the Mohaka catchment. These coefficients are a general assumption and derived from literature (Menneer 2004) and expert opinion. Obviously nutrient loss is based on land management practices so Figure 4-7 is only meant as a relative guide. Table 4-7 shows the N loss values that have been used and it is understood that these values can show a considerable variation from farm to farm.

Table 4-7: Generic Nitrogen Loss Coefficients.

Land Use	N Loss (kg/ha/yr)
Arable	60
Beef	22
Dairy	35
Deer	15
Forestry	4
Fruit	10
Native Bush	4
Non-Productive Land	3
Sheep	15
Sheep and Beef	20

When the values presented in Table 4-7 are assigned to the land use distribution shown in Figure 4-1, a new map is produced that shows the variation in predicted nitrogen loss across the catchment. Generally there is relatively low nitrogen loss across the catchment (Figure 4-8). There are however some areas that do show high losses. The red areas reflect the areas of dairying within the catchment and the small purple areas denote areas of cropping (as mentioned earlier). Despite these areas being classed as relatively high nitrogen loss areas, this may not inevitably lead to environmental problems. A link to surface water or groundwater needs to be in place and even then other factors such as natural attenuation in the soil can reduce any effect.

Using the values stated in Table 4-7 it is estimated that annually the Mohaka catchment loses 1,587 tonnes of Total Nitrogen from land each year. Table 4-8 shows a breakdown of nitrogen loss by sub-catchment. A large proportion of the nitrogen that is lost from the land will find its way to either ground water or directly to surface water. As nitrogen is transported through the soil profile some of it will be attenuated (used up) through microbial and geochemical processes.

Table 4-8: Estimated Total Nitrogen Loss from the Mohaka catchment by Sub-catchment.

Mohaka Sub -catchment	Area of Sub-catchment (Ha)	Tonnes of Nitrogen Lost per Year	Average nitrogen lost (kg/ha/yr)
Hautapu	36,911	155	4
Kaipo	5,219	21	4
Lower Mohaka	31,940	285	9
Middle Mohaka	36,273	370	10
Oamaru	6,552	27	4
Otapua	3,377	17	5
Puneketoro	9,363	48	5
Ripia	18,620	96	5
Taharua	12,750	177	14
Upper Mohaka	34,636	183	5
Waipunga	47,097	209	4
Total	242,738	1,587	7

4.8 Summary and conclusions- Land Resource and Land Use

From a ‘land’ perspective the Mohaka catchment is generally in a very healthy state. Most of the catchment is in native bush, with the next biggest land use/cover being commercial forestry. There is scope for land use intensification in the catchment, but large scale intensification is unlikely due to the high relief and difficulty of access to land in the catchment (see section 4.3). It is possible that commercial forestry could expand within the region. However, forestry is generally considered one of the ‘less intensive’ land use systems and expansion of forestry should not detrimentally affect the ecological ‘health’ of Mohaka catchment. However, there are areas of concern in the upper catchment due to nutrient losses from dairy farms that have affected water quality and ecosystem health in both the Taharua River and the upper Mohaka River. This issue is currently being addressed with the help of the farmers concerned and other stake holders.

5 Geology and Groundwater Resources of the Upper, Middle and Lower Zones of the Mohaka catchment

5.1 Regional Geological Setting

The east coast of New Zealand is on a colliding plate boundary, between the Australian plate to the west and the Pacific plate to the east (Lee et al., 2001). The Hawke's Bay region is located where the Pacific plate to the east is subducting (moving beneath) the Australian plate in the west (Figure **5-1**). North-south faulting activity and volcanic eruptions centred on the Taupo Volcanic Zone are related to the subduction of the Pacific plate beneath the North Island.

Compressional processes along the plate boundary have produced extensive faulting and folding of marine sediments that have accumulated, uplifted and accreted against the North Island axial ranges (Figure **5-1**). The North Island axial ranges (Ahimanawa, Kaweka and Kaimanawa ranges) have been uplifted as part of the plate compressional processes and form the upper boundary of the Mohaka catchment.

The Ahimanawa, Kaweka and Kaimanawa ranges in the upper catchment are primarily composed of weakly metamorphosed sandstone and mudstone accreted against the margin of the Gondwana super continent 145 million years ago (late Mesozoic Era) (Lee et al., 2011). To the east of the ranges are Miocene and Pliocene age (24 to 1.8 million years old) marine and terrestrial sedimentary mudstones, sandstone and limestone that were deposited in sedimentary basin (East Coast forearc basin) on top of an erosional surface of the late Mesozoic era (145 to 65 million years B.P) basement greywacke rock(Lee et al., 2011). This rock is form much of the basement rock of the North Island

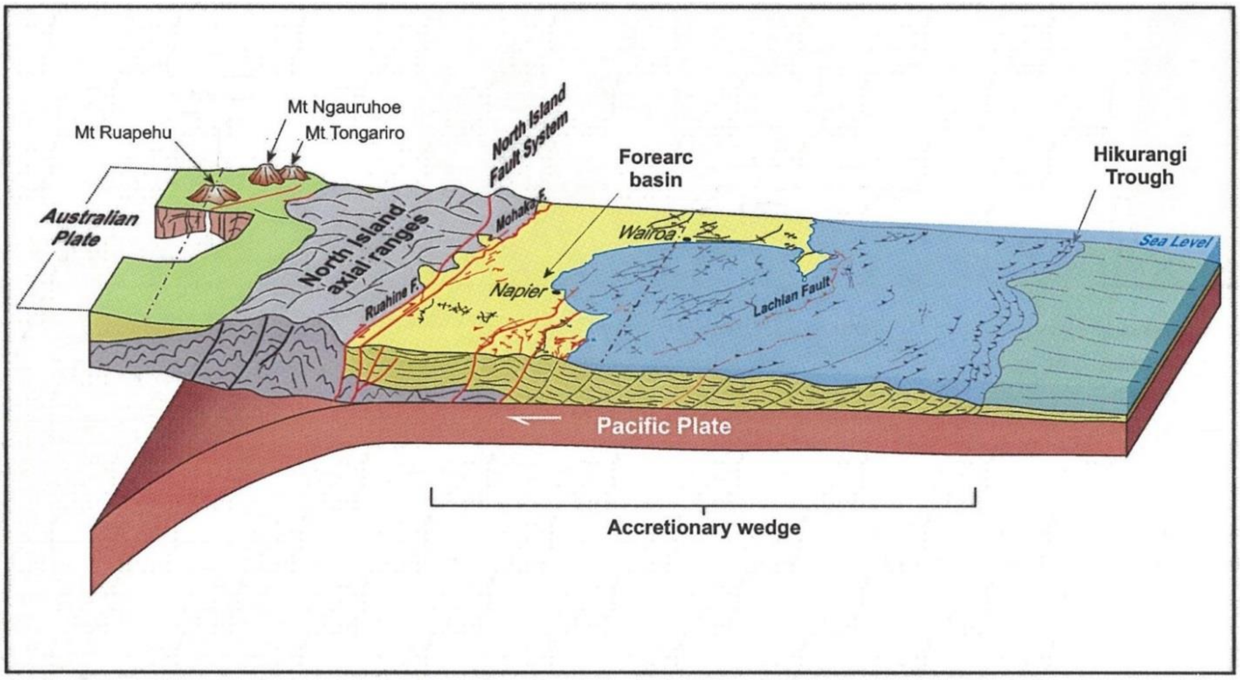

Figure 5-1: Interpretation of the current tectonic and geological setting of the Hawkes Bay and Mohaka catchment. (After Lee et al., 2011)

The Miocene and Pliocene age sedimentary rocks were then uplifted by tectonic faulting and folding, forming the topographical highs exposed at the eastern edge of the mid and lower sections in the Mohaka catchment as shown in Figure 5-2 (Lee et al., 2011).

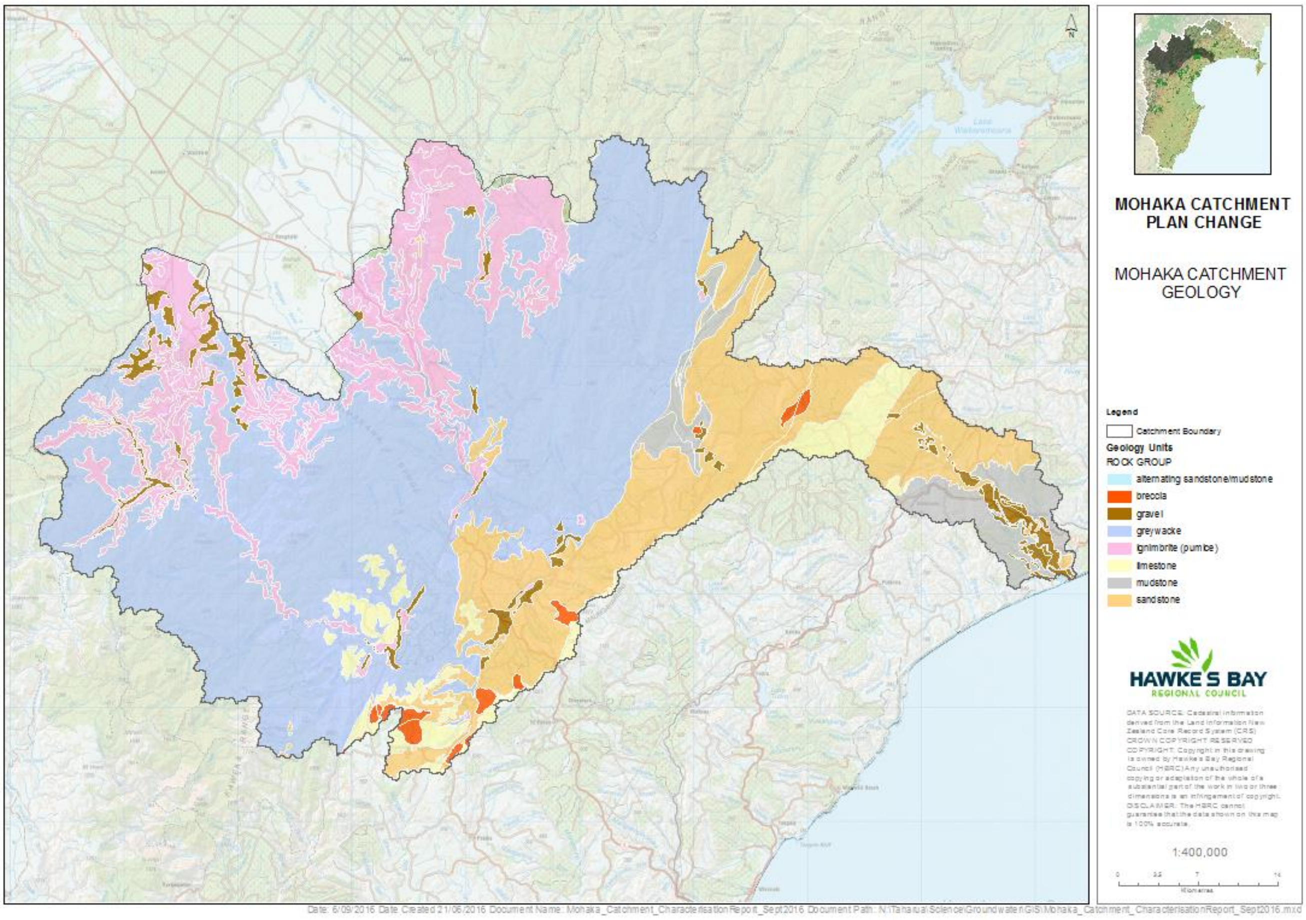

Figure 5-2: Mohaka catchment Geology (After Lee et. al. 2011).

Tectonic movement along the Mohaka fault has resulted in a distinct geological boundary between the greywacke to the west and the younger Miocene and Pliocene age sedimentary rocks of the East Coast basin.

To the west of the upper Mohaka catchment boundary is the Taupo Volcanic Plateau which extends over most of the Central North Island. The Taupo Volcanic Plateau was formed from successive eruptions from the Taupo Volcanic Zone (TVZ) during the last 500,000 years. These eruptions deposited volcanic ash, pumice and ignimbrites over the steep sided catchments of the upper Mohaka catchment (Figure 5-3). Erosion of the greywacke, sedimentary rocks and TVZ volcanic material has resulted in gravels and volcanoclastic pumiceous sediments deposited as river valley terraces (Cutten, H.N.C., 1994; Lee et al., 2001.).

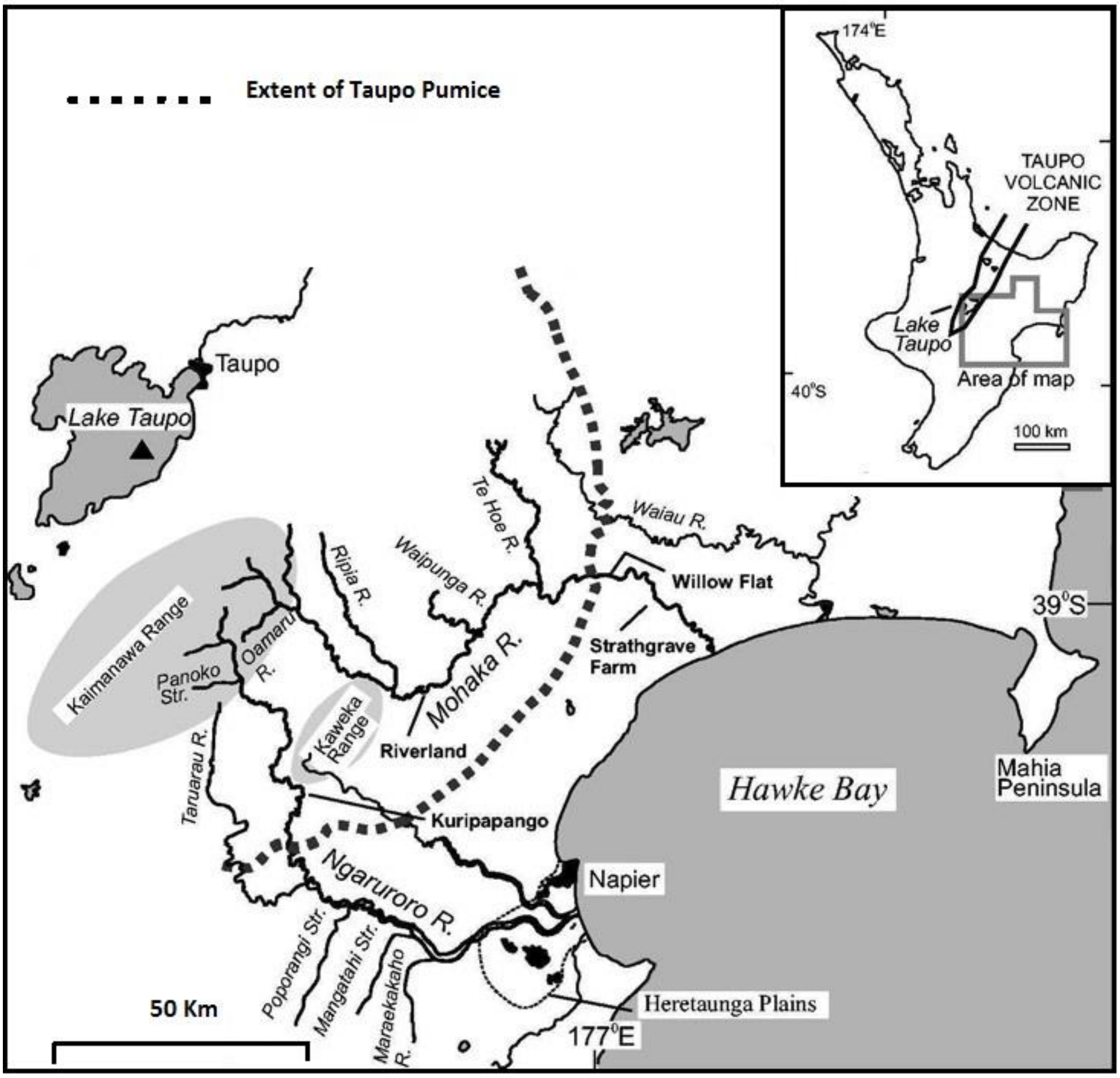

Figure 5-3: Taupo Pumice eruption 1800 years B.P., was an explosive volcanic rhyolitic eruption from a vent located beneath Lake Taupo. The dotted line indicates the extent of the ignimbrite from the Taupo eruption sequence (after Segschneider et al., 2002).

5.2 Mohaka catchment Geology

The main types of geological formations in the Mohaka river catchment are summarised in Table 5-1. Greywacke argillite is the oldest rock predominately exposed rock type in the western catchment composing which makes up the steep rugged Ahimanawa, Kaweka and Kaimanawa mountain ranges of the upper and mid catchment, that rise up to 1700m above sea level. Erosion of the greywacke rock over millions of years has formed the deeply incised valleys of the upper and mid catchments. The structural trend of the Miocene and Pliocene formations is to the northeast with a gentle regional southeast dip, producing a series of steep northwest-facing fault scarp slopes such as the Maungaharuru Ranges. The fault scarps were formed by tectonic faulting and folding pressures. Below the escarpments, hills have been formed by slumping and erosion (Cutten, H.N.C., 1994; Lee et al., 2001).

Table 5-1: Geological formations found in the Mohaka catchment.

Relative	Geological Unit	Geological Era	Geological epoch	Age (Millions of years) B.P	Catchment Zone exposure
Oldest	Greywacke (argillite) basement Weakly metamorphic hard sedimentary sandstone and mudstones.	Mesozoic	Jurassic to Cretaceous	145 – 65	Upper and mid
	Sedimentary sandstone, mudstones, and limestone.	Tertiary	Miocene	24 - 5	Mid and lower
	Sedimentary sandstone mudstone, siltstone and limestone.	Tertiary	Pliocene	5– 2	Mid and lower
	Volcanic ignimbrite rock and unconsolidated pyroclastic (pumice) flows and ashes.	Quaternary	Early Pleistocene to Holocene	2 - 0	Upper and mid
Youngest	Alluvium - unconsolidated terrace gravels and pumiceous sands.	Quaternary	Late Pleistocene to Holocene	0.2 - 0	All catchments

The catchment drainage is controlled by the northeast structural trend. Thus, the Mohaka River generally meanders east, but is deflected to the north by uplifted, erosion-resistant Miocene and Pliocene sandstones and mudstones of the Maungaharuru range (Cutten, H.N.C., 1994). The Mohaka fault forms the major boundary between the greywacke and younger, softer sedimentary rock formations.

The Mohaka River flows northeast along the Mohaka fault zone and then cuts through the Maungaharuru range at Maungataniwha, upstream of the confluence with the Te Hoe River sub-catchment (Hawkes Bay Catchment Board & Regional Water Board, 1985). The river then travels southeast through the Miocene and Pliocene age mudstone, sandstone and limestone sediments before a succession of progressively lower marine terraces near Willowflat, to emerge at the sea. Changing sea levels during glacial and interglacial periods for the past 250,000 years, along with tectonic uplift, have created river terraces at different elevations.

In the upper and middle catchment zones, hard consolidated volcanic ignimbrites from the Taupo Volcanic zone have been mapped (Lee et al., 2011) in the Taharua, upper Ripia and Waipunga sub-catchments. These are collectively known as the Whakamaru group ignimbrites and have been dated at between 330,000 and 340,000 years (Brown S.J.A. et al., 1998) old. On the eastern side of the Taupo Volcanic Plateau, the ignimbrite formations are known as the Te Whaiti and Rangitaiki ignimbrites (Figure 5-4).

The Taupo eruption in 1800 B.P then infilled the valleys of the Taharua, upper Ripia and Waipunga sub-catchments with unconsolidated ignimbrite composing of pumice and ash within the steep sided greywacke valleys, as the molten pyroclastic (ash and pumice) material flowed down valleys. This was accompanied by air fall ash and pumice that mantled much of the Mohaka catchment. Following this eruption, new river and stream drainage networks have subsequently cut through the unconsolidated Taupo ignimbrite and have incised within degradation terraces (Segschneider, 2000). These terraces are mostly derived from eroded tephra, volcanic ash, pumice and rock fragment material that have redeposited from the steep greywacke ranges as pumice alluvium in the current river and stream valleys. Some alluvial river terrace deposits eroded from greywacke ranges are also found in the upper Mohaka river catchments (Segschneider, 2000).

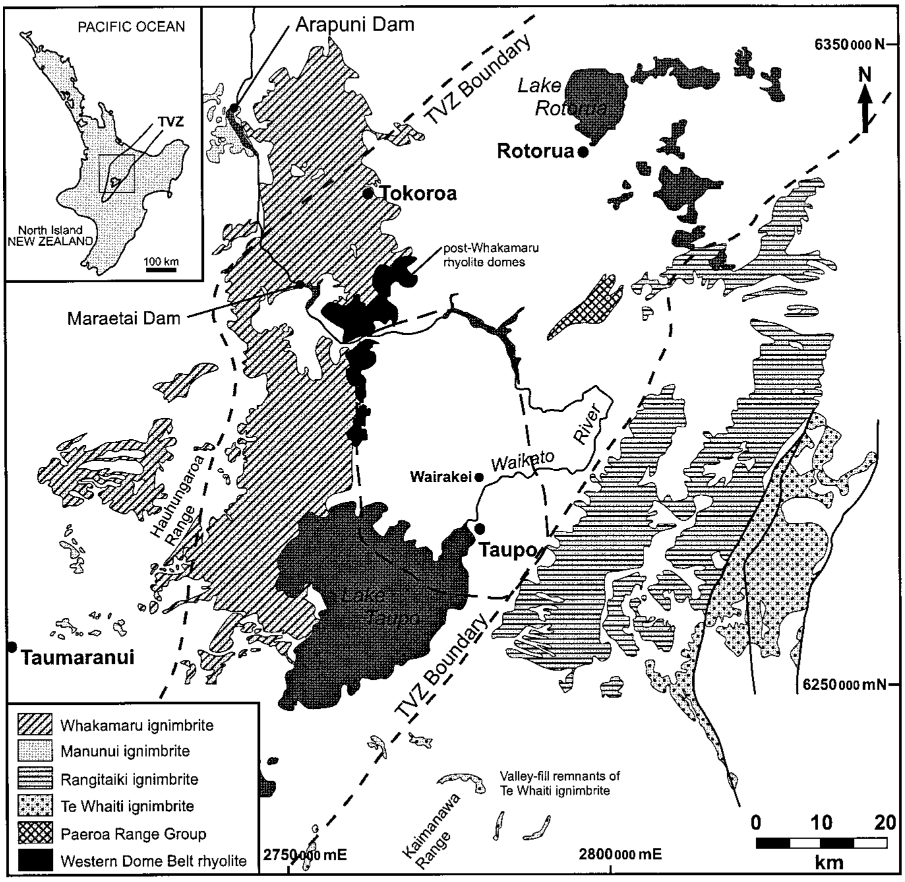

Figure 5-4: Distribution of Whakamaru group ignimbrites outcropping on the central volcanic plateau and upper Mohaka catchments, (after Brown et al., 1998). The dashed line enclosing an area north of Lake Taupo is the inferred Whakamaru caldera as proposed by Wilson et al. (1986).

5.3 Taharua Valley Sub-catchment Geology

The Taharua valley sub-catchment is confined by the Kaimanawa Ranges to the west and Ahimanawa ranges to the east, with the Central Volcanic Plateau to the north. The broad flat area of the Taharua valley is approximately 5-6 km at the widest point and narrows at the confluence with the Mohaka River. The ranges that confine the valley are composed of greywacke argillite that has been infilled with volcanic ignimbrites and alluvium.

The Whakamaru group ignimbrite sequence is exposed at depth in the catchment as the Rangitaiki ignimbrite, which is a sub-unit of the Whakamaru group sequence. The Rangitaiki ignimbrite has been mapped on the surface at the margins of the valleys and is a strongly welded hard rock formation. The ignimbrite rock is observed to form the stream bed of the Taharua River in the mid to lower sections of the valley.

The Whakamaru ignimbrite sequence is overlaid by unconsolidated sequences of ash, tuff and pumice, along with crystalline to glassy deposits, derived from Lake Taupo volcanic centre eruptions. The prevalent formation is the Taupo ignimbrite that erupted 1800 years B.P. This formation covers the Taharua valley in the northern and middle reaches of the Taharua River sub-catchment. The Taharua River has subsequently cut through Taupo ignimbrite in the valley and become incised (Segschneider, 2000). The valley narrows towards the south and down gradient, where the Taupo ignimbrite is likely to lap onto the greywacke argillite basement rock of the valley walls.

5.4 Groundwater Resources of the Mohaka catchment

Most known groundwater bores in the catchment are either in the Taharua catchment or the lower Mohaka catchment (Figure 5-5). The bores in the mid and lower catchment are drilled into sedimentary rock formations: limestone, sandstone or mudstone. The deepest known bore in the sedimentary rock is 140 m deep although most bores range in depth between 40 m and 80 m. The bores in this formation are typically low producing (2 L/s or less) and only known to be used for stockwater supplies. Some bores in the mid and lower catchments penetrate shallow gravel river terraces and are typically less than 10 m deep.

There is no information available that identifies the hydraulic properties (such as hydraulic conductivity, or storativity) of the sedimentary formations. There is unlikely to be a significant groundwater resource in the mid and lower catchment zones, because the intrinsic hydraulic properties of limestone, sandstone and mudstone formations are typically lower yielding, with limited fracture flow. Water yields from shallow bores that penetrate greywacke gravels associated with the river channels are likely to be more productive. These shallow bores are also likely to have strong hydraulic links with surface water flows of the Mohaka River main stem and tributary streams. In general, there is unlikely to be a significant groundwater resource in mid to lower Mohaka catchment zones because of the hard rock geology of the catchments. Further investigations would be needed to confirm groundwater resources in these zones.

There is no catchment specific groundwater information available for the mid- and lower-Mohaka catchment zones to assess groundwater nutrients. In general, there is unlikely to be a significant groundwater resource in these zones because of the hard rock geology of the catchments. Further investigations would be needed to confirm groundwater resources in these catchments.

Water bearing units in the Taharua catchment have been found within Rangitaiki ignimbrite, greywacke gravels and Taupo pumice formations. Bores drilled into these formations currently provide sufficient water to supply the existing needs of dairy and dry stock farms, along with the Poronui tourist fishing lodge. There is likely to be a significant amount of aquifer storage within Rangitaiki ignimbrite greywacke gravels because of large thickness of the units. However, there is currently no available information to confirm the hydraulic properties and to assess the availability and sustainability of the water bearing units of the Rangitaiki ignimbrite, greywacke gravel or Taupo pumice formations. In general, there is unlikely to be a significant groundwater resource in mid to lower Mohaka catchment zones because of the hard rock geology of the catchments. Further investigations would be needed to confirm hydraulic properties and to assess the availability and sustainability of the resource.

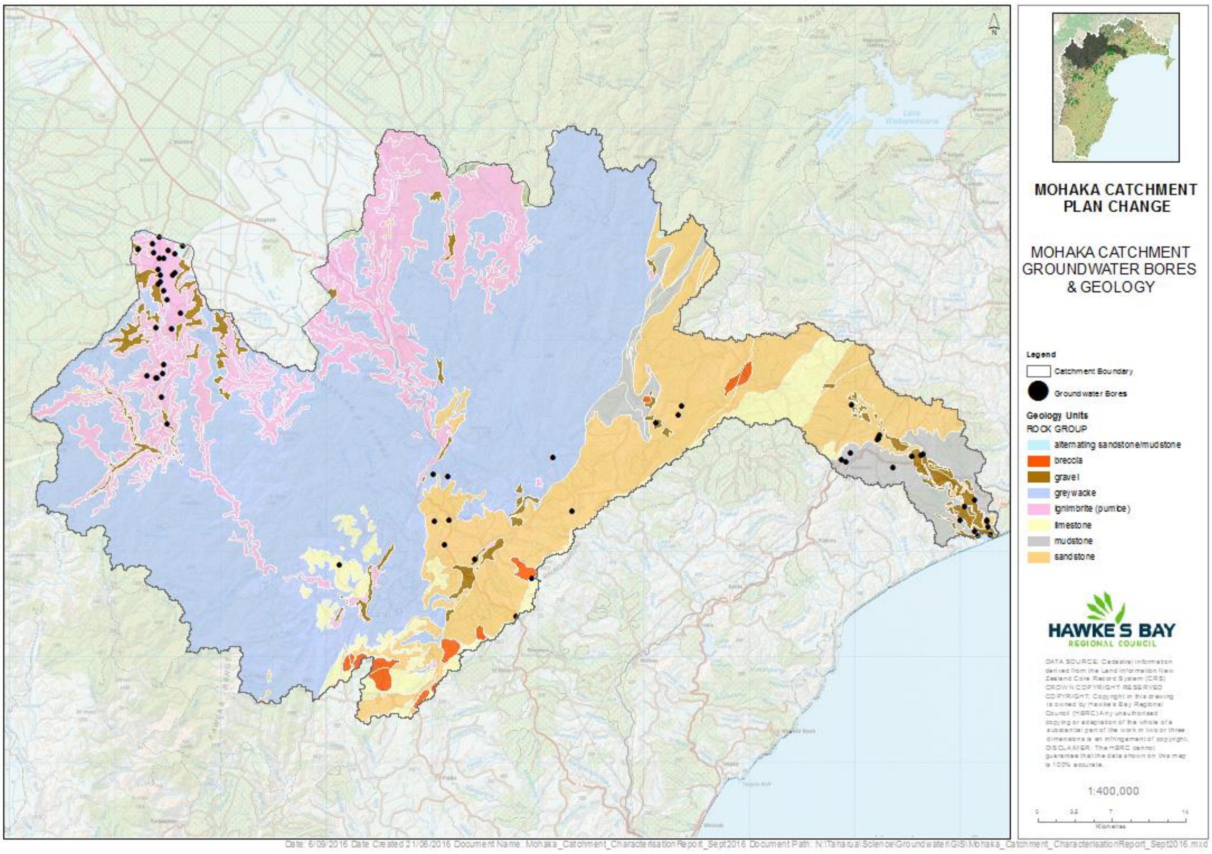

Figure 5-5: **Location of known groundwater bores in the Mohaka catchment.**

5.5 Groundwater Allocation

Driller's logs indicate that most groundwater taken in the Mohaka catchment is used for domestic and stockwater supplies. Details of the consented groundwater abstractions are presented in Table 5-2. Locations of the three consented takes in the lower Mohaka catchment are shown in Figure 5-6. Water from 2 of the consented takes is used for irrigation. The first irrigation take is for 54 L/s from a shallow bore, penetrating gravels close to the river channel, while the other is for 50 L/s from an infiltration gallery. The third consented take is for 1 L/s from a 92m deep, uncased bore for diary wash down.

Table 5-2: **Consented groundwater use in the lower Mohaka catchment.**

Consent No.	Purpose	Bore No.	Maximum Rate (L/s)	Maximum Weekly Allocation Take (m3)
WP080172T	to take water from well no. 4001 (100 mm diameter) to provide water for a rotary dairy shed	4001	1	605
WP080196T	to take water from well no. 4903 (300 mm diameter) adjacent to the Mohaka River by means of an infiltration chamber to irrigate 70 hectares of olives and 50 hectares of kiwifruit	4903	54	21250
WP080130T	to take water from a gallery structure (well no. 3710) adjacent to the Mohaka River via a submersible pump to irrigate 38.22 hectares of pasture	3710	50	10400

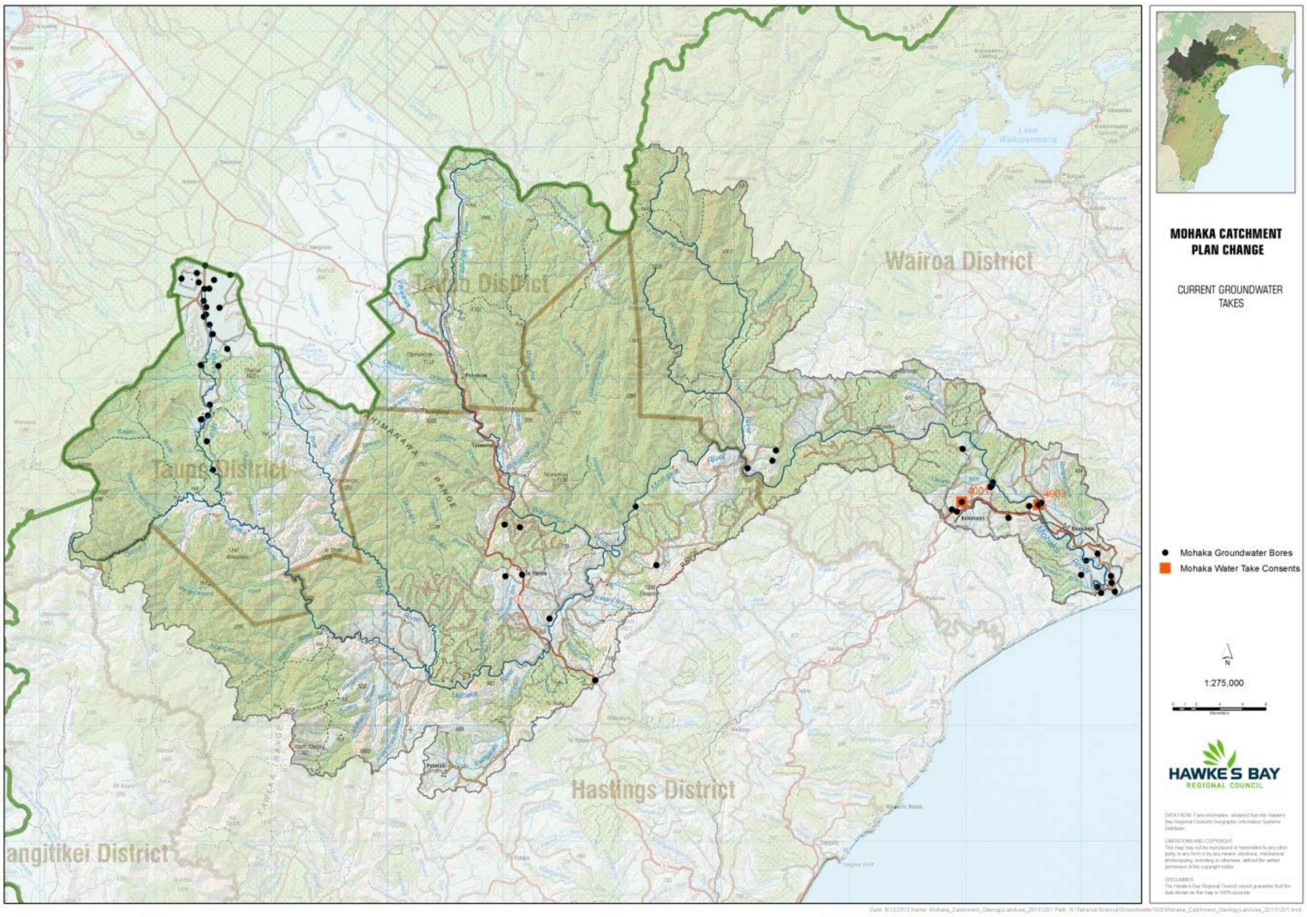

Figure 5-6: Location of known groundwater bores and consented groundwater takes in the Mohaka catchment.

5.6 Groundwater Resources of the Taharua Sub-catchment

Five water supply bores have been drilled in the valley to maximum depth of 192m below ground surface (bgs). An array of 12 shallow monitoring bores has been drilled to depths up to 20m bgs in 2013 and 2014 by HBRC (Figure 5-7). Most of the shallow monitoring bores located in the upper catchment are to:

i. collect water quality data;
ii. characterise and track trends in water quality;
iii. assess the flow direction of the shallow groundwater;
iv. help define groundwater catchment boundaries; and
v. monitor potential effects on water quality resulting from intensive land-uses in the upper catchment.

Of the monitoring bore 12 sites, 5 have been selected for HBRC's long term groundwater quality monitoring programme in the Mohaka catchment. The longer term groundwater quality monitoring sites are located on public road reserve land and are distributed spatially down the catchment.

Geological bore log descriptions available for these bores reveal a sequence of unconsolidated pumice, volcanic ignimbrite rock and greywacke gravels. A geological cross section of the Taharua catchment has been constructed along the north – south alignment of the valley and is based on bore log data (Figure 5-7). Greywacke basement rock has been encountered only in bore 5811 at a depth of 124 m. Greywacke rock is also found at the surface, to the west and eastern areas of the catchment. This is likely to constrain groundwater flows to a north south direction.

Based on borelog descriptions and the steep and incised geomorphology of the Kaimanawa range terrain, the structure of the Taharua Valley is a steep sided V-shape that has been infilled with gravels eroded from the greywacke argillite of the Kaimanawa and Ahimanawa Ranges. The gravel deposits range from approximately 20m to 60m thick. Gravels units are not present in the driller's logs for bore 4287, which is located at the southern terminus of the valley near the confluence with the Mohaka River. Therefore, the spatial extent and thickness of the greywacke gravel units in the valley are likely to be limited because the gravel units do not outcrop at the surface elsewhere in the catchment. Furthermore, the units are only found at depth, buried by volcanic material in the northern Taharua valley. The gravels are buried beneath ignimbrite and likely to have unique hydraulic properties. However, the gravels are likely to be hydraulically linked to the ignimbrite above and share the same recharge source from the overlying water bearing units.

A hard consolidated volcanic rock formation is found in almost all of the available borelogs greater than 20 m in depth. The rock formation found in the borelogs is interpreted as the Rangitaiki ignimbrite, which was sourced from the Whakamaru volcanic centre to the north of the catchment[3]. This formation has been mapped throughout the Taharua catchment by Lee et al*.,* (2011) and is in direct contact with the greywacke basement. This is consistent with the lithology of bore 5811 (Figure 5-8). Further south, the rock formation overlies the gravels in the north as observed in bores 5812 and 5813 (Figure 5-8). Based on the available hydrogeological data, the Rangitaiki Ignimbrite is considered to be a key aquifer unit in the Taharua catchment but further investigations is needed to assess the significance of the gravels units in bores 5812 and 5813 and because all 3 deep bores have open casings within the ignimbrite and gravels below in 5812 and 5813.

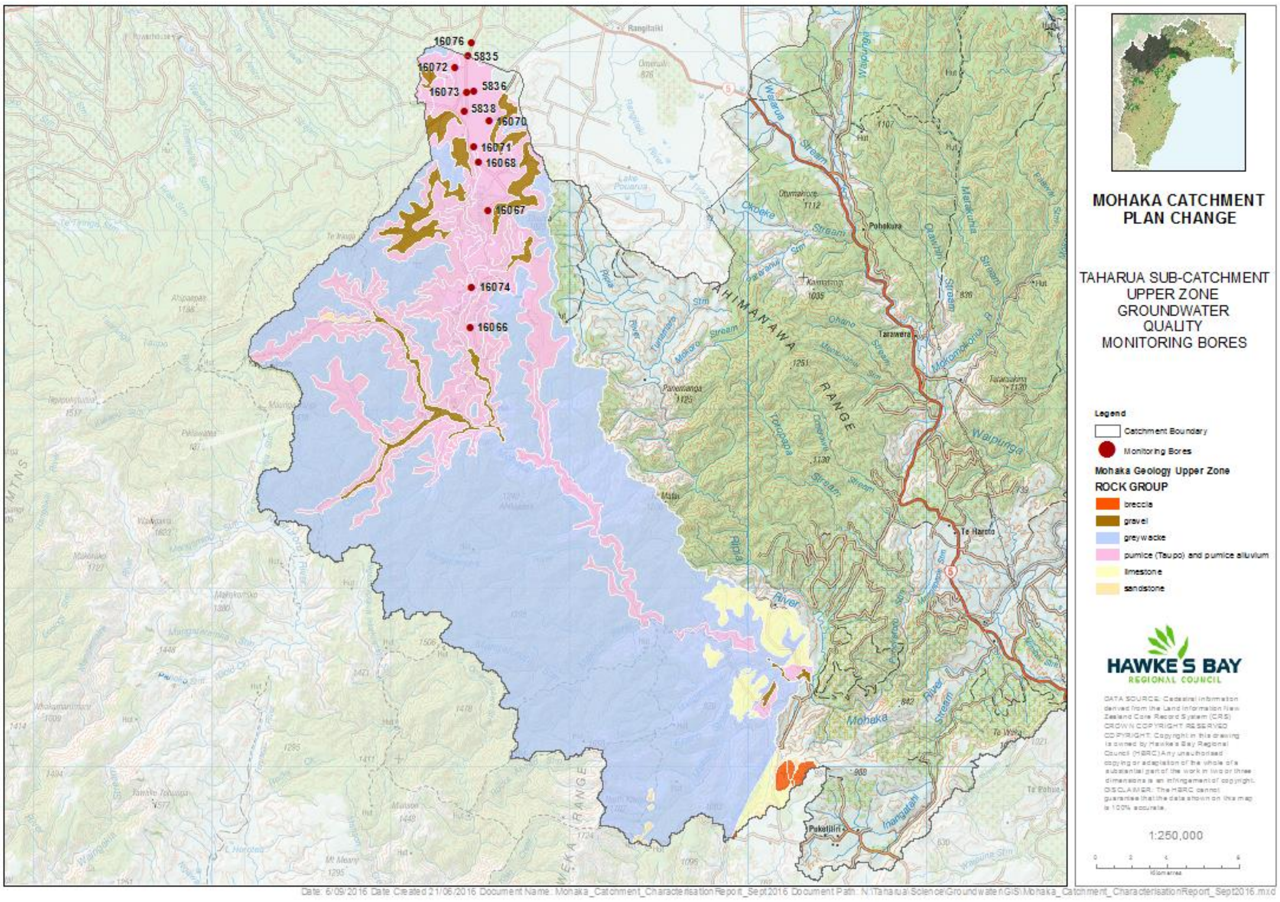

Figure 5-7: Location of HBRC monitoring bores drilled into Taupo Pumice Ignimbrite and volcanoclastic alluvium within the Taharua River sub-catchment.

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[3] personal communication with Michael Rosenberg - GNS Science., 2014

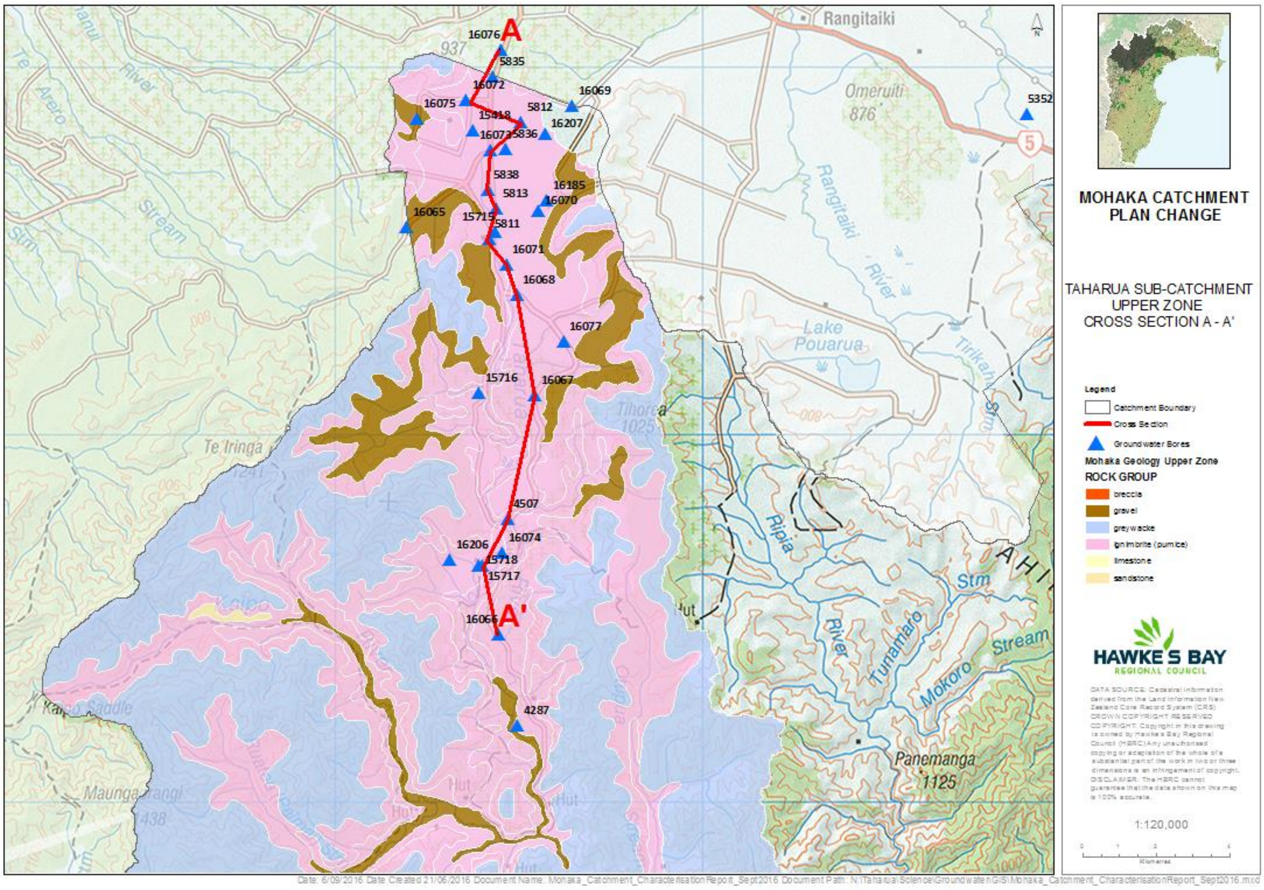

Figure 5-8: **Location of geological cross-section in the Taharua River catchment A to A' as in Figure 5-9.**

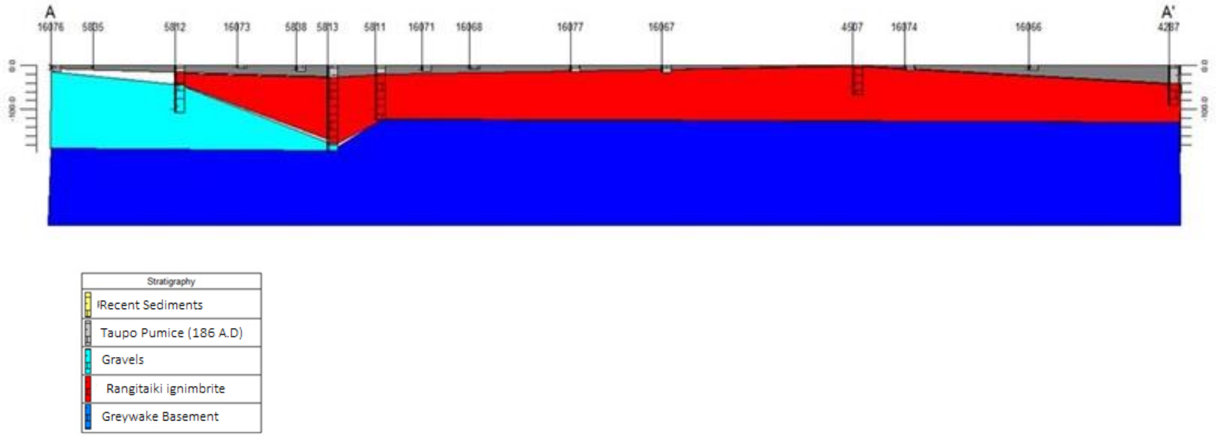

Figure 5-9: **Interpreted stratigraphic cross section from available geological drill logs for the Taharua River sub-catchment.**

The recent pumice formations overlie the older Rangitaiki Ignimbrite and provide the main land surface in the catchment. The pumice was deposited in the valley from the 1800 B.P. Taupo eruption, along with pumice alluvium that subsequently eroded from the surrounding elevated areas of the catchment.

The pumice infills the Taharua Valley up to 30 metres in depth and is water bearing, forming an unconsolidated pumice aquifer that is used as a water supply for landowners in the valley. The Taharua River has incised the pumice to become a steep sided stream bed that is likely to be in hydraulic connection with the surrounding pumice aquifer.

5.6.1 Surface Catchment and Administrative Boundaries

Surface water catchments used in this report to delineate the Taharua catchment boundary are based on NIWA's River Environment Classification and are known as Water Management Catchments in HBRC's GIS database. The Taharua sub-catchment is located at the administrative boundary of two other regions:

i. Waikato region to the west, which is also the boundary of the Lake Taupo catchment; and

ii. Bay of Plenty region to the north, which is also the boundary of the Upper Rangitaiki catchment.

There are differences between the administrative regional boundaries when compared to the watershed boundary for the Taharua sub-catchment. The most significant difference is at the northern watershed boundary with the Upper Rangitaiki catchment. The Taharua watershed extends approximately 1.8km into the Bay of Plenty Region This is an area of 395 hectares as indicated by the red shaded area in Figure 5-10) and is currently used for exotic forestry. The Bay of Plenty Regional Council boundary extends into the Taharua watershed by approximately 1.3 km and covers an area of 235ha, which is mostly pasture. This is indicated by the yellow shaded area in Figure 5-10.

The differences between the administrative and catchment boundaries may need to be considered for resource management planning requirements and may require engagement with Bay of Plenty Regional Council. However, HBRC groundwater science staff are working collaboratively with Bay of Plenty Regional Council staff to identify the groundwater catchment boundaries. The Bay of Plenty Regional Council is also undertaking an investigation to characterise the groundwater resources of the Upper Rangitaiki catchment[4].

The surface water catchment boundaries are not necessarily the same as groundwater boundaries because geological formations extend beyond surface catchment boundaries. Groundwater catchments and flow directions can be defined from water level data, if there is a sufficient spatial distribution of bores.

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[4] Personal communication with J. Barber and D. Harvey – Bay of Plenty Regional Council, 2014

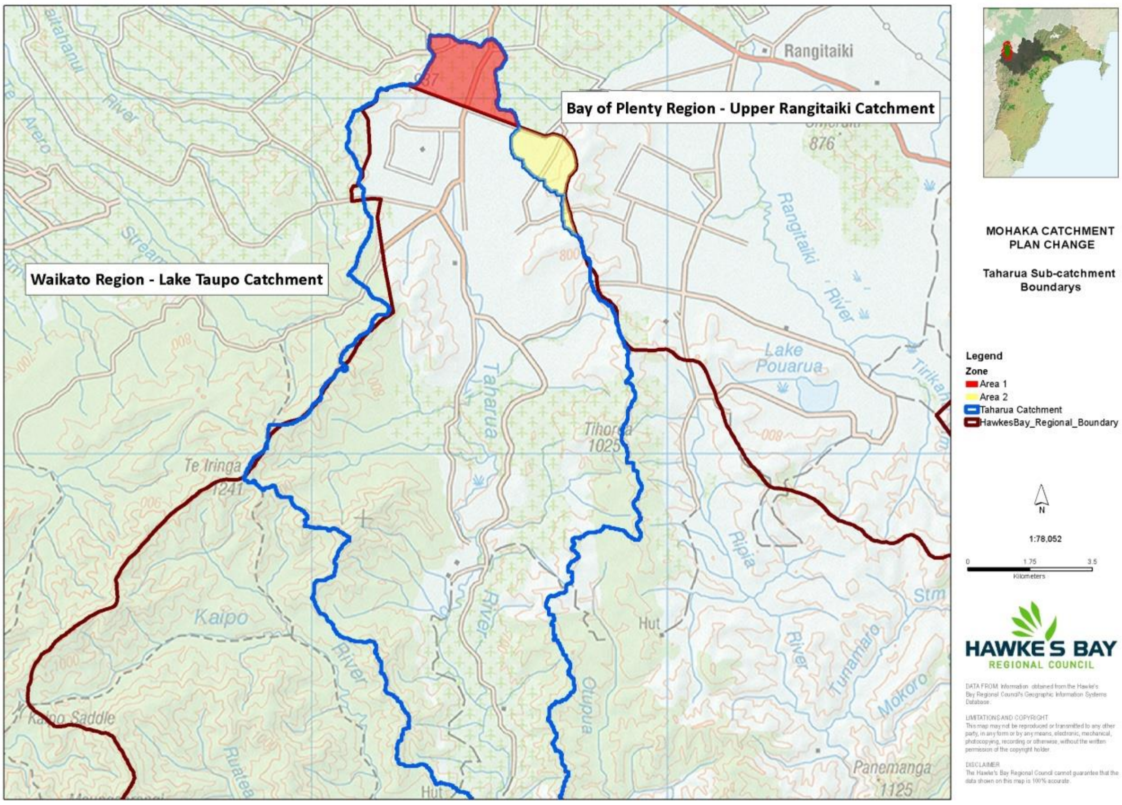


Figure 5-10: Taharua sub-catchment watershed boundary derived from NIWA River Environment Classification (REC) and regional council administrative boundaries

5.6.2 Groundwater Levels and Flow Direction

To delineate the groundwater catchment, the construction of a regional piezometric surface can be used to identify the boundaries of the aquifer system and flow direction. Water level measurements from individual monitoring bores are used to construct piezometric surface contours. For the Taharua catchment, regular monthly groundwater level data are captured from HBRC monitoring bores as part of the shallow groundwater quality monitoring programme for the Taupo pumice aquifer. A synoptic survey of private water supplies in 2009 provided groundwater quality and level data, including the deep bores 5011, 5012, 5013 in Rangitaiki Ignimbrite aquifer. Water level observations from shallow private bores in the pumice aquifer were recorded during a subsequent survey in 2010. Data from the sites were divided into two groups, based on the hydrogeology and bore depth:

1. Bores less than 30m depth that penetrate the Taupo pumice and alluvium aquifer; and
2. Bores greater than 30m depth that penetrate the Ignimbrite aquifer and gravels.

A piezometric analysis was initiated by collating water level data from 7 private bores and 14 HBRC monitoring sites. Because the water level observations used in the analysis are from several sources, data from the same year and month were used when possible. However, when this was not possible, data from the closest month of the same year were used. Groundwater levels were then contoured using the Kriging geostatistical gridding method in Surfer Mapping Software (version 9.7.5.4.3), with the kriging boundary set to the surface catchment boundary. The default options of linear variogram kriging and point kriging interpolator were used to generate a contoured piezometric surface.

Piezometric contours indicate north to south flow directions in both the pumice aquifer and the deeper Ignimbrite aquifer. Groundwater in the deeper ignimbrite aquifer was also found to have similar static water levels to the shallow Taupo pumice and alluvium aquifer (**Figure 5-11**).

This indicates the aquifer formations are hydraulically linked. The groundwater divide of the with Upper Rangitaiki catchment is likely to be north of the current REC surface water catchment, as indicated by the water level contouring in (**Figure 5-11**). Additional monitoring bores are required to accurately define the groundwater divide at the northern end of the catchment. Flow gaugings at sites down the Taharua River indicate there is considerable gain in flow as the river commences (predominantly as springs). There is another large gain in flow between 8km and 15km down the catchment (Figure 5-12) which is believed to be from groundwater as there are minor inputs from tributaries during low conditions during summer.

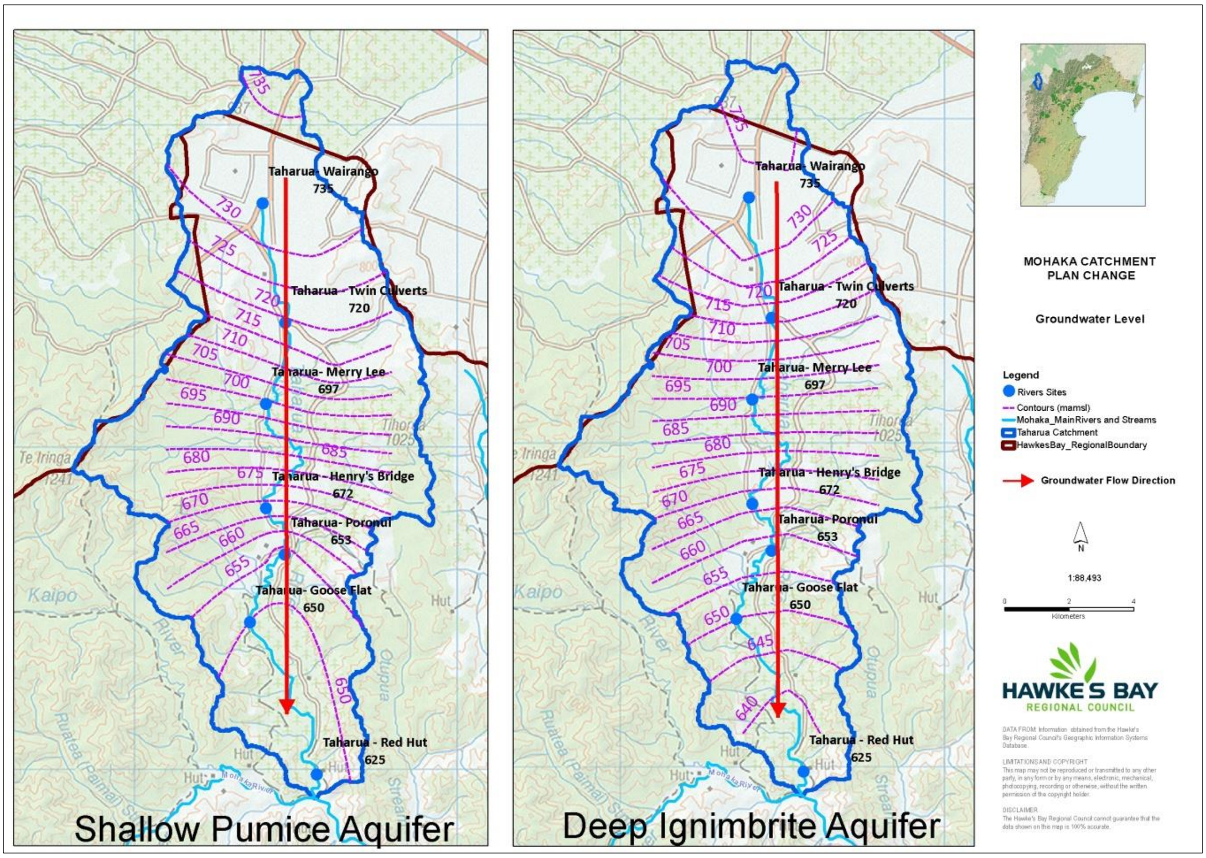


Figure 5-11: Water levels contours (amsl in purple) and flow direction (red arrow) for the shallow Taupo pumice aquifer and deep ignimbrite aquifer in the Taharua catchment. Taharua flow gauging sites (blue dots and gauging site and and levels) are also shown.

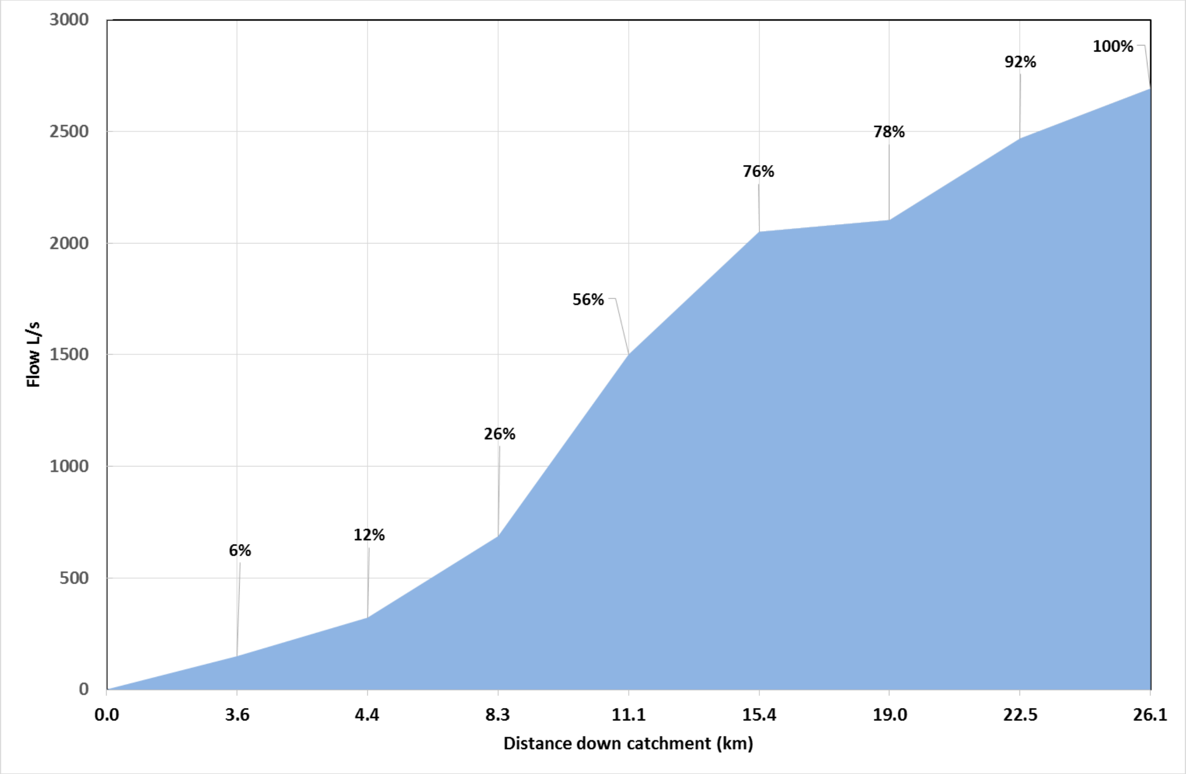


Figure 5-12: Flow gain in the Taharua River from source to the confluence with the Mohaka River, based on averages from 3 concurrent gauging measurements during February and March 2009.

5.6.3 Groundwater Recharge and Water Age

Rainfall infiltration is the primary source of recharge to most aquifer systems. Under natural conditions, groundwater generally moves in three dimensions from a recharge area to a discharge area. The course taken by water moving through the aquifer is called a flow path and may vary from tens of metres to hundreds of metres in the vertical direction (depending on the total thickness of the aquifer) and from hundreds to thousands of metres horizontally (determined by the spatial extent of the aquifer). Figure 5-13 shows a range of typical travel times for flow paths in idealised aquifer systems.

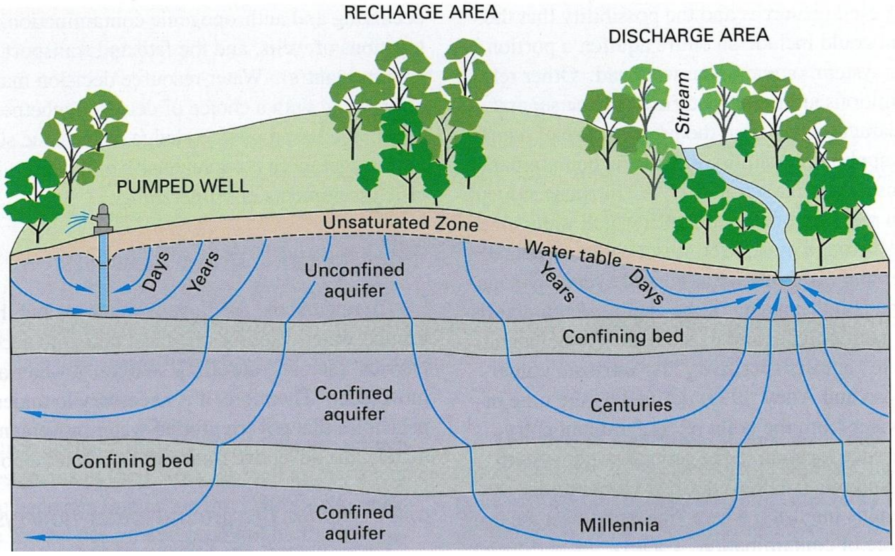


Figure 5-13: Conceptual representation of groundwater flow path and groundwater residence time in an aquifer system, (USGS, 2006).

The age or residence time of groundwater in an aquifer system progressively increases along the flow path. In most aquifer systems groundwater flow in the horizontal direction predominates over flow in the vertical direction. Groundwater commonly flows more rapidly through the upper parts of an aquifer system, causing an increase in groundwater age along deeper flow paths. This is sometimes accompanied by changes in groundwater quality with depth, but the residence time of groundwater is largely determined by groundwater flow rates (USGS, 2006). Water dating methods can be used to define the water age or residence time in groundwater and surface water, which is valuable when evaluating the impacts of land-use changes and management responses.

5.6.4 Surface and Groundwater Age Assessment

Water dating measurement is based on one or more tracer substances. Tracers have either time-dependent input functions in groundwater system, or a well-defined decay rate (e.g. natural radioactive decay) that is then applied to tracer concentration data in a predictive model. A mean residence time (MRT), or age, for a water sample is calculated from a model that describes the distribution of ages arising from mixing of groundwater of different ages within the aquifer or at a bore (Stewart et al., 2001). Tritium, chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF6) are common tracers used for dating groundwater that is less than 100 years old. The dating methods for groundwater do have some limitations, due to ambiguous ranges and the complexity of groundwater processes. Therefore, complementary tracers with different decay rates or transport mechanisms are typically used to find unique age solutions.

Water dating assessment has been conducted for sites in the Taharua catchment, to understand the residence time of groundwater and to quantify groundwater contribution to the Taharua stream. Water samples were collected from the shallow Taupo Pumice aquifer and the deeper ignimbrite/gravel aquifer, for analysis of tritium isotopes, along with CFC and SF6 gas tracers. (Figure **5-14**). Surface water samples were also collected for tritium isotopes analysis at selected gauging sites in the Taharua River catchment under low flow (baseflow) conditions from the Taharua spring to the confluence with the Mohaka River (Figure **5-15**).

Sampling was undertaken using the New Zealand Groundwater Sampling protocols and chain of custody methods specified by GNS Science. Water samples were analysed at the GNS Science water dating laboratory located in Lower Hutt, New Zealand.

5.6.5 Surface and Groundwater Age Results

Results from isotope and gas tracers indicate that the groundwater from the deep ignimbrite/gravel aquifer has a water age of greater than 100 years suggesting that the groundwater in the deeper ignimbrite aquifer is very old and has a long residence time indicating that the active groundwater flows does no reach this depth. However, bores 5811 has a younger water with a mean age of 17 years. This is may not represent the age of a single aquifer, but the average of the aquifers that the bores penetrate. This is because the bore 5811 has shallow well casing that overlaps the shallow Taupo pumice aquifer and deeper ignimbrite-gravel aquifers.

Groundwater in the shallower Taupo Pumice aquifer groundwater has a mean residence time of less than five years suggests that recharge source is derived from local rainfall recharge sources (**Figure 5-14**).

Water from the spring source in the upper Taharua catchment has a mean residence time (Mean water age) of one year. The age of river water increased down the catchment, to a mean residence time of eight years at the confluence with the Mohaka River (Figure **5-15**).

The young water at the Taharua spring indicates that there are short flow paths close to the recharge area. The steady increase in water age downstream in the Taharua River indicates an increasing contribution of water from longer flow paths from deeper parts of the groundwater system with increasing distance from the head of the recharge area. The presence of significant amounts of old water in the stream is probably related to larger water storage capacity of the volcanic pumice aquifer material. Good hydraulic conductivity of the volcanic material in the Taupo Pumice aquifer is suggested by streams sourced from the greywacke rock hill country running dry at the interception with the volcanic pumice which infills the valley forming the current topographic surface (Morgenstern, 2014).

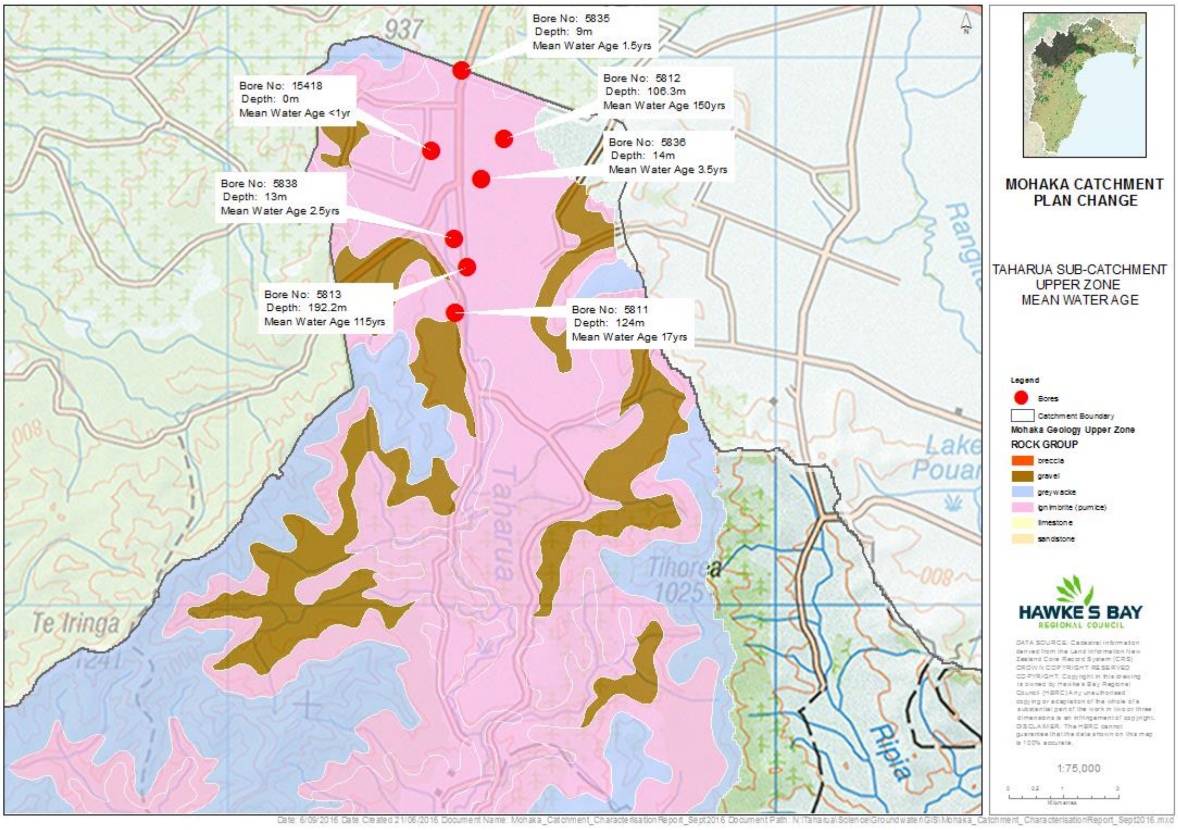


Figure 5-14: Mean water age for bores in the upper Taharua sub-catchment. Bores 15418, 5835 and 5816 penetrates the shallow Taupo pumice aquifer. Bores 5811, 5812 and 5813 penetrate the ignimbrite-gravel aquifer. Bore 5811 is likely to penetrate both aquifers because of a short well casing.

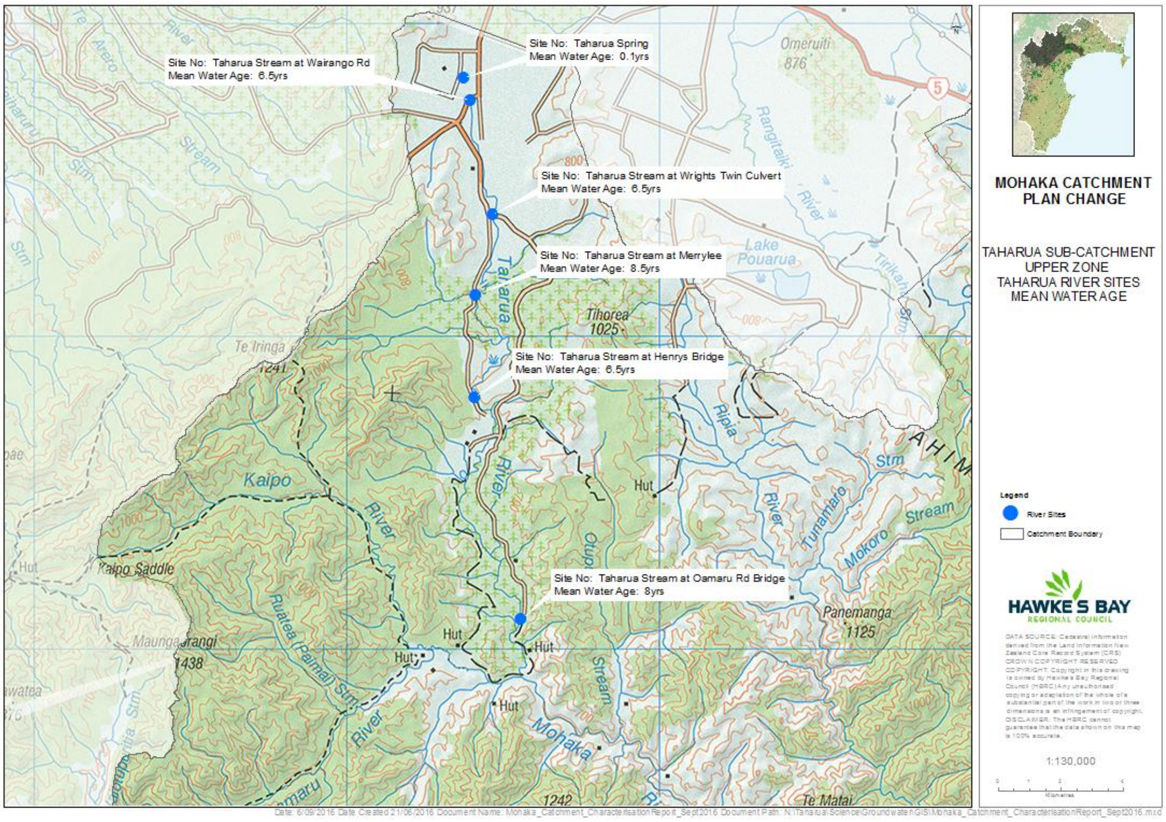


Figure 5-15: Mean water age for selected surface water gauging sites in the Taharua catchment.

5.7 Groundwater Quality

Groundwater generally contains an array of dissolved ions as a consequence of: i) interaction with minerals in the geological material; and ii) residence time of groundwater within the aquifer. Groundwater becomes enriched with dissolved material with age. In general, surface water and recently recharged groundwater are dominated by calcium and bicarbonate ions, following rapid dissolution of carbonate minerals from soil or from limestone. The amount of dissolved solids within groundwater varies according to rock type, along with the solubility and rate of mineral dissolution within these rock types.

Rainfall infiltration is likely to be the primary source of recharge to aquifer systems in the Mohaka catchment and is the transport mechanism for contaminants entering groundwater. Contaminants are transported by infiltration of soil water into the underlying aquifer system. Therefore, human land-use activities can have a strong influence on the groundwater quality.

In the Mohaka catchment, groundwater is an important source of domestic and stock water supplies for rural landowners. However, there are a smaller number of abstractions for domestic and stock water in the Mohaka catchment, compared to other catchments in the Hawke’s Bay region. This is because: i) the groundwater resource in the hard rock geology is limited (particular in the mid and lower catchments); and ii) the land use is mostly exotic forestry, conservation estate or hill country sheep and beef pastoral (see Section 4.1.1.

Nonetheless, because groundwater provides a large proportion of baseflow to streams and rivers, the quality of groundwater has a direct influence on stream and river water quality and ecology. The effect of intensive land-uses on groundwater quality is particularly important in the Upper Mohaka and Taharua catchments, where groundwater contributes a large proportion of flow to the Taharua River. Surface water quality and ecology in these waterways have been affected by nutrient discharges, as described in Section 4.

5.7.1 Water Quality Guidelines Limits

The Regional Policy Statement (RPS) and Regional Plan deliver the Hawke’s Bay Regional Council policy framework for the management of natural resources of the region. The RPS establishes high level objectives and outcomes which are implemented through detailed Policies and Rules outlined in Regional Plan. The Regional Policy statement refers to the New Zealand Drinking Water Standards (DWSNZ) published by the Ministry of Health as the relevant standards for groundwater quality limit setting (MoH, 2008). The Regional Plan also refers to Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters (Australian and New Zealand Environment and Conservation Council - ANZECC, 1998) for irrigation as a management standard. These ANZECC guidelines were updated in 2000 (ANZECC, 2000). Although compliance for irrigation and stock water was not specifically examined in this report, the drinking water standards are more stringent than guideline values (GV) for irrigation as specified by ANZECC (2000) (Table 5-4).

The DWSNZ defines a “potable water supply” as drinking-water that does not contain any water quality variable to an extent that causes exceedance of maximum acceptable values (MAV). The allowable number of MAV exceedances is calculated on the basis that there is 95% confidence that the supply complies with the DWSNZ 95% of the time. The DWSNZ also specifies guideline values for aesthetic variables which relate to assessing if a potable supply is “wholesome”. A wholesome drinking water supply is defined in the DWSNZ as potable water that does not contain any material that causes one of the variables to exceed a guideline value. The MAV and GV limits for the DWSNZ are listed in Table 5-3.

Table 5-3: Key water quality parameters in the New Zealand drinking water standards (DWSNZ).

Parameter	Parameter	Units	Water Quality Standard (MAV)	Water Quality Guideline Value (GV)
Chemical	pH	Units		7-8
Chemical	Ammoniacal Nitrogen	mg/L		1.5
Chemical	Nitrate-N	mg/L	11.3	
Chemical	Nitrite – N *	mg/L	0.0609	
Chemical	Nitrite – N #	mg/L	0.9134	
Chemical	Manganese (soluble)	mg/L	0.4	0.04
Chemical	Iron (soluble)	mg/L		0.2
Chemical	Sulphate	mg/L		200
Chemical	Sodium (soluble)	mg/L		200
Chemical	Chloride	mg/L		250
Chemical	Total hardness	mg/L		200
Chemical	Total dissolved solids	mg/L		1000

*Long term exposure, #Short term exposure.

Table 5-4: Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters irrigation guidelines (ANZECC, 2000).

Variable type	Variable	Units	Water Quality Trigger Value	Explanation
EC	Electrical Conductivity	µS/cm	1000	Most sensitive plants
Chemical	pH	Units	6 – 8.5	Prevent corrosion
Chemical	Manganese (soluble) #	mg/L	0.2	Clogging of irrigation equipment and crop sensitivity
Chemical	Iron (soluble)	mg/L	0.2	Clogging of irrigation equipment and crop sensitivity
Chemical	Sodium (soluble)	mg/L	115#	Production based on most sensitive crop toxicity
Chemical	Chloride	mg/L		Production based on most sensitive crop
Chemical	Total hardness	mg/L		Risk of fouling of equipment
Chemical	Total hardness	mg/L		Risk of corrosion

5.7.2 Mid and Lower-Mohaka catchment Zones Groundwater Quality

There is no catchment specific groundwater information available for the mid- and lower-Mohaka catchment zones to assess groundwater quality. Further investigations would be needed to confirm groundwater state of groundwater quality in these catchments.

5.7.3 Taharua Catchment Groundwater Quality

In 2008, 3 shallow monitoring bores (5835, 5836, and 5638) were installed and monitored by the owners of the Taharua farm to assess the nutrient status and trends in groundwater beneath the farm. These bores penetrated the shallow Taupo Pumice aquifer in the upper catchment. The owners discontinued the monitoring in 2010 because of financial constraints. Hawkes Bay Regional Council recommenced monitoring of these bores as part of the Taharua catchment investigation.

The groundwater quality nutrient investigation programme has been augmented with the establishment of 13 additional shallow monitoring bores in 2013 in the shallow Taupo pumice aquifer. These monitoring sites extended the spatial coverage in the Taharua Valley for the purposes of:

- characterising the nutrient profile of land-uses in the catchment; and
- identifying groundwater catchment boundaries.
- calibration of nutrient transport models that may be developed in the future

Water quality monitoring data has been collected at 13 sites (12 bores and 1 spring) for key water quality parameters (Table 5-9). The locations of the HBRC shallow groundwater quality monitoring sites are shown in Figure 5-17.

HBRC has also conducted water quality surveys of key chemical water quality parameters Table 5-10 to characterise the water chemistry of the shallow Taupo pumice aquifer and using private water supply bores located in the ignimbrite aquifer from 2009 to 2013. A total of 22 sites were included in the water quality survey (Figure 5-16).

Analysis of the major ion chemistry in the Taharua catchment is summarized in Figure 5-18 and medium values of major ion chemistry are presented in Table 5-5. The dominant ion chemistry at most sites is sodium bicarbonate (82 % of sites) followed by calcium carbonate at 18 % of sites. Seventy-eight percent of sites in the shallow pumice aquifer are dominated by sodium bicarbonate ions. All sites in the ignimbrite aquifer are dominated by sodium bicarbonate ions. The dominance of sodium cation ion is likely to be due to the prevalence of volcanic geology in the area and low abundance of carbonate rock types in the catchment.

An automated spreadsheet programme (Daughney, 2010) was used to compute descriptive statistics based on the available data. Summary statistics were calculated to enable comparisons with water quality standards to account for positively skewed datasets that commonly occur with environmental data (Hem 1985). The 95th percentile is a measure of the spread of results and to provide for comparison with New Zealand drinking water standards (DWSNZ). The DWSNZ require comparison with the 95th percentile of the data set.

Key groundwater quality chemistry parameters in the Taharua catchment complies with the New Zealand Drinking water Standard (DWSNZ) for the MAV's for nitrate-nitrogen, nitrite-nitrogen and for manganese. However a number of sites in the shallow aquifer have moderate (1.0 mg/L to 5.65 mg/L) to high (>5.65 mg/L and 11.3 mg/L) levels of nitrate-N. The sites with elevated nitrate-N are located in the area under Dairy land-use. Most sites in the groundwater water quality survey comply with most guidelines aesthetic parameters in the DWSNZ except for elevated manganese and iron (Table 5-6). These sites are mostly located in the Taupo pumice aquifer and one site in the Ignimbrite-gravel aquifer. Most sites in the catchment also comply with most parameters for Irrigation except for corrosion (Table 5-8).The water is “soft” with low concentrations of dissolved ions and is likely to result in corrosion of metal pipework.

Table 5-5: Major ion chemistry (Median 50 percentile) at groundwater bores sites and Taharua Spring data period 2009 to 2013.

Site	Bore Depth	Number of Samples	Electrical Conductivity µS/cm	pH	Bicarbonate mg/L	Calcium mg/L	Chloride mg/L	Iron mg/L	Magnesium mg/L	Manganese mg/L	Sodium mg/L	Potassium mg/L	Sulphate mg/L	Silica as SiO_2 mg/L	Nitrate-N mg/L	Ammonical -N (total) mg/L	Nitrite- N (mg/L)	Phosphorus (soluble) mg/L	Total Hardness mg/L	Total Dissolved Solids mg/L	Water Type	Aquifer
4507	67.0	3	68	6.50	36	3.90	1.90	0.01	1.56	0.0015	8.60	0.99	2.2	58.00	0.470	0.01	0.00	0.0700	16	94	Na-HCO3	Ignimbrite
5811	124.0	1	73	6.75	25.5	3.75	2.90	0.01	1.45	0.0004	6.90	2.45	1.9	56.50	2.000	0.01	0.00	0.0500	15	90	Na-HCO3	Ignimbrite
5812	106.3	2	110	7.70	56	6.10	2.20	0.10	4.30	0.0440	9.30	2.00	6.5	24.00	0.001	0.01	0.00	0.0400	33	87	Na-HCO3	Ignimbrite & Gravels
5813	192.2	1	81	7.10	36.5	3.75	4.75	0.01	1.85	0.0225	9.50	1.19	1.8	50.50	0.360	0.01	0.00	0.1200	17	74	Na-HCO3	Ignimbrite & Gravels
5835	9.0	2	149	6.70	32.5	10.85	4.80	0.03	2.70	0.0019	10.30	4.80	14.7	61.00	5.550	0.01	0.00	0.0100	36	99	Ca-HCO3	Taupo Pumice
5836	14.0	6	189	6.90	45	15.15	5.80	0.01	3.50	0.0003	14.80	0.56	15.4	58.00	8.400	0.01	0.00	0.0100	52	141	Ca-HCO3	Taupo Pumice
5838	13.0	6	129	6.70	24	7.80	3.20	0.01	1.78	0.0003	10.00	2.80	10.5	60.83	6.500	0.01	0.00	0.0100	27	81	Na-HCO3	Taupo Pumice
15418	2.0	5	106	6.80	21	7.80	5.50	0.01	1.10	0.0100	7.80	4.20	7.5	60.00	4.200	0.01	0.00	0.0200	24	130	Ca-HCO3	Taupo Pumice
15715	10.7	1	90	6.40	29	6.00	3.30	0.02	1.85	0.0003	8.00	3.60	4.1	53.00	2.800	0.01	0.00	0.0200	23	92	Na-HCO3	Taupo Pumice
15716	6.4	1	83	6.70	40	4.40	2.90	0.01	1.60	0.0003	10.70	2.30	3.6	66.00	0.120	0.01	0.00	0.0100	18	104	Na-HCO3	Taupo Pumice
15717	15.0	1	76	6.20	41	7.00	2.10	0.03	2.10	0.0003	6.40	1.38	1.8	47.00	0.120	0.01	0.00	0.0300	26	73	Ca-HCO3	Taupo Pumice
16066	13.8	1	82	6.80	33	5.60	1.70	0.02	1.31	0.0071	7.10	3.20	6.3	66.00	1.160	0.01	0.00	0.0500	19	55	Na-HCO3	Taupo Pumice
16067	11.8	5	56	7.05	31.5	3.60	1.25	0.24	0.86	0.2700	7.40	0.60	1.7	60.50	0.600	0.01	0.00	0.0100	13	37	Na-HCO3	Taupo Pumice
16068	17.4	2	77	6.80	31	4.30	1.80	0.03	0.97	0.0011	7.70	3.10	3.9	58.00	1.510	0.01	0.00	0.0100	15	52	Na-HCO3	Taupo Pumice
16070	9.9	5	230	6.90	50.5	16.70	12.90	0.04	4.35	0.0293	22.50	0.69	9.7	58.00	9.850	0.01	0.00	0.0100	60	154	Na-HCO3	Taupo Pumice
16071	12.9	4	170	6.80	40.5	12.10	5.10	0.06	2.90	0.0114	15.65	1.67	11.7	62.50	7.350	0.01	0.00	0.0100	42	114	Na-HCO3	Taupo Pumice
16072	9.9	4	110	6.50	24	6.85	4.45	0.01	1.90	0.0038	8.65	3.75	6.8	55.00	4.350	0.01	0.00	0.0100	25	74	Na-HCO3	Taupo Pumice
16073	6.9	4	81	6.87	37	5.50	1.50	0.08	1.22	0.1020	9.60	0.86	4.3	54.00	1.350	0.01	0.00	0.0100	19	55	Na-HCO3	Taupo Pumice
16074	11.7	3	45	6.50	24.5	2.55	0.85	0.30	0.45	0.0315	5.25	2.60	1.9	66.50	0.080	0.01	0.00	0.0100	8	30	Na-HCO3	Taupo Pumice
16075	12.9	2	96	6.70	48	5.20	2.90	3.00	1.81	0.3900	10.60	3.30	3.5	66.00	0.001	0.01	0.00	0.1000	21	64	Na-HCO3	Taupo Pumice
16076	14.9	1	67	6.90	34	3.70	2.30	0.01	1.06	0.0008	7.10	2.90	1.7	58.50	0.400	0.01	0.00	0.0100	14	45	Na-HCO3	Taupo Pumice
Spring	0.0	4	82	6.7	30	5.20	2.80	0.01	1.46	0.00025	6.9	3.00	4.7	55.00	1.930	0.01	0.00	0.0110	19	53	Na-HCO3	Taupo Pumice

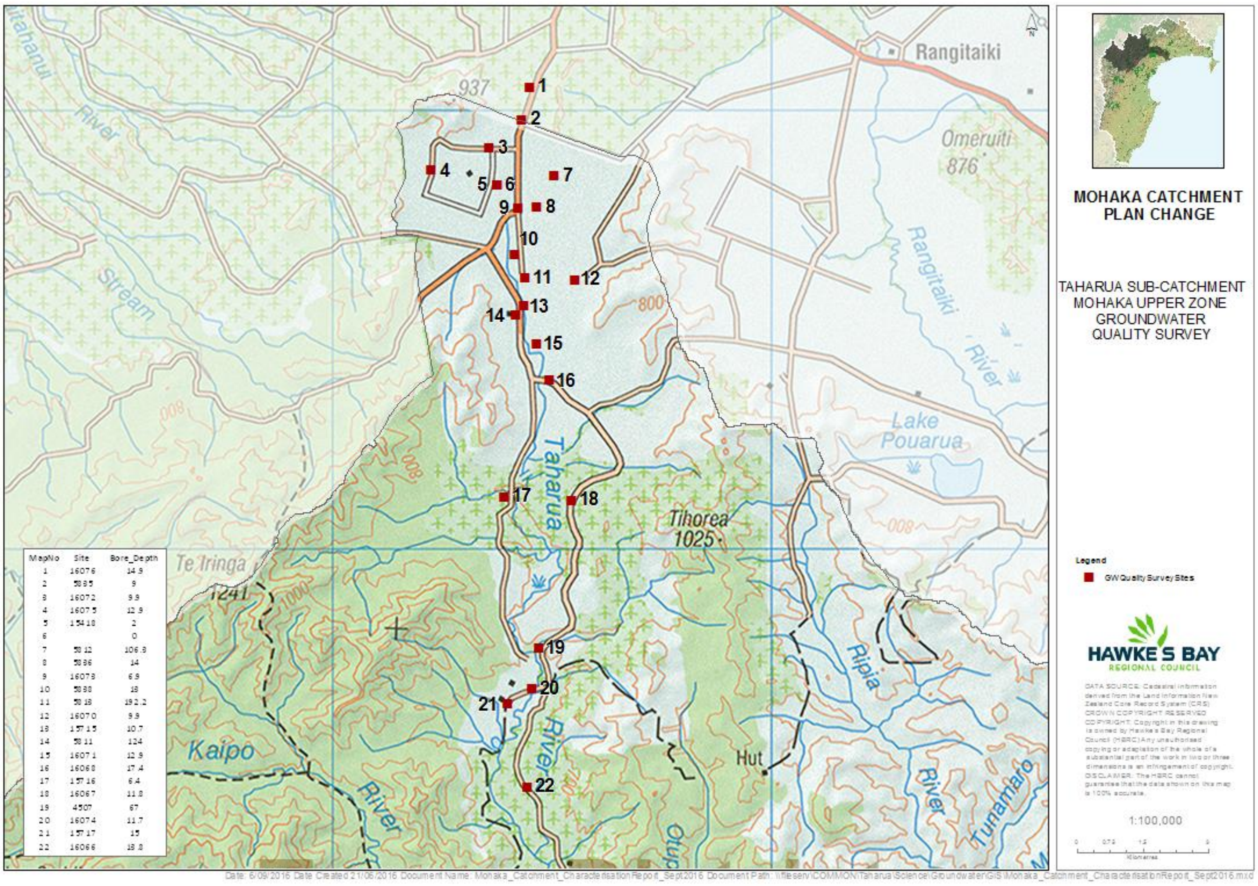


Figure 5-16: Location of groundwater quality survey sites in the Taharua sub-catchment.

Table 5-6: Compliance of key chemical water quality parameters at groundwater bores sites and Taharua spring relative to the MAV limits in the New Zealand Drinking Water Standard. Data period 2009 to 2013.

Site	Depth (m)	Aquifer	Number of Samples	Nitrate-N (NO_3-N) (mg/L)			Nitrite-N (NO_2-N) (mg/L)			Manganese (mg/L)		
				Results	Level	Complaince with DWSNZ MAV (<11.3)	(mg/L)	Level	Compliance with MAV (<0.0609)	(mg/L)	Level	Complaince with MAV < 0.4 (mg/L)
Spring	0	Taupo Pumice	3	2.623	Moderate	100%	0.001	Low	100%	0.0003	Very Low	100%
4507	67	Ignimbrite	1	0.470	Low	100%	0.001	Low	100%	0.0015	Very Low	100%
5811	124	Ignimbrite	2	2.090	Moderate	100%	0.001	Low	100%	0.0005	Very Low	100%
5812	106	Ignimbrite & Gravels	1	0.001	Low	100%	0.001	Low	100%	0.0440	Moderate	100%
5813	192	Ignimbrite & Gravels	2	0.369	Low	100%	0.001	Low	100%	0.0248	Low	100%
5835	9	Taupo Pumice	6	6.800	High	100%	0.001	Low	100%	0.0024	Very Low	100%
5836	14	Taupo Pumice	6	7.100	High	100%	0.001	Low	100%	0.0003	Very Low	100%
5838	13	Taupo Pumice	5	9.780	High	100%	0.001	Low	100%	0.0003	Very Low	100%
15418	2	Taupo Pumice	1	4.200	Moderate	100%	0.001	Low	100%	0.0100	Very Low	100%
15715	11	Taupo Pumice	1	2.800	Moderate	100%	0.001	Low	100%	0.0001	Very Low	100%
15716	6	Taupo Pumice	1	0.122	Low	100%	0.001	Low	100%	0.0003	Very Low	100%
15717	15	Taupo Pumice	1	0.120	Low	100%	0.001	Low	100%	0.0001	Very Low	100%
16066	14	Taupo Pumice	3	1.160	Moderate	100%	0.001	Low	100%	0.0195	Very Low	100%
16067	12	Taupo Pumice	2	0.654	Low	100%	0.0029	Low	100%	0.3330	High	100%
16068	17	Taupo Pumice	5	2.162	Moderate	100%	0.001	Low	100%	0.0020	Very Low	100%
16070	10	Taupo Pumice	4	10.050	High	100%	0.001	Low	100%	0.0439	Moderate	100%
16071	13	Taupo Pumice	4	7.910	High	100%	0.001	Low	100%	0.0191	Very Low	100%
16072	10	Taupo Pumice	4	4.740	Moderate	100%	0.001	Low	100%	0.0061	Very Low	100%
16073	7	Taupo Pumice	2	1.539	Moderate	100%	0.001	Low	100%	0.1524	Moderate	100%
16074	12	Taupo Pumice	2	0.094	Low	100%	0.001	Low	100%	0.0455	Moderate	100%
16075	13	Taupo Pumice	1	0.001	Low	100%	0.001	Low	100%	0.3900	High	100%
16076	15	Taupo Pumice	4	0.408	Low(<1.0 mg/L	100%	0.001	Low	100%	0.0009	Very Low	100%

Table 5-7: Compliance of key chemical water quality parameters at groundwater bores sites and Taharua spring relative to the New Zealand Drinking Water Standard guideline values for aesthetics. Data period 2009 to 2013.

Aquifer	Number of Samples	pH	Complaince with DWSNZ GV 7-8	Ammonical Nitrogen (mg/L)	Complaince with DWSNZ GV (<1.5) mg/L	Manganese (mg/L)	Complaince with GV < 0.04 (mg/L)	Iron (mg/L)	Complaince with GV< 0.04 (mg/L)	Sulphate (mg/L)	Complaince with GV< 200 (mg/L)	Total Dissolved Solids (mg/L)	Complaince with GV< 1000 (mg/L)	Hardness (mg/L)	Complaince with GV< 200 (mg/L)	Sodium (mg/L)	Complaince with GV< 200 (mg/L)	Chloride (mg/L)	Complaince with GV< 250 (mg/L)
Taupo Pumice	3	6.9	0%	0.005	100%	0.0003	100%	0.010	100%	4.9	100%	98	100%	20	100%	6.99	100%	3.3	100%
Ignimbrite	1	6.5	0%	0.005	100%	0.0015	100%	0.010	100%	2.2	100%	94	100%	16	100%	8.60	100%	1.9	100%
Ignimbrite	2	6.8	0%	0.005	100%	0.0005	100%	0.010	100%	2.3	100%	94	100%	17	100%	7.17	100%	3.0	100%
Ignimbrite & Gravels	1	7.7	100%	0.005	100%	0.0440	0%	0.100	100%	6.5	100%	87	100%	33	100%	9.30	100%	2.2	100%
Ignimbrite & Gravels	2	7.2	100%	0.005	100%	0.0248	100%	0.010	100%	2.2	100%	81	100%	19	100%	10.67	100%	5.1	100%
Taupo Pumice	6	7.0	100%	0.005	100%	0.0024	100%	0.056	0%	16.0	100%	150	100%	41	100%	11.23	100%	7.8	100%
Taupo Pumice	6	7.2	100%	0.005	100%	0.0003	100%	0.010	100%	19.1	100%	172	100%	54	100%	16.18	100%	8.4	100%
Taupo Pumice	5	7.2	100%	0.005	100%	0.0003	100%	0.010	100%	13.3	100%	150	100%	38	100%	11.80	100%	5.4	100%
Taupo Pumice	1	6.8	0%	0.014	100%	0.0100	100%	0.010	100%	7.5	100%	130	100%	24	100%	7.80	100%	5.5	100%
Taupo Pumice	1	6.4	0%	0.005	100%	0.0001	100%	0.020	100%	4.1	100%	92	100%	23	100%	8.00	100%	3.3	100%
Taupo Pumice	1	6.7	0%	0.005	100%	0.0003	100%	0.010	100%	3.6	100%	104	100%	18	100%	10.70	100%	2.9	100%
Taupo Pumice	1	6.2	0%	0.005	100%	0.0001	100%	0.030	100%	1.8	100%	73	100%	26	100%	6.40	100%	2.1	100%
Taupo Pumice	3	6.8	0%	0.005	100%	0.0195	100%	0.020	100%	7.0	100%	NA	NA	20	100%	7.72	100%	2.1	100%
Taupo Pumice	2	7.4	100%	0.005	100%	0.3330	0%	0.294	0%	1.8	100%	NA	NA	13	100%	7.58	100%	1.4	100%
Taupo Pumice	5	6.8	0%	0.005	100%	0.0020	100%	0.054	0%	4.2	100%	NA	NA	15	100%	7.89	100%	2.5	100%
Taupo Pumice	4	6.9	0%	0.005	100%	0.0439	0%	0.057	0%	10.6	100%	NA	NA	61	100%	23.00	100%	13.2	100%
Taupo Pumice	4	6.8	0%	0.005	100%	0.0191	100%	0.128	0%	11.8	100%	NA	NA	43	100%	15.97	100%	5.2	100%
Taupo Pumice	4	6.8	0%	0.005	100%	0.0061	100%	0.010	100%	7.2	100%	NA	NA	26	100%	8.79	100%	5.1	100%
Taupo Pumice	2	7.0	100%	0.005	100%	0.1524	0%	0.161	0%	4.3	100%	NA	NA	19	100%	9.58	100%	1.5	100%
Taupo Pumice	2	6.9	0%	0.005	100%	0.0455	0%	0.354	0%	2.0	100%	NA	NA	9	100%	5.48	100%	1.1	100%
Taupo Pumice	1	6.7	0%	0.189	100%	0.3900	0%	3.000	0%	3.5	100%	NA	NA	21	100%	10.60	100%	2.9	100%
Taupo Pumice	4	7.3	100%	0.005	100%	0.0009	100%	0.01	100%	1.7	100%	NA	NA	14	100%	7.27	100%	2.4	100%

Table 5-8: Compliance of key chemical water quality at groundwater bores sites and Taharua spring with the ANZECC irrigation guideline values (GV). Data period 2009 to 2013.

Site	Depth (m)	Aquifer	Number of Samples	pH	Complaince with GV 6-8	Manganese (mg/L)	Complaince with GV < 0.2 (mg/L)	Iron (mg/L)	Complaince with GV< 0.2 (mg/L)	Hardness (mg/L)	Hardness (mg/L) GV >60 mg/L	Complaince with GV< 350 (mg/L)	Sodium (mg/L)	Complaince with GV< 200 (mg/L)	Chloride (mg/L)	Complaince with GV< 250 (mg/L)
Spring	0	Taupo Pumice	3	6.9	100%	0.0003	100%	0.010	100%	20	0%	100%	6.99	100%	3.3	100%
4507	67	Ignimbrite	1	6.5	100%	0.0015	100%	0.010	100%	16	0%	100%	8.60	100%	1.9	100%
5811	124	Ignimbrite	2	6.8	100%	0.0005	100%	0.010	100%	17	0%	100%	7.17	100%	3.0	100%
5812	106	Ignimbrite & Gravels	1	7.7	100%	0.0440	100%	0.100	100%	33	0%	100%	9.30	100%	2.2	100%
5813	192	Ignimbrite & Gravels	2	7.2	100%	0.0248	100%	0.010	100%	19	0%	100%	10.67	100%	5.1	100%
5835	9	Taupo Pumice	6	7.0	100%	0.0024	100%	0.056	100%	41	0%	100%	11.23	100%	7.8	100%
5836	14	Taupo Pumice	6	7.2	100%	0.0003	100%	0.010	100%	54	0%	100%	16.18	100%	8.4	100%
5838	13	Taupo Pumice	5	7.2	100%	0.0003	100%	0.010	100%	38	0%	100%	11.80	100%	5.4	100%
15418	2	Taupo Pumice	1	6.8	100%	0.0100	100%	0.010	100%	24	0%	100%	7.80	100%	5.5	100%
15715	11	Taupo Pumice	1	6.4	100%	0.0001	100%	0.020	100%	23	0%	100%	8.00	100%	3.3	100%
15716	6	Taupo Pumice	1	6.7	100%	0.0003	100%	0.010	100%	18	0%	100%	10.70	100%	2.9	100%
15717	15	Taupo Pumice	1	6.2	100%	0.0001	100%	0.030	100%	26	0%	100%	6.40	100%	2.1	100%
16066	14	Taupo Pumice	3	6.8	100%	0.0195	100%	0.020	100%	20	0%	100%	7.72	100%	2.1	100%
16067	12	Taupo Pumice	2	7.4	100%	0.3330	0%	0.294	0%	13	0%	100%	7.58	100%	1.4	100%
16068	17	Taupo Pumice	5	6.8	100%	0.0020	100%	0.054	100%	15	0%	100%	7.89	100%	2.5	100%
16070	10	Taupo Pumice	4	6.9	100%	0.0439	100%	0.057	100%	61	0%	100%	23.00	100%	13.2	100%
16071	13	Taupo Pumice	4	6.8	100%	0.0191	100%	0.128	100%	43	0%	100%	15.97	100%	5.2	100%
16072	10	Taupo Pumice	4	6.8	100%	0.0061	100%	0.010	100%	26	0%	100%	8.79	100%	5.1	100%
16073	7	Taupo Pumice	2	7.0	100%	0.1524	100%	0.161	100%	19	0%	100%	9.58	100%	1.5	100%
16074	12	Taupo Pumice	2	6.9	100%	0.0455	0%	0.354	0%	9	0%	100%	5.48	100%	1.1	100%
16075	13	Taupo Pumice	1	6.7	100%	0.3900	0%	3.000	0%	21	0%	100%	10.60	100%	2.9	100%
16076	15	Taupo Pumice	4	7.3	100%	0.0009	100%	0.01	100%	14	0%	100%	7.27	100%	2.4	100%

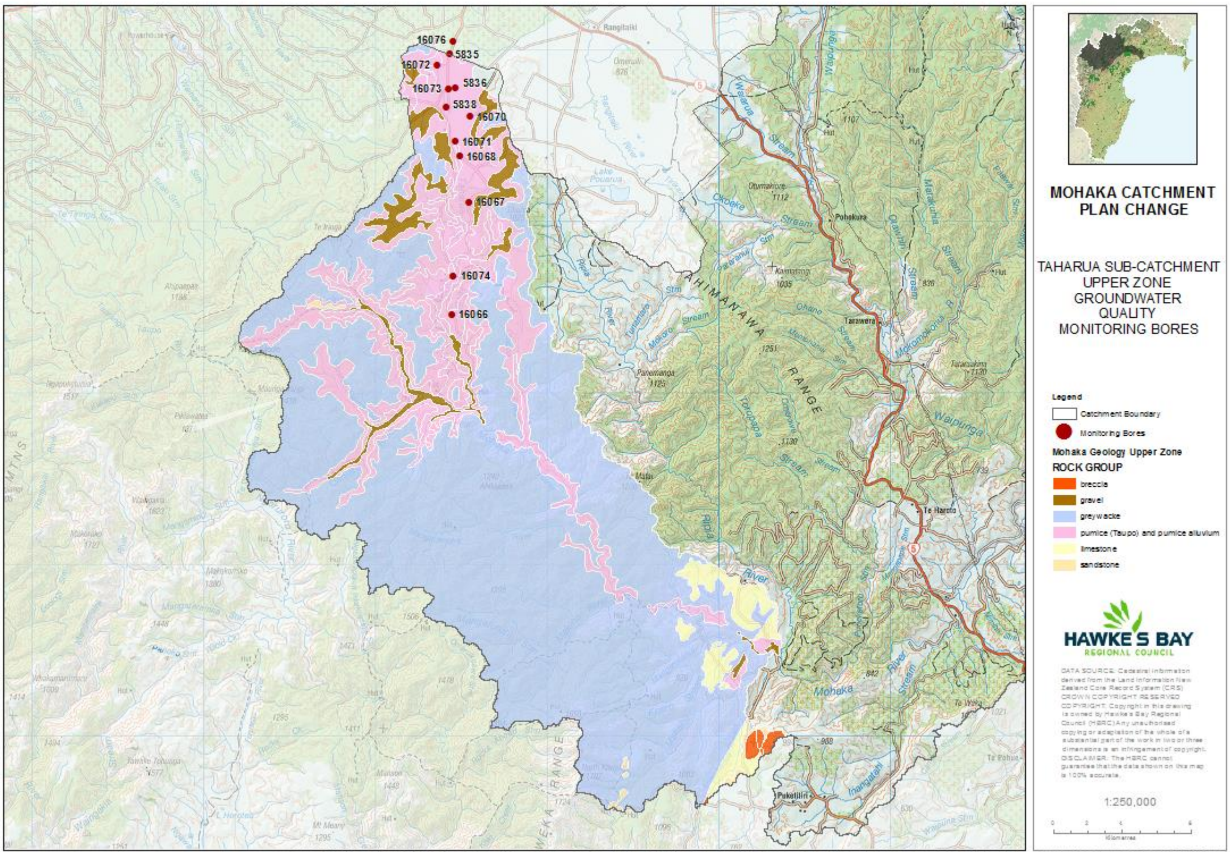


Figure 5-17: Location of Hawk's Bay Regional Council groundwater quality monitoring sites in the Taharua sub-catchment.

Table 5-9: Water chemistry parameters measured in the nutrient monitoring programme.

Nutrient	Ammonia- N	Indicator of reducing vs. oxidising conditions which may be associated with leaching from agricultural and other land-use activities.
	Nitrate-N	Indicator of seasonal variations associated with recharge and leaching of fertilisers, contamination from agricultural land-use activities.
	Nitrite-N	Indicator of reducing vs. oxidising conditions which may be associated with leaching from agricultural and other land-use activities
	Dissolved Reactive Phosphorus	Indicator of leaching of fertilisers, contamination from agricultural land-uses or human waste
Physical	Temperature	Physical variable
	pH	Measure of acidity or alkalinity
	Dissolved Oxygen	Measure of dissolved oxygen concentration (mg/L) or percent saturation.
	Electrical Conductivity	Indicator of ionic concentration of groundwater and correlates with the total dissolved solids

Table 5-10: Water Chemistry Parameters measured in the State of the Environment monitoring programme.

Variable class	Variable	Indicator/explanation
Chemical	Alkalinity	Indicator of hydrogeology and dairy shed effluent leaching into groundwater.
	Bicarbonate	Indicator of hydrogeology - presence of carbonate rocks.
	Calcium	Indicator of hydrogeology and leaching of fertiliser to groundwater.
	Chloride	Indicator of seasonal variations associated with recharge, leaching of contaminates to groundwater, salt water intrusion.
	Iron (dissolved)	Indicator of hydrogeology, reducing-oxidising conditions (i.e. casing corrosion, iron bacteria) and aesthetic and health quality of groundwater
	Magnesium	Indicator of hydrogeology and leaching of fertiliser into groundwater.
	Manganese (dissolved)	Indicator of hydrogeology, reducing-oxidising conditions and aesthetic and health quality of groundwater.
	Potassium	Indicator of hydrogeology and leaching from land-use activates into groundwater.
	Silica	Indicator of hydrogeology - water rock interaction.
	Sulphate	Indicator of hydrogeology and leaching from land-use activities to groundwater.
	Total hardness	Indicator of hydrogeology and aesthetic quality of groundwater.
	Total dissolved solids	Indicators of overall water quality, mineralisation and used for comparison of groundwater quality over time.
Nutrient	Ammoniacal-N	Indicator of reducing vs. oxidising conditions which may be associated with leaching from agricultural and other land-use activities.
	Nitrate-N	Indicator of seasonal variations associated with recharge and leaching of fertilisers, contamination agricultural land-use activities.
	Nitrite-N	Indicator of reducing vs. oxidising conditions which may be associated with leaching from agricultural and other land-use activities
	Dissolved Reactive Phosphorus(DRP)	Indicator of leaching of fertilisers, contamination from agricultural land-uses or human waste.
Physical	Temperature	Physical variable.
	pH	Measure of acidity or alkalinity.
	Dissolved Oxygen	Measure of dissolved oxygen concentration (mg/L) or percent saturation.
	Electrical Conductivity	Indicator of ionic concentration of groundwater and correlates with the total dissolved solids.

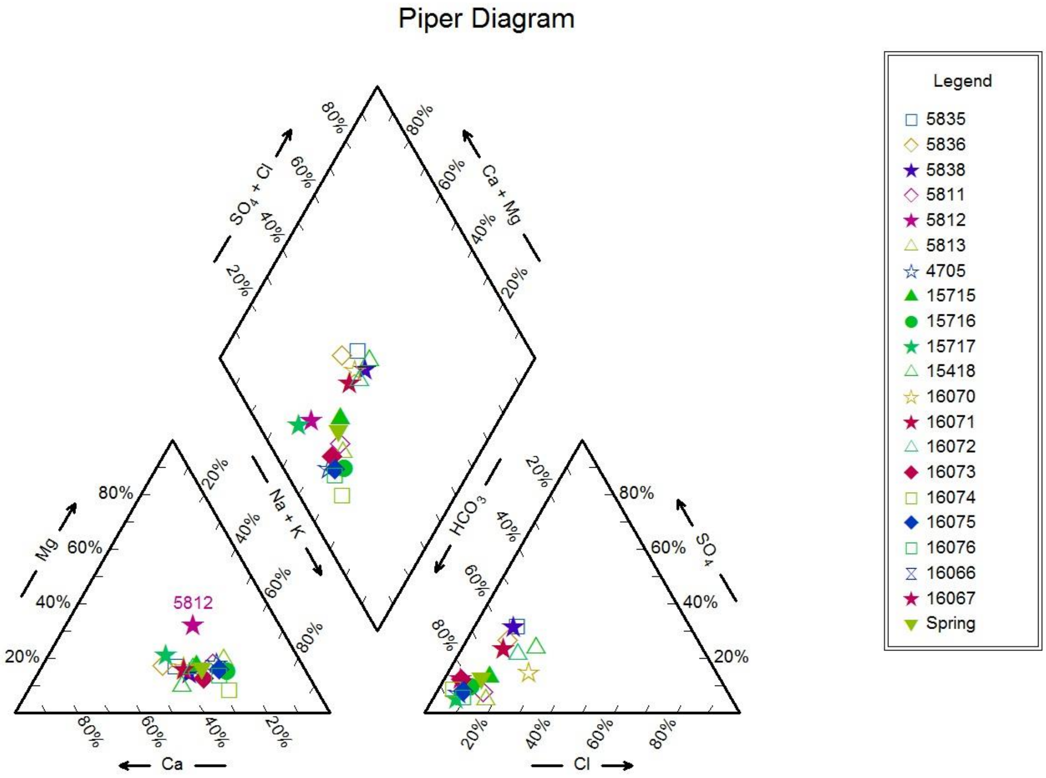


Figure 5-18: Piper diagram of major ion chemistry of bore in the Taharua catchment.

5.7.4 Taharua Groundwater Nutrient Investigations

Dissolved nitrogen and dissolved phosphorus has been monitored at a monthly frequency at 13 sites from 2008 to 2013 in response to declines in water quality in the Taharua and Upper Mohaka Rivers.

5.7.5 Dissolved nitrogen species

Nitrogen (N) typically occurs in groundwater as three soluble forms – ammoniacal-N, nitrite-N and nitrate-N. Soil microbes may convert nitrogen into other forms, from organic sources such as plant material, animal dung or urine. There may also be inter-conversion of these forms within the soil or groundwater. Some biochemical processes convert soluble nitrogen into gaseous forms (nitrogen gas or nitrous oxide), which are lost to the atmosphere.

These three soluble forms of nitrogen are important plant nutrients. Elevated concentrations discharging from groundwater may stimulate nuisance plant growth in surface waterways. Ammoniacal-N may be toxic to aquatic life and nitrite-N has also been associated with adverse human health effects. Management of land use is one option that may be used to minimise inputs of soluble-N to groundwater.

5.7.6 Dissolved phosphorus

Natural sources of phosphorus occur in rocks and minerals and is a common component in soils and sediments as phosphate (compounds containing the phosphate ion, PO_4^{-3}). The most common mineral form is apatite in the form of calcium phosphate. Weathering of rocks with this mineral releases phosphorus ion into bio-available forms, suitable for uptake by plants.

Apatite is common in volcanic rocks and is abundant in sediments. It has been demonstrated that phosphorus may leach apatite minerals from fresh volcanic pumice in the Taupo catchment (Timperly, 1983).

Other sources of phosphorus are phosphate fertilisers which are widely applied to improve phosphorus availability, enabling agricultural intensification and improved production. Phosphorus (in both soluble and complex organic forms) is also a key component of domestic wastewater and animal waste.

Phosphorus is highly reactive and will adsorb onto clay and organic matter in the soil and aquifer material so its mobility in most aquifers is relatively low. High calcium, aluminium and iron concentrations will reduce phosphorus solubility (Rosen, 2001). Elevated concentrations in groundwater may indicate influences of human and agricultural land-use activities where the capacity of the soil has been saturated. Phosphorus is also a key plant nutrient together with nitrogen, and elevated phosphorus concentrations are associated with undesirable growths (periphyton, algae and vascular plants) in streams, rivers and lakes.

5.7.7 State of nutrient in Taharua groundwater

Monitoring results from shallow bores and synoptic surveys of water supply bores indicate that concentrations of nitrate-N in the shallower Taupo pumice aquifer of the upper Taharua catchment (Figure 5-19) are elevated compared to sites in the lower catchment. This is likely to be related to the intensive dairy land-use in the upper catchment compared to sheep and beef and forestry land-use in the lower catchment (Figure 5-21). By comparison, the Nitrate-N concentrations in the deep bores within the gravel and ignimbrite aquifer have little variation and concentrations are less than 2 mg/L.

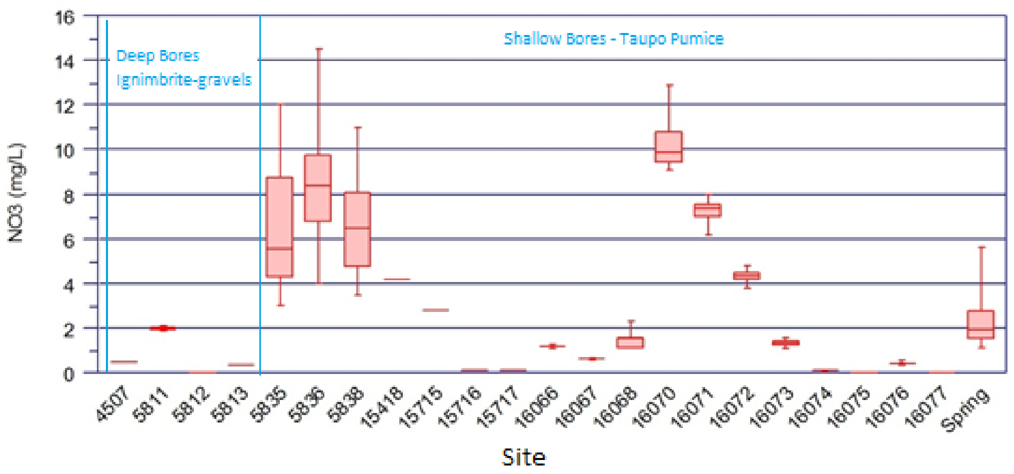


Figure 5-19: Box plot of nitrate-N concentrations from all bores surveyed in the Taharua catchment. Boxes show medians, with inter-quartile range (25% and 75 % in the boxes) and whiskers show 5%-95% percentile.

Soluble phosphorus concentrations are generally low in shallow bores in the pumice aquifers (Figure 5-20). Greater concentrations were observed in bores from the deeper aquifers within the ignimbrite and gravel formations. This is consistent with results from studies in Rotorua, which identified elevated phosphorus due to long residence time of groundwater that caused dissolution of apatite minerals in volcanic ignimbrite rock formations (Morgenstern et al., 2004). Isotope analysis of deeper bores in the Taharua catchment has confirmed the long residence time in the deeper groundwater. However, because the deep bores are screened across several formations, the sources of phosphorus cannot be identified. Additionally, two shallow bores (16066 and 16075) also have higher phosphorus content. The reason for anomalous concentrations in these two shallow bores is not known at this time.

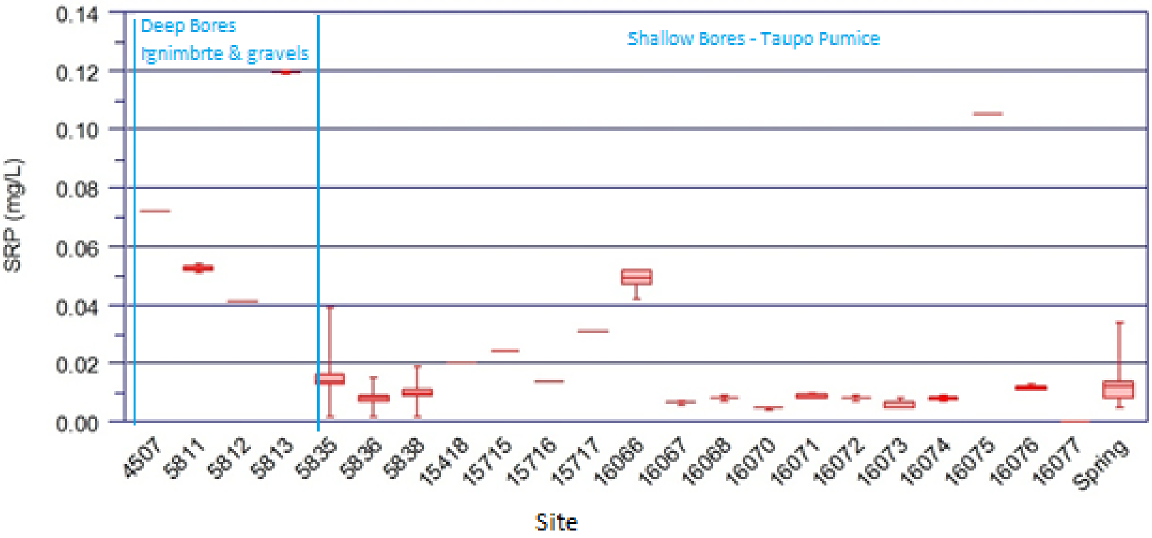
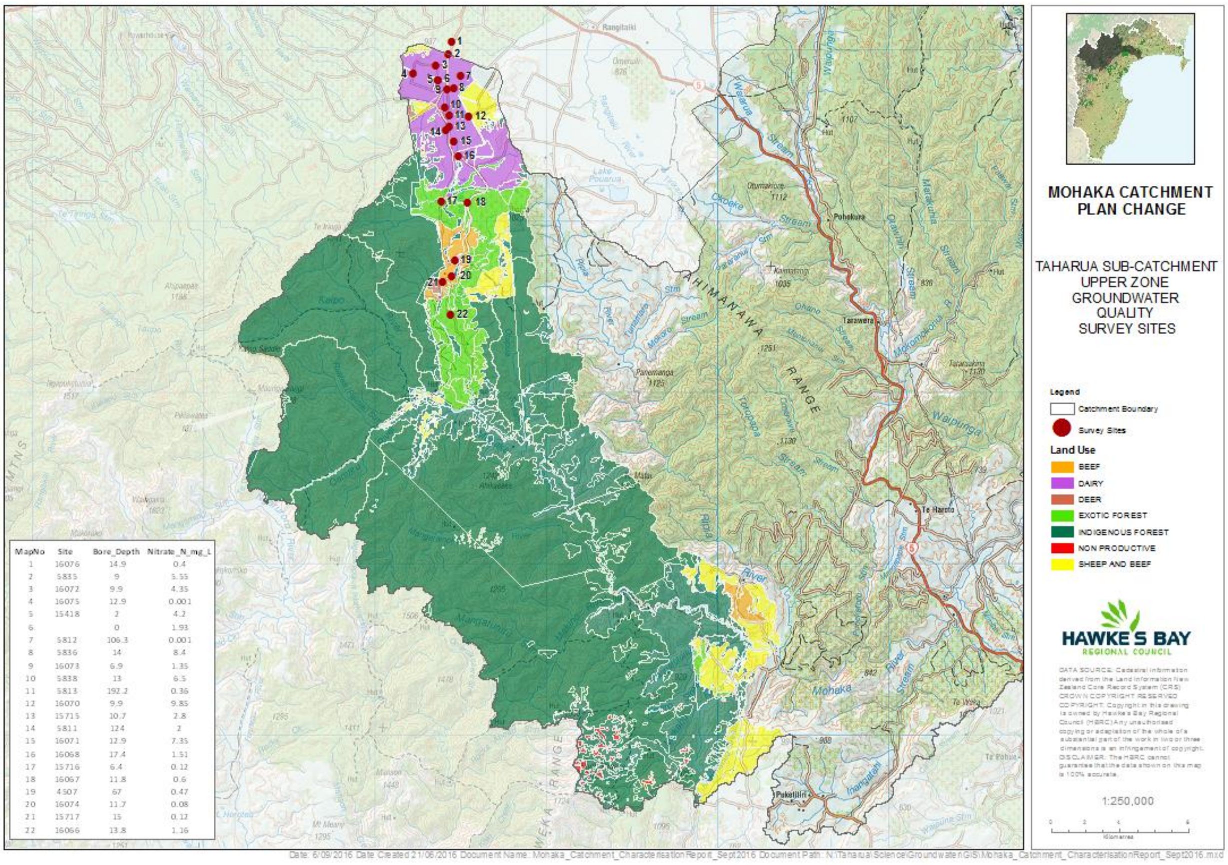


Figure 5-20: Box plot of soluble phosphorus concentrations from bores sampled in the Taharua catchment.



MapNo	Site	Bore_Depth	Nitrate_N_mg_L
1	16076	14.9	0.4
2	5835	9	5.55
3	16072	9.9	4.35
4	16075	12.9	0.001
5	15418	2	4.2
6		0	1.93
7	5812	106.3	0.001
8	5836	14	8.4
9	16073	6.9	1.35
10	5838	13	6.5
11	5813	192.2	0.36
12	16070	9.9	9.85
13	15715	10.7	2.8
14	5811	124	2
15	16071	12.9	7.35
16	16068	17.4	1.51
17	15716	6.4	0.12
18	16067	11.8	0.6
19	4507	67	0.47
20	16074	11.7	0.08
21	15717	15	0.12
22	16066	13.8	1.16

Figure 5-21: Median Nitrate-Nitrogen levels and land-use at groundwater quality survey sites in the Taharua-sub-catchment.

5.7.8 Nutrients Trends

Environmental data may show changes through time. A non-parametric statistical trend approach is used here because the data are not normally distributed (Hem, 1990). The statistical trend analysis method used here is similar to that used by Ballantine (2013) in a recent national water quality project for advice on trend analysis. However, this report includes the additional step of identifying whether the water quality exhibits seasonal variation. Seasonality in water quality data may prevent the detection of trends because concentrations of some water quality parameters vary through the year, such as seasonal rainfall and temperature.

This analysis approach includes the following steps:

1. Kruskal-Wallis one-way analysis of variance to identify if seasonal variation is present.
2. If seasonality is evident, then a Seasonal Kendall test was used with four seasons of multiple values from each calendar year. If no seasonality is evident, the non-parametric Mann-Kendall test was performed using all values.

Trend analysis was performed using NIWA time-trends analysis package for monitoring sites. Trend analysis was carried out on sites with monthly data available for at least three years.

The Mann-Kendall and seasonal Mann-Kendall are commonly used non-parametric methods for detecting statistical trends. Non parametric techniques are those that do not rely on data belonging to any particular distribution. Both of these tests identify if the variability in the data is randomly distributed or if a significant trend exists through time. The null hypothesis or baseline condition for this test is that there is no temporal trend in the data. The alternative condition or hypothesis will be either an upward trend or a downward trend.

A statistically significant trend exists when there is less than a 5% probability (p-value) that the trend could have arisen by chance alone. Therefore, if the associated p-value is small ($P < 0.05$), then the null hypothesis of “no trend” is rejected and a significant trend (positive or negative) is identified.

To estimate the strength of the trend, the non-parametric median Kendall Slope Estimator (KSE) was used to identify the magnitude and direction of each individual trend. Values of the KSE were divided by the raw data median to normalise and present the Relative KSE (RKSE) as a percent change per year. A positive RKSE value indicates an overall increasing trend, while a negative RKSE value indicates an overall decreasing trend.

A statistically significant trend may not represent a ‘meaningful trend’. Scarsbrook (2006) recognised a meaningful trend as one that is statistically significant ($P<0.05$) and has a rate of change > 1% per year. The concept of a meaningful trend relates to a change of at least 1% per annum, which corresponds to at least 10% change per decade. A meaningful trend is one that would be noticed by water users and observers within a human lifespan and is therefore considered to be meaningful in a resource management context. The meaningful trend concept has been adopted by the Ministry for the Environment and is used here for interpretation of water quality trend statistics.

Trends were categorised as follows;

No significant trend – the null hypothesis for the Kendall test was not rejected ($P > 0.05$);

Significant trend (increase/decrease) – the null hypothesis for the Kendall test was rejected ($P < 0.05$). Note that the trend at some sites may be significant, but not meaningful;

Meaningful trend (increase/decrease) – the null hypothesis for the Kendall test was rejected ($P < 0.05$) and the relative magnitude of the trend was greater than one percent per annum of the raw data median (i.e., the KSE value was greater than 1% per year).

Trends could only be evaluated for three monitoring bores (5835, 5836 and 5838), along with the Taharua spring, because only these sites have greater than 3 years of monthly data. Bores 5835, 5836 and 5838 have greater than 5 years of monthly data, while the Taharua spring has 3 years and 11 months of data. No detectable seasonality was found for groundwater monitoring bores 5835, 5836 and 5838. However, seasonal variation was observed in the Taharua spring data. Therefore, Mann-Kendall Tests were performed on data from the groundwater monitoring bores and Seasonal Kendall test was performed on Taharua spring.

5.7.9 Nutrient Trend Results

The results of the Kendall trend analyses for nitrate-nitrogen are summarized in Table 5-11.

Table 5-11: Trend analyses(Kendall) for nitrate-nitrogen ($N0_3$-N) in monitoring bores and Taharua spring.

Site	Period	No of Samples	Median	P-value	KSE/SKSE	Statistically significant (p<0.05) Trend	Relative Percent Annual Change	Meaningful Trend >1%/year)
5835	30/5/08-19/12/13	59	5.55	0.000	-1.278	Decreasing	22%	Decreasing
5836	30/5/08-19/12/14	61	8.40	0.000	0.856	Increasing	10%	Increasing
5838	30/5/08-19/12/15	39	6.50	0.000	-1.216	Decreasing	20%	Decreasing
Taharua Spring	23/2/10-19/12/13	59	1.96	0.284	-0.282	No trend	21%	No trend

Meaningful decreasing trends in nitrate-N were identified for bores 5835 (Figure 5-22) and 5838 (Figure 5-23) (Table 5-11). In bore 5835, the most significant decrease occurred from 2008 to 2011, while nitrate-N levels varied between 4 mg/L and 6 mg/L from 2011 to 2014 (Figure 5-22).

No trend was found in nitrate-N concentrations for the Taharua spring during the period of monitoring (Figure 5-24). A meaningfully increasing nitrate-N trend was identified for bore 5836 (Figure 5-25). The reason for the increasing trend in bore 5836 compared to monitoring bores 5835 and 5838 is likely to be related to lag-time effects of nitrogen moving through shallow groundwater of the Taupo pumice aquifer. This interpretation is based on the mean residence time of groundwater in bore 5836 which, at 3.5 years, has the oldest residence time of the three monitoring bores.

All three monitoring sites are located on a dairy farm which has undergone a significant decrease in stocking rate and associated reduction in nitrogen inputs after a change in farm ownership in 2009[5]. Further monitoring is needed to confirm the validity of these trends. Five years may be sufficient for identifying short term trends (LAWNZ, 2010) but a period of 10 years is required for robust trend analyses (Ballentine, 2012).

Two of the five sites had increasing meaningful trends in soluble phosphorus (Table 5-12); 5835(Figure 5-26) and Taharua spring (Figure 5-27). It is unclear what caused the increasing trends at these sites. However, the Taharua spring and bore 5835 have younger groundwater age closer to the recharge source which may indicate breakthrough of phosphorus to the aquifer occurred when absorption capacity of soils was exceeded.

No statistically significant trends in ammoniacal–N or nitrate-N were found at monitoring sites 5835, 5836, 5838 and Taharua spring.

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[5] personal communication with B Powell, Hawke's Bay Regional Council, 2014

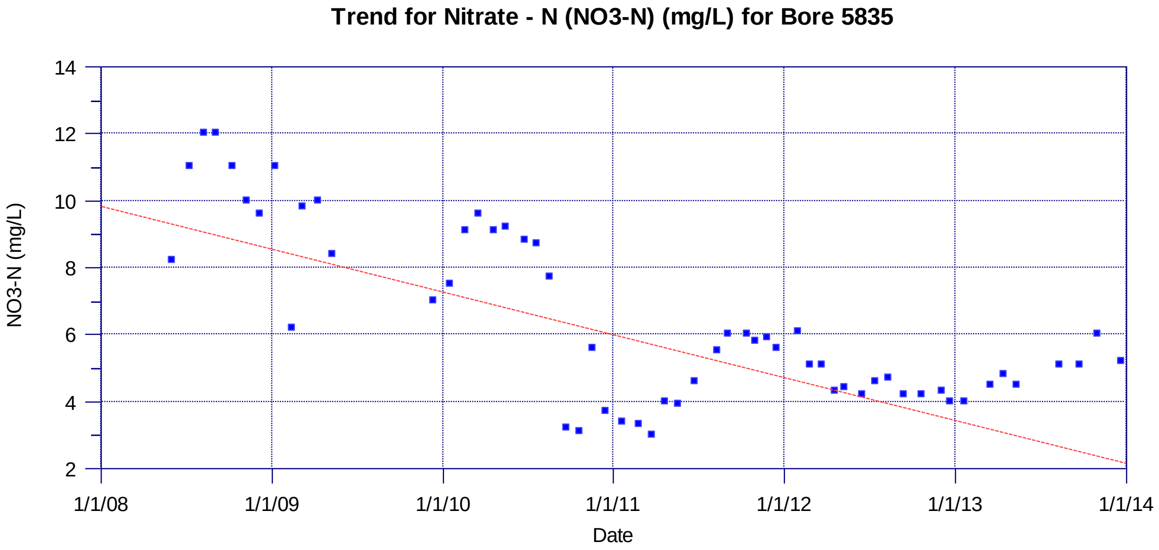

Figure 5-22: Nitrate-N trend in shallow monitoring bore 5835.

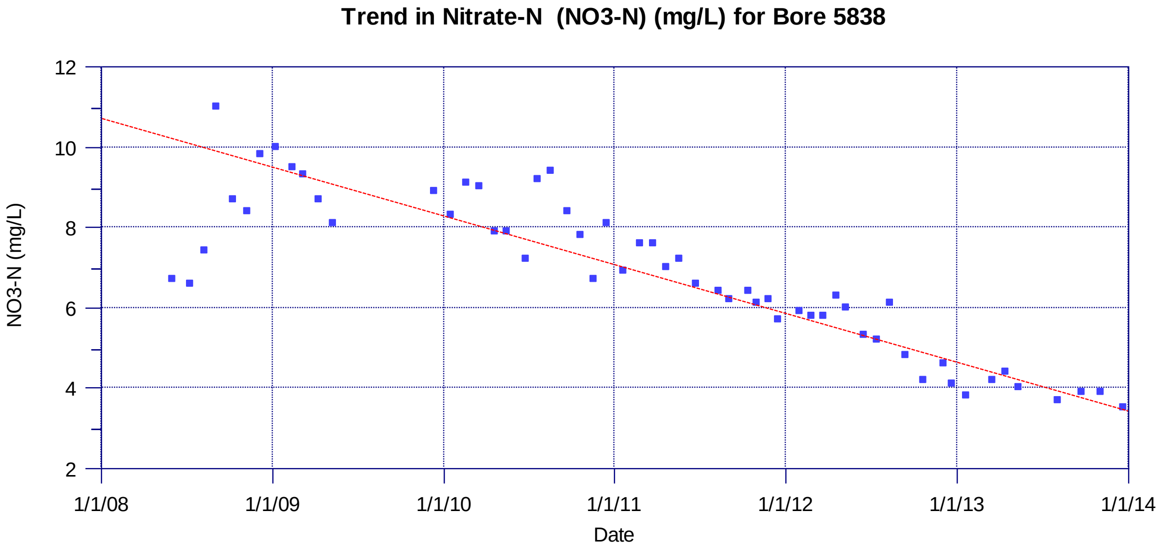

Figure 5-23: Nitrate-N trend in shallow monitoring bore 5838.

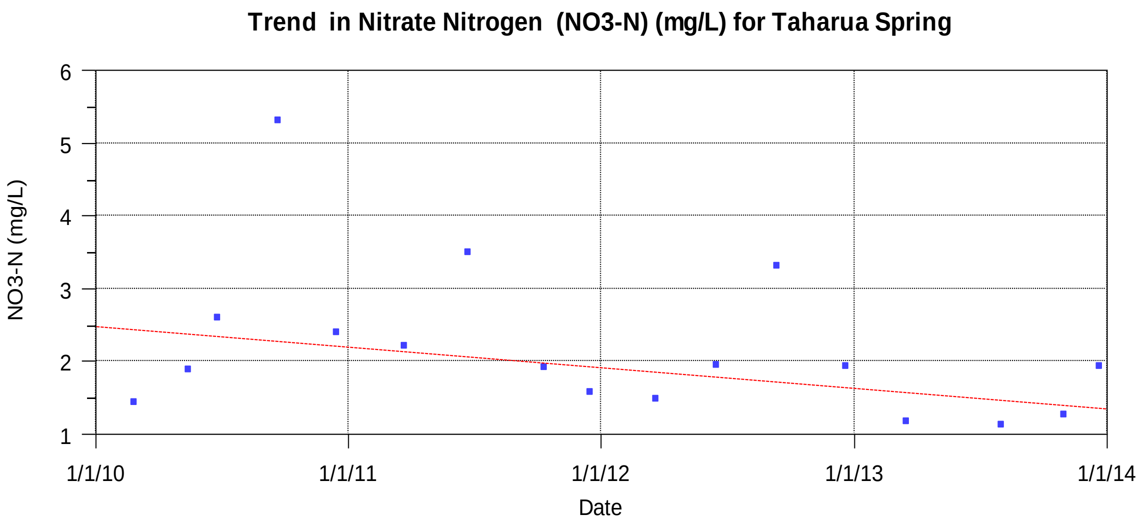

Figure 5-24: Nitrate-N trend in Taharua spring.

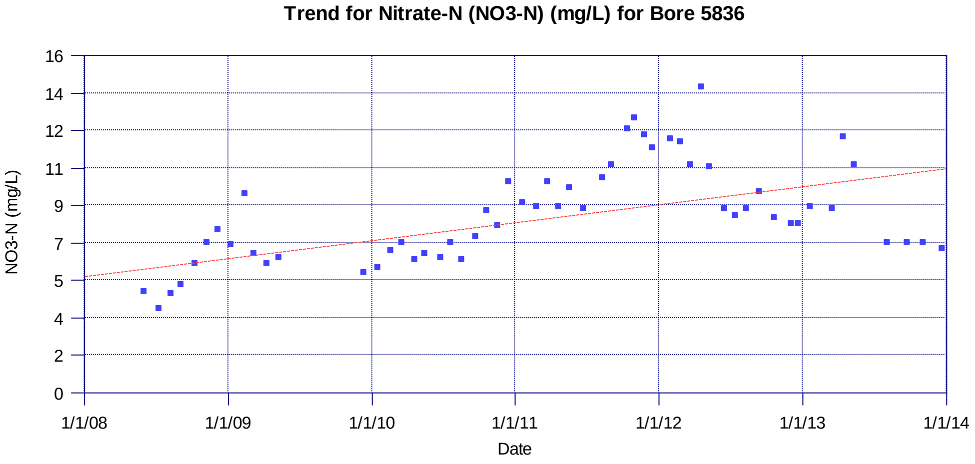

Figure 5-25: Nitrate-N trend in shallow monitoring bore 5836.

Table 5-12: Trend analysis(Kendall) for phosphorus (soluble) in monitoring bore 5835, 5836, 5838 and Taharua Spring.

Site	Period	No. of Samples	Median	P-value	KSE/SKSE	Statistically significant (p<0.05) Trend	Relative Percent Annual Change	Meaningful Trend >1%/year)
5835	30/5/08-19/12/13	59	0.0140	0.062	0.00050	Increasing	4%	Increasing
5836	30/5/08-19/12/14	59	0.0080	0.000	0.00000	No trend	0%	No trend
5838	30/5/08-19/12/15	61	0.0100	0.000	0.00000	No trend	0%	No trend
Taharua Spring	23/2/10-19/12/13	39	0.0120	0.023	-0.28200	Increasing	14%	Increasing

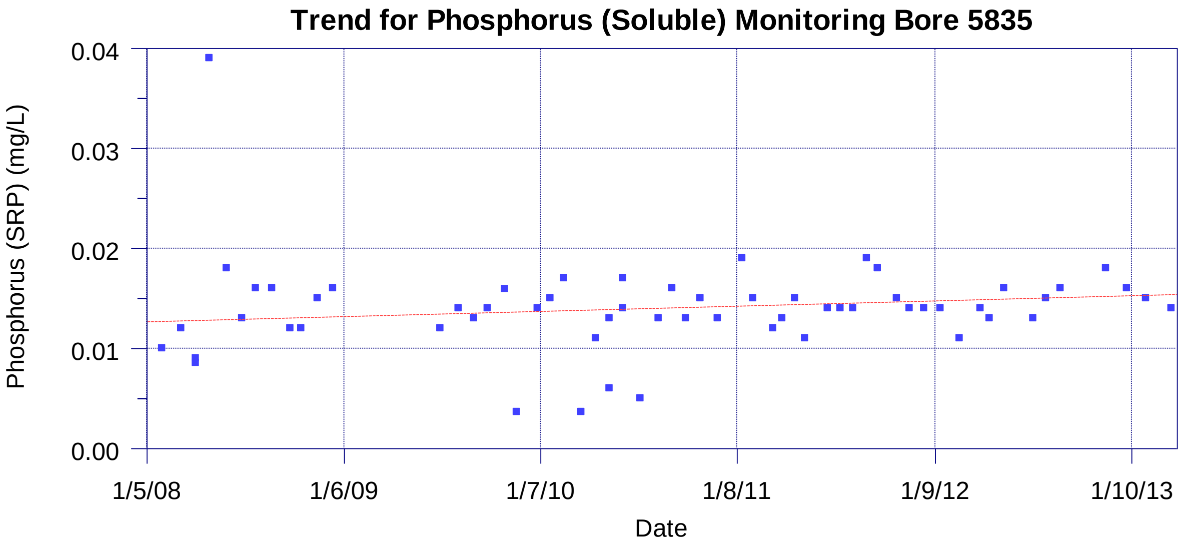

Figure 5-26: Phosphorus trend in shallow monitoring bore 5835.

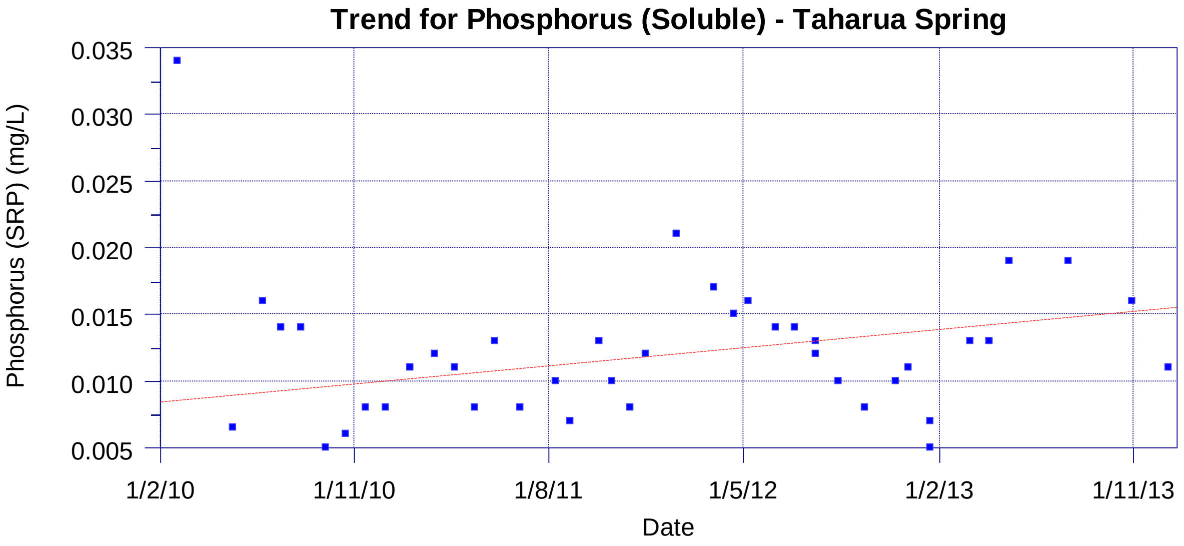

Figure 5-27: Phosphorus trend at Taharua Spring.

5.8 Summary and conclusions

The geology of the Mohaka catchment consists of mostly soft sedimentary rock in the mid to lower catchment and hard Greywake basement rock, volcanic ignimbrite rock and unconsolidated pumice in the upper cathcment. The volcanic ignimbrite rock and unconsolidated pumice are sourced from the Taupo Volcanic Zone.

The known groundwater resource in the Mohaka catchment is mostly confined to the volcanic ignimbrite in the upper catchment of the Taharua valley. The remainder of the Mohaka catchment is dominated by greywacke rock, which is unlikely to yield a productive groundwater resource. In the lower Mohaka catchment several bores have been drilled into the sedimentary mudstone, sandstone and limestone rock formations, but there is little information known about the groundwater resource in these rock formations.

The focus of groundwater investigation has been on the Taharua sub-catchment to support water quality investigations. From available geological bore logs, three water bearing formations are found in this sub-catchment:

4. Gravels eroded from the nearby greywacke ranges.
5. Ignimbrite rock aquifer sourced from the eruptions in the northern Taupo Volcanic Zone. Both of these formations are between 30m and 100m depth.
6. A shallow Taupo Pumice aquifer up to 20m thick forms the third and main aquifer in the Taharua catchment.

Chemical groundwater quality assessment of shallow investigations bores and private water supply bores in the Taharua Catchment indicate the groundwater in both the shallow Taupo pumice aquifer and the deeper Ignimbrite/gravel aquifer ignimbrite can be used for drinking without treatment in terms of the MAV. The Taupo pumice aquifer is impacted by nitrate-N in the upper Taharua sub-catchment and at some sites have high nitrate-N which is half the MAV. The most likely sources of the nitrate-N are from intensive dairying in this area. Some sites in the shallow pumice aquifer are also elevated in iron and manganese and do not meet the guideline values for aesthetics. Most sites also comply with the ANZECC irrigation guidelines except for low hardness. The low hardness may cause corrosion of metal pipework.

Trend analyses of data from shallow bores and Taharua spring indicates that nitrate-N in groundwater has decreased in 2 bores and increased in 1 monitoring bore and phosphorus levels have increased in 1 monitoring bore and the Taharua spring. The sites with both increasing and decreasing trends are located in the vicinity of dairy farms. All 3 monitoring sites are located on a dairy farm which has undergone a significant decrease in stocking rate and associated reduction in nitrogen inputs after a change in farm ownership in 2009[6]. Further monitoring is needed to confirm the validity of these trends.

Results from water age assessment indicate that the groundwater from the deep ignimbrite/gravel aquifer has a mean residence time greater than 90 years suggesting that the groundwater in the deeper ignimbrite aquifer is very old and has a long residence time indicating that the active groundwater flows does not reach this depth. Groundwater in the shallower Taupo Pumice aquifer groundwater has a mean residence time of less than 5 years suggests that recharge source is derived from local rainfall recharge sources.

The age of Taharua River water increases down the catchment from 1 year at the spring to 8 years at the confluence with the Mohaka River. This steady increase in water age downstream in the Taharua River

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[6] personal communication with B Powell, Hawke's Bay Regional Council, 2014

indicates an increasing contribution of water from longer flow paths from deeper parts of the groundwater system with increasing distance from the head of the recharge area. The presence of significant amounts of old water in the stream is probably related to larger water storage capacity of the volcanic pumice aquifer material. Good hydraulic conductivity of the volcanic material in the Taupo Pumice aquifer is suggested by streams sourced from the greywacke rock hill country running dry at the interception with the volcanic pumice which infills the valley forming the current topographic surface (Morgenstern, 2014).

6 Terrestrial Ecology of the Mohaka catchment

This section characterises the terrestrial ecology, including land environments, indigenous habitats defined by vegetation types, and threatened species of the Mohaka catchment.

6.1 Land environments

The land environments of the catchment are characterised using Land Environments of New Zealand (LENZ). LENZ is a national classification based on climate, soil and landform, which ultimately defines flora and fauna adapted to the environment. Land environments of the Mohaka catchment are classified in four major classes (**Figure 6-1**). These include the following:

- Central Mountains (P): cool climate, steep mountainous terrain with well drained and low fertility soils.
- Central hill country and volcanic plateau (F): mild winter climate, undulating landforms with well-drained and very low fertility tephra based soils.
- Central dry foothills (E): dry foothills and basin floors at mid elevations with well-drained, low fertility soils.
- Northern hill country (D): warm climate, rolling hills with imperfectly drained soils of moderate fertility.

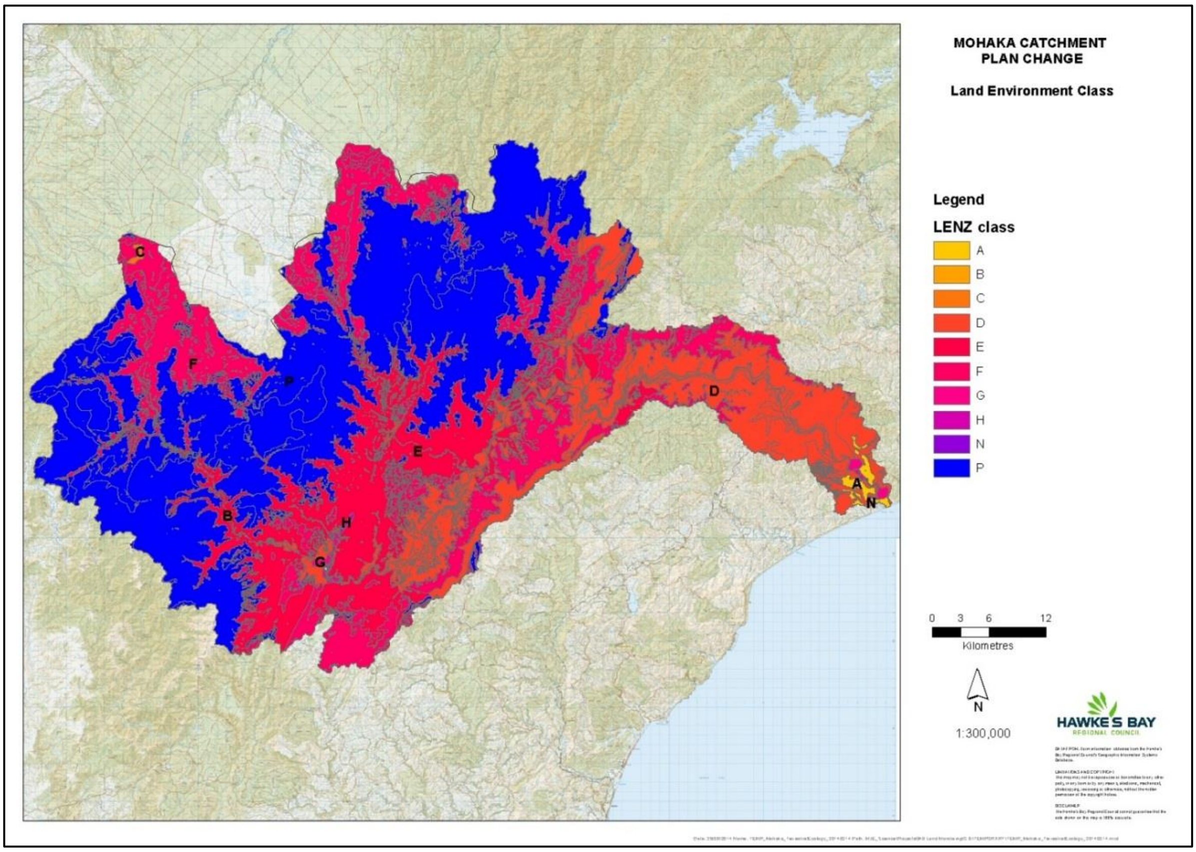

Figure 6-1: Land Environments of New Zealand classifications in Mohaka catchment. LENZ is a national classification based on climate, soil and landform. There are 4 levels of classifications (Levels 1, 2, 3 and 4) of which Level 1 is shown here.

6.2 Past and Present Terrestrial Habitats

The main indigenous habitat types of the catchment used to be indigenous forest, comprising nearly 100% of the land (Figure 6-2). Beech forest dominated the higher elevations and steeper terrain. Podocarp and broadleaved forests were extensive from middle altitudes down to the coast. Kahikatea dominant swamp forest was the main vegetation of the Mohaka river mouth.

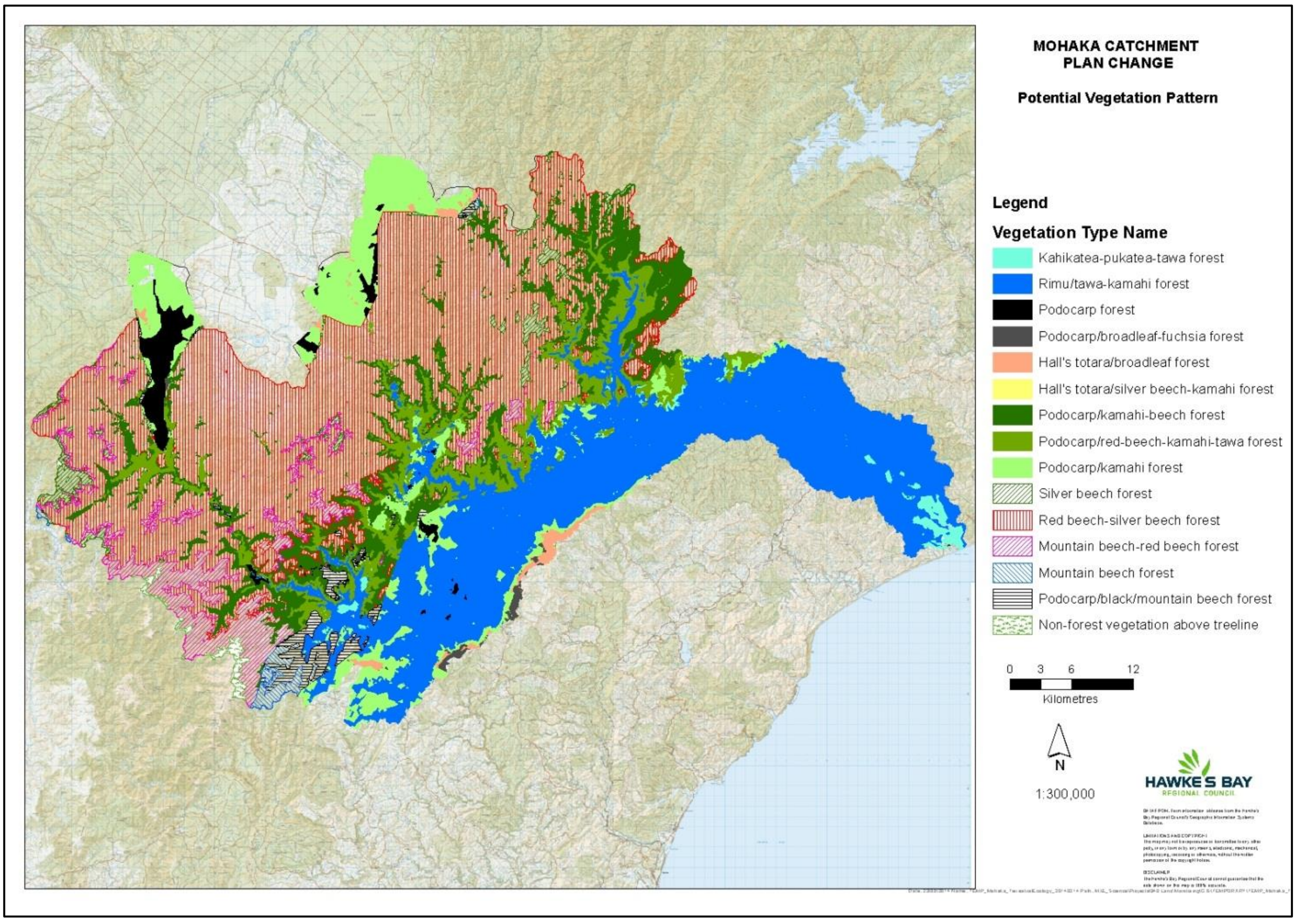

Figure 6-2: Potential indigenous vegetation patterns of Mohaka catchment. The potential vegetation pattern shows the extents of broadly categorised forest communities under optimal conditions. "Optimal conditions" assumes the absence of large-scale disturbances such as fire. According to this model, nearly all of the land areas within the catchment supported indigenous forest habitats, with scrub habitats above the treeline.

Approximately 51% of the original indigenous forest extent remains today (Figure 6-3). Most of the remaining indigenous forest is at higher elevation mainly due to the presence of formal protection (Figure 6-4), as well as difficult terrain unsuitable for agricultural use. Podocarp forest in the middle to lowland has been reduced dramatically, largely being converted to exotic plantation forest and pastures.

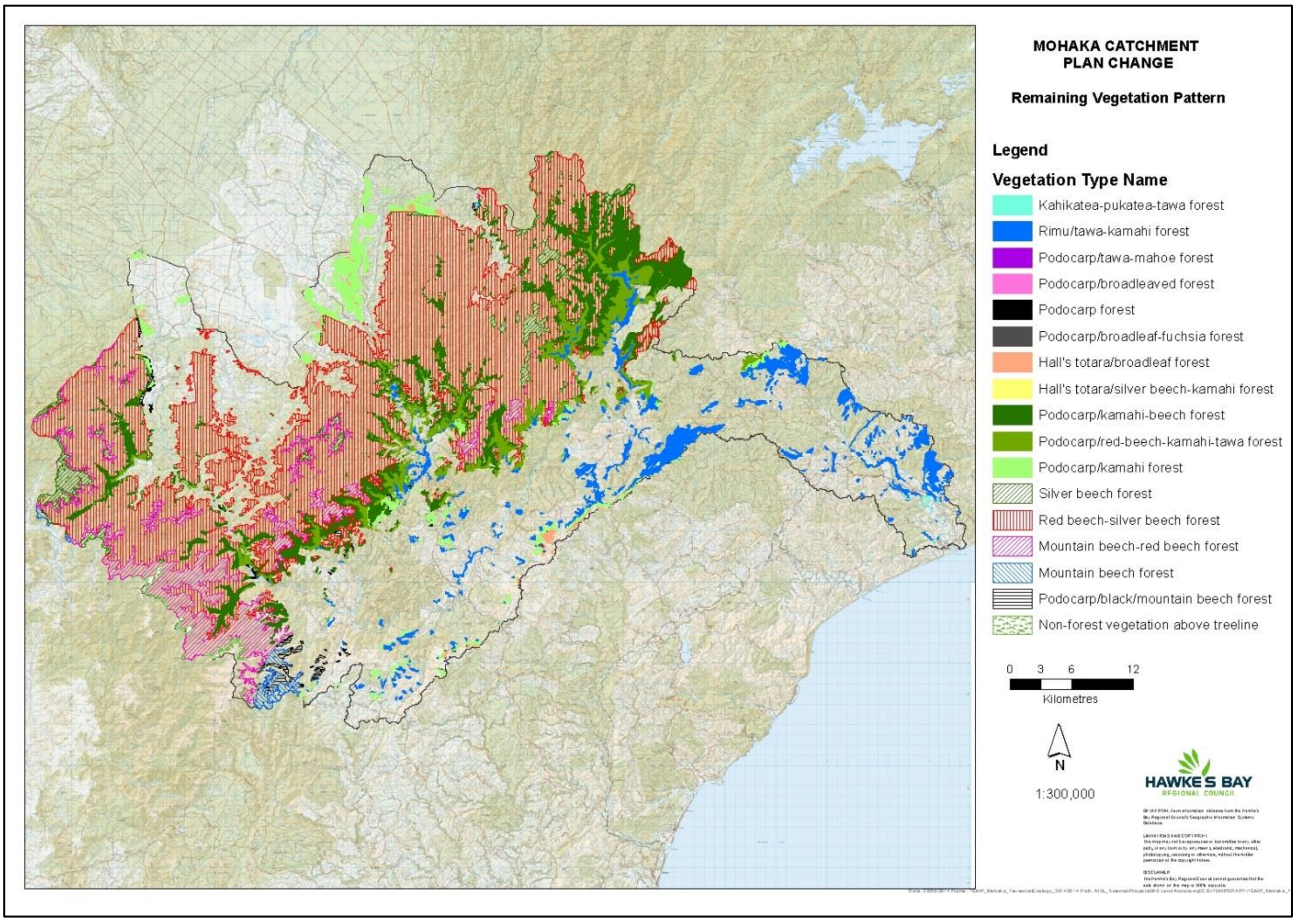

Figure 6-3: Remaining indigenous forest and alpine vegetation in Mohaka catchment. The extent of current indigenous forest and alpine vegetation is derived from Land Cover Database (version 3). Note that the extent of manuka/kanuka shrubland is not included in this map.

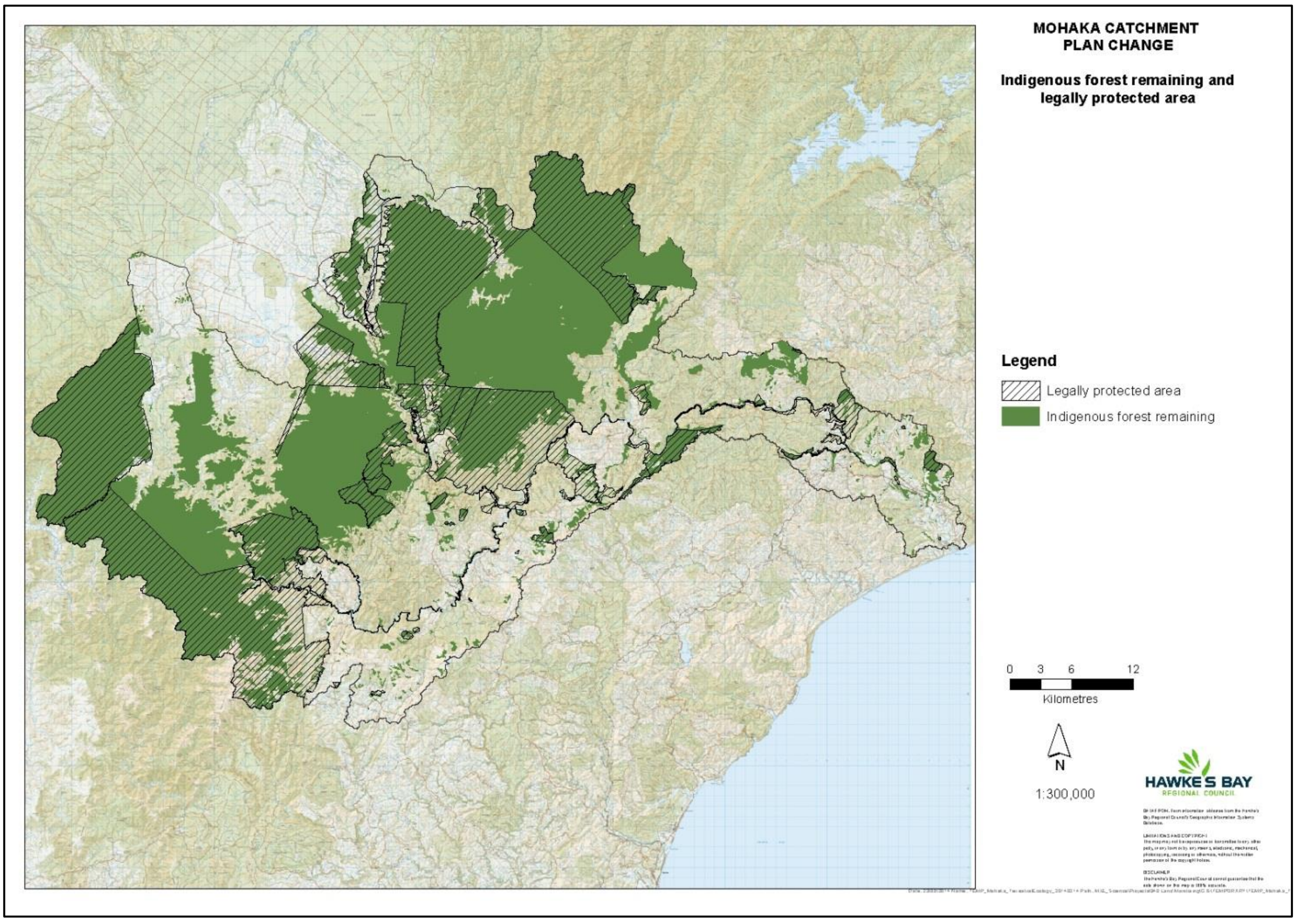

Figure 6-4: Indigenous forest and alpine vegetation remaining and legally protected areas. Indigenous forest remaining (green shaded areas) contains all vegetation types shown in above figures. Legally protected areas include DoC's public conservation area, Nga Whenua Rahui, and QEII.

Indigenous forest is the most dominant landcover type, at 48% of the total catchment area, followed by exotic forest (15%), manuka/kanuka shrubland (15%) and exotic grassland (13%) (Figure 6-5). This is different to the regional picture, where exotic grassland dominates the landscape (48% of the region's land area) and a relatively smaller proportion of the land area is indigenous forest (20%) (Figure 6-6).

Thirty-six percent of the catchment area is under some form of formal protection. This proportion is higher than the regional proportion, where 22% of the regional land area is protected.

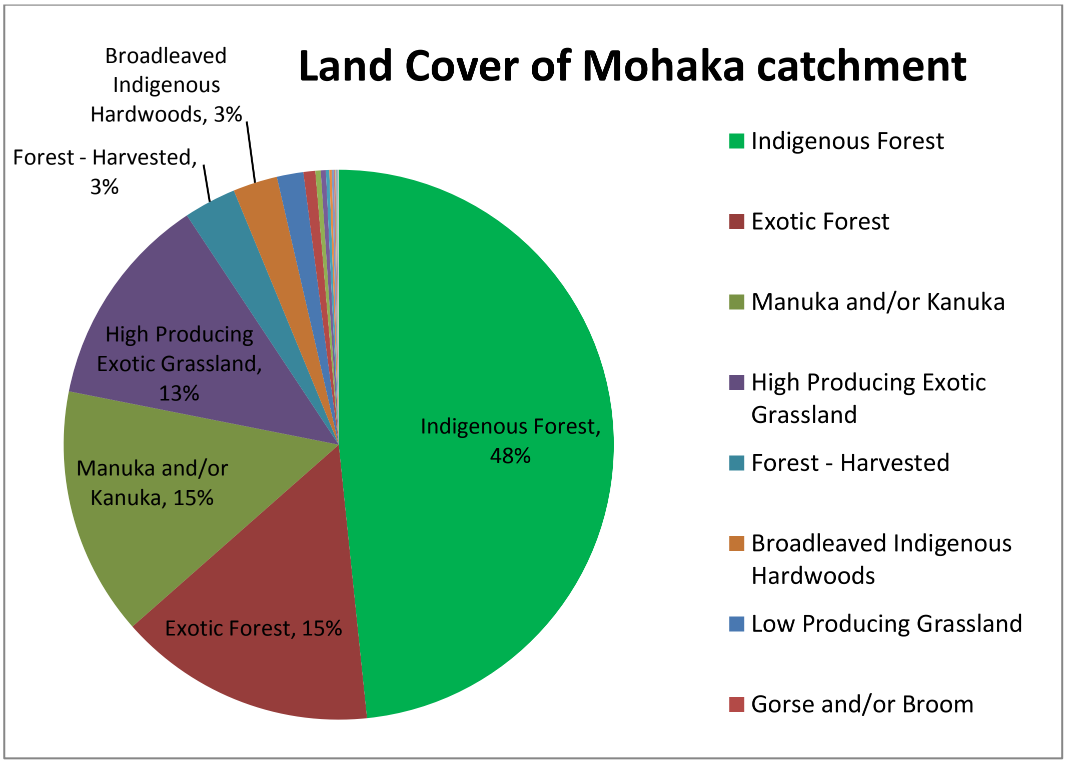

Figure 6-5: Land cover of Mohaka catchment. Data is derived from Land Cover Database (version 3).

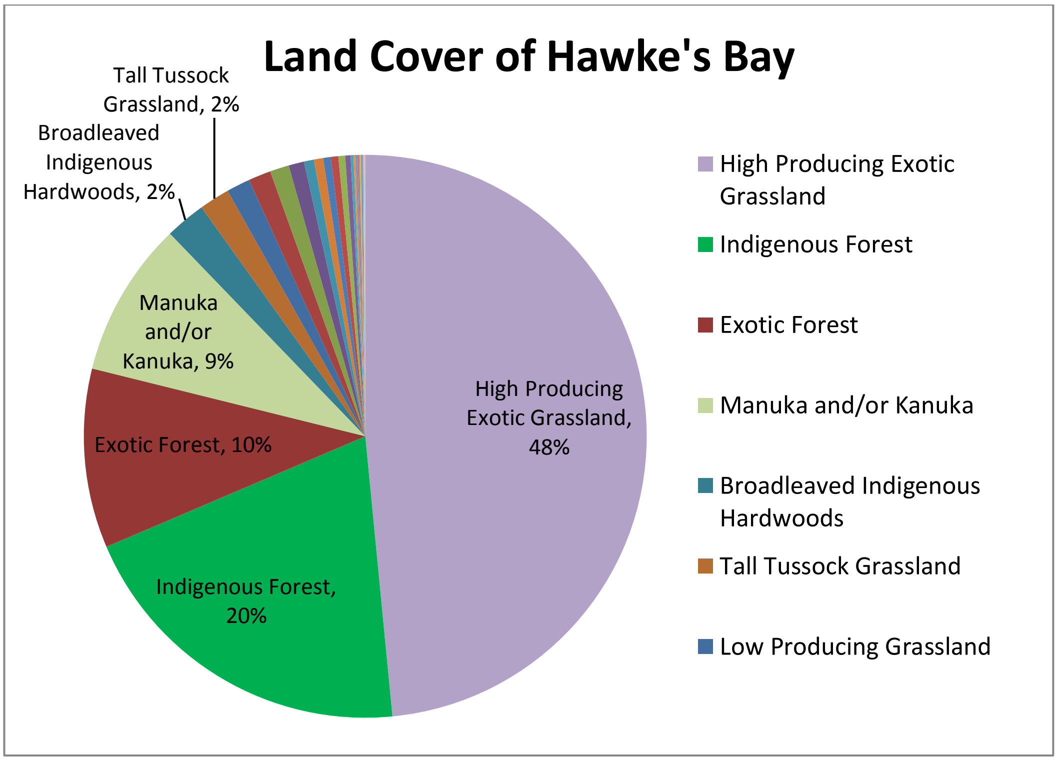

Figure 6-6: Land cover of Hawke's Bay region. Regional picture of land cover pattern. Data is derived from Land Cover Database (version 3).

6.3 Threatened environments[7]

Parts of the Taharua, Ripia and Waiaura sub-catchments and the Mohaka River mouth are classified as 'Acutely Threatened' land environments (where less than 10% of indigenous cover remains) (Figure 6-7). Small areas within protected areas are classified as ‘Acutely Threatened’. Land along the main stem of the Mohaka River is classified as 'Chronically Threatened' (10-20% indigenous cover remaining). However, overall the Mohaka catchment has a much lower proportion of Acutely Threatened and Chronically Threatened land environments than the regional total (55%).

Podocarp forests were once extensive in the catchment, but are now reduced in their extents, and remaining forests are fragmented. Where such remnants are reduced to less than 20% of their original sizes are likely to degrade quickly, which may lead to irreversible loss of those forest communities.

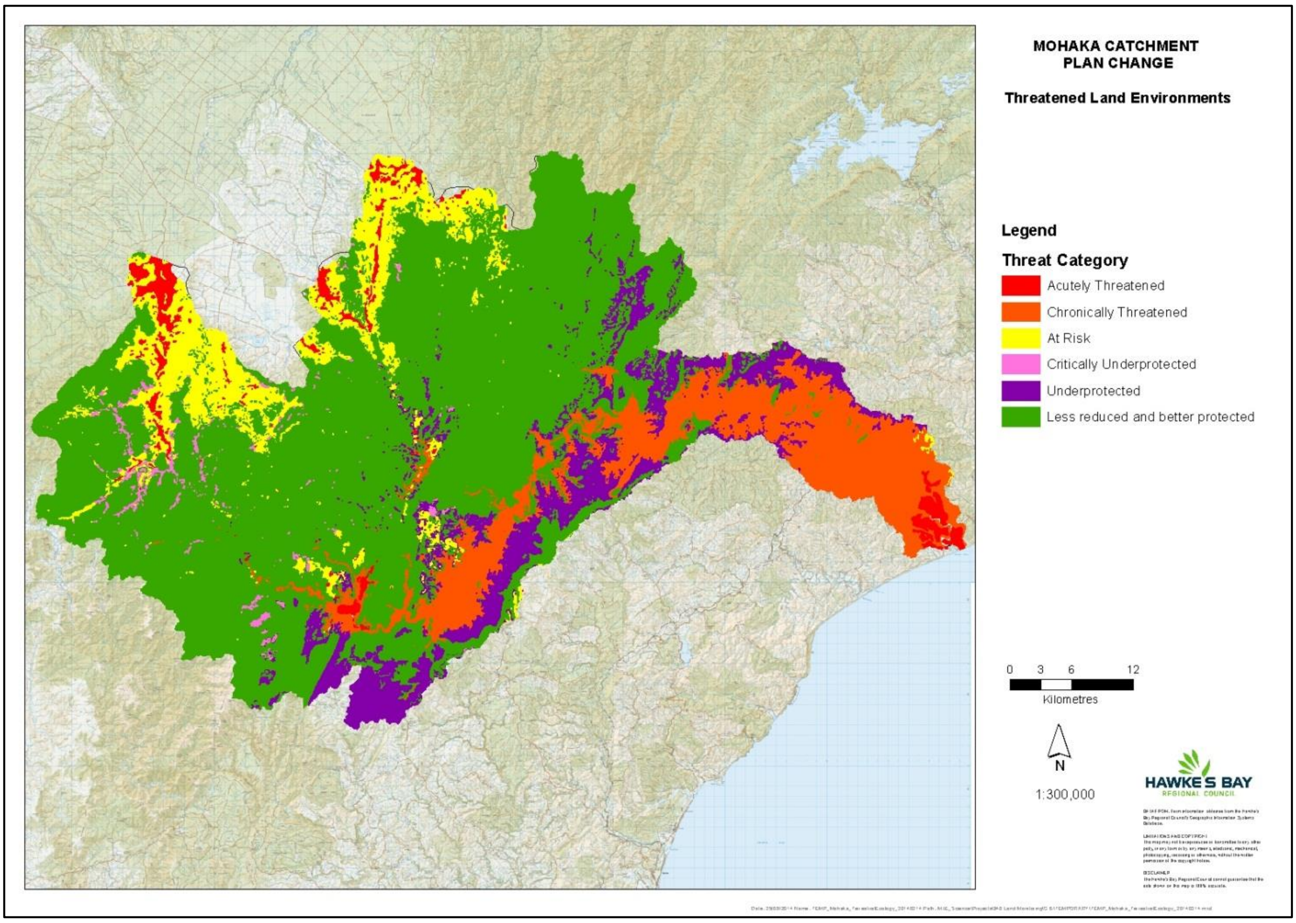

Figure 6-7: Threatened environments of Mohaka catchment. Threat classification is based on Walker et al. (2007).

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[7] See Appendix A for Threatened Environment Classification framework

6.3.1 Historically Rare Terrestrial Ecosystems

Historically Rare Terrestrial Ecosystems are those having a total extent less than 0.5% (approximately 134,000 ha) of New Zealand's total area (Williams, 2007). Ecosystems are defined by physical environments (such as soil age and parent material). There are seventy-two rare ecosystems nationally.

Frost flats are one such ecosystem, which is found on flat-floored pumice-filled basins with year-round frosts and very infertile soils (Smale, 1990). They are usually dominated by the shrub monoao (*Dracophyllum subulatum*), which was once the most characteristic shrub habitat of the North Island central plateau. The extent of this ecosystem has been severely reduced by land development for plantation forestry and agriculture over the past seventy years, and which is now confined mainly to the Rangitaiki Conservation Area.

Large remnant frost flats have been identified in the Ripia and Waipunga valleys. These remnants are the second and third largest remnant frost flats respectively in New Zealand (Smale, unpublished). One of the frost flat remnants is located entirely on private land, and the other's land tenure is a combination of private, Maori and DoC lands. The major threats to this ecosystem are weed invasion, agrichemical drift from the surrounding land use, and off-road vehicle use damaging the ecosystem

6.4 Threatened species

'Threatened' and 'At Risk' species are recorded throughout the catchment both within and outside of the formally protected areas. Remaining indigenous forests in the catchment is one of the key breeding grounds for North Island kaka (*Nestor meridionalis septentrionalis*) in the region, and also provides habitats for many other forest dwelling birds such as North Island rifleman (*Acanthisitta chloris granti*). Some of the tributaries in headwater sub-catchments where high water quality and stable riparian habitats are retained support blue duck (*Hymenolaimus malachorhynchos*) population[8]. The rivermouth of the Mohaka River is a breeding site for banded dotterel (*Charadrius bicinctus bicinctus*).

Several threatened plants are recorded throughout the catchment, including kakabeak (*Clianthus maximus*), wood rose (*Dactylanthus taylorii*) and tree daisy (*Olearia gardneri*).

Long-tail bats (*Chalinolobus tuberculata*) are recorded both within and outside of the conservation area.

Most of the NZ lizard species have been reduced in numbers because of exotic predators (rats, mice and cats), together with loss of continuous habitats. Their cryptic nature and sparse distributions makes it hard to grasp the full picture of lizard status. The existing records in the region suggest that there are several 'At Risk' lizard species present in the catchment. Given that they can be present in a range of habitat types such as alpine gravels, tussock grasslands, indigenous forests, wetlands, manuka/kanuka shrubland or even in the exotic grassland, their distribution can be throughout the catchment where predator numbers are low or where refuges such as big rocks with very thin cracks exist.

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[8] There are two key sites for whio recovery in the catchment, one of which is designated as a 'Recovery Site' by the Department of Conservation in the Mohaka catchment **Invalid source specified.**. These sites are under private ownership and located around Te Hoe River (Maungataniwha Forest) and near Pohokura (Pohokura Forest) **Invalid source specified.**.

6.5 Summary and conclusion

The pattern of indigenous habitat loss – as defined by vegetation – in the Mohaka catchment is similar to the regional and national situation, where these habitats have been lost from lowlands but remain on mountain ranges. However, the catchment is characterised by a higher proportion of indigenous forest and scrub than the region. Most of the catchment is part of, or adjacent to, key public and privately-owned conservation areas where conservation efforts have been made. The catchment is also home to two of the few remnants of frost flats left in New Zealand. Although there is no quantitative framework, the Mohaka catchment has high values of terrestrial biodiversity.

7 Wetlands

This section characterises wetlands of the Mohaka catchment. A wetland is a place where the ground is permanently or intermittently wet, supporting flora and fauna that are adapted to such conditions. Lake is a fully aquatic system with its own physical, chemical and biological properties contained within water bodies. Thus lake is not included in the analyses.

Analyses use spatial information available, primarily the Freshwater Ecosystems of New Zealand (FENZ) and the HBRC Wetland Inventory, which is under development. The FENZ is a national database consisting of a large set of spatial data around freshwater ecosystems such as rivers, streams and wetlands in New Zealand (Leathwick et. al., 2010). Wetland database is built upon other databases such as soil and digital elevation model. The HBRC Wetland Inventory is an inventory of wetlands identified through aerial survey of the catchment. Wetland is classified using aerial photographs and its approximate extent is delineated to the best possible way.

Both of these main datasets used will ultimately require ground-trothing, should there be any need for information of conditions of wetlands, or site-specific information a wetland. Therefore, analyses in this section is made in a spatial context only, and at a catchment level, i.e. not site-specific.

7.1 Wetland extent

Historic (pre-human) extent of wetland suggest that approximately 2% of the catchment area used to support wetland ecosystem. Fen, one of the 9 wetland classes (see Appendix B), was dominant wetland class followed by swamp and marsh. Seepage was a very small component of the total wetland extent.

Approximately 6% of the original wetland extent remains in the catchment, which is slightly better than the regional picture (regionally, only 2% of the original wetland extent is remaining) but still worse than the national picture (10% of the original extent remaining) (Table 7-1). The largest loss is areas of swamp, followed by fen. Geographically, there is a significant loss of lowland swamp near the coast of the catchment (Figure 7-1). Very little (less than 2%) of the remaining wetlands are under formal protection (Department of Conservation and Nga Whenua Rahui).

There is an increase in the extent of marsh and seepage (Table 7-1). One of the possible causes is that the increase may be driven by modification and degradation of other wetland types such as fen and swamp. For example, some of the seepage may be caused by vegetation clearance and draining of a swamp. However, the cause of the increase as well as the decline of other wetland types require field investigation.

In the Taharua sub-catchment, a number of wetlands (mainly fen) was not identified by the FENZ database (historic extent) (Figure 7-1). However, the latest inventory suggests they would have existed before human settlement. Detailed delineation of vegetation along the main stem of the Taharua River might have been completed (pers. comm. Nicholas Singers, 26 May 2016) but the information is yet to be made available for this analyses. Therefore, some of the wetland extent delineated in the HBRC Wetland Inventory requires ground truthing.

Most of the remaining wetlands in the Mohaka catchment is less than 1 ha in sizes (Figure 7-2). There is little guidance on a size threshold at which a wetland no longer maintains its ecological integrity[9]. Reeves *et al.* (2012) suggest that a wetland smaller than 50 m^2 is unlikely to maintain its functions particularly in a highly modified landscape, hence recommending a minimum size of 0.1 ha for determining wetlands under a

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[9] This is the reason why there is few regional councils whose regional plans contain size threshold for defining wetlands (Reeves, et. al., 2012).

regional plan. Small wetlands may hold important values, and the size should not be used as a determinant of; a) if the area of interest is a wetland, or; b) if the wetland is significant (or not). However smaller wetlands are generally more prone to threats such as surrounding land use and predator incursion, and would require urgent protection and enhancement should they be identified as significant wetlands.

Table 7-1: Change in wetland extent. Historic extent is derived from Freshwater Ecosystems of New Zealand (FENZ). Current extent is derived from HBRC Wetland Inventory (under development). Shallow water is not included in the analyses because as mapping of them would require information on the depth of standing water that is not available.

	Historic wetland extent	**Current wetland extent**	
Wetland Type	**Area (ha)**	**Area (ha)**	**% remaining**
Fen	2,403	93	4%
Swamp	2,138	36	2%
Marsh	127	162	128%
Seepage	2	6	308%
Total	**4,670**	298	6%

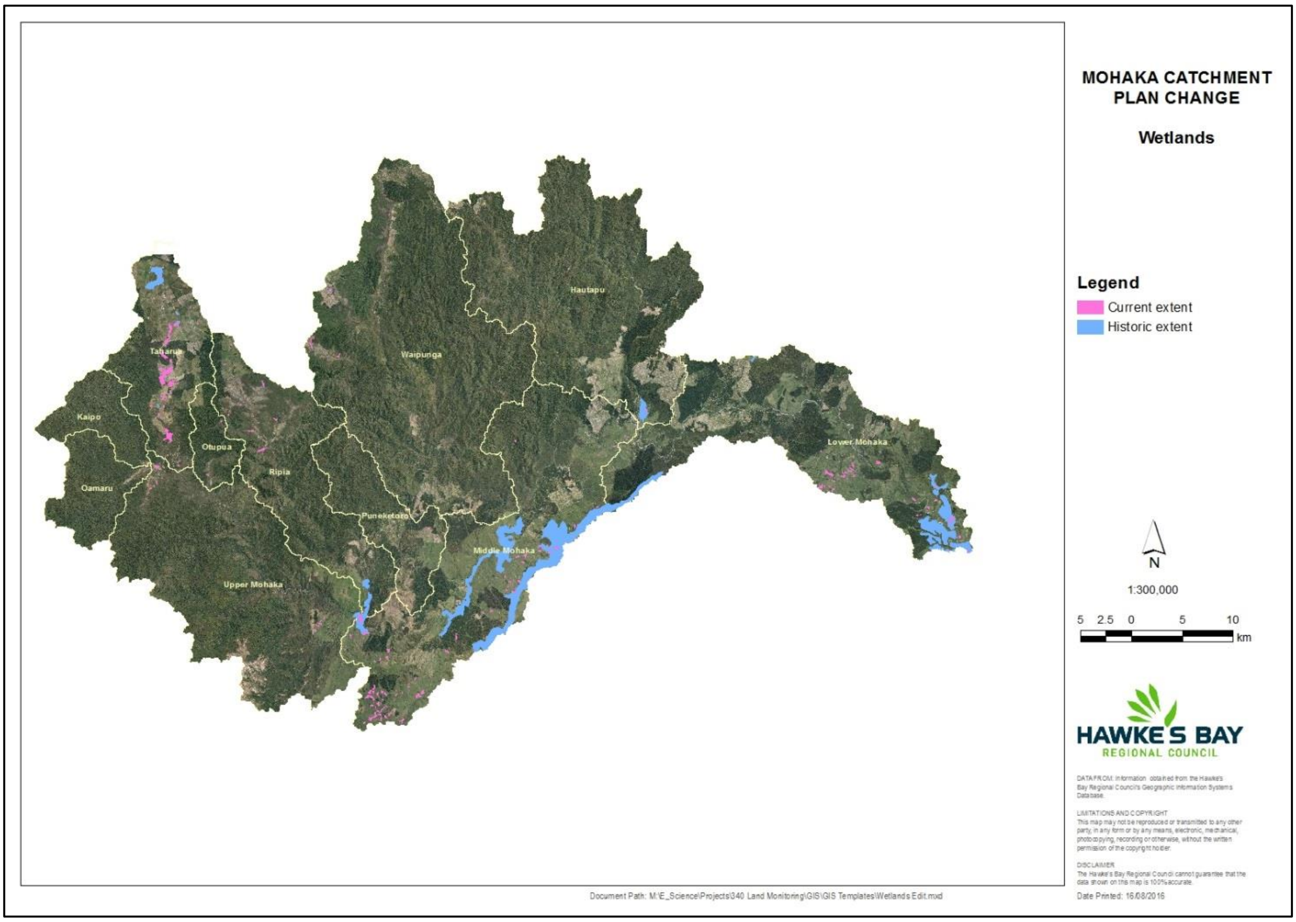

Figure 7-1: Historic and current extents of wetlands in the Mohaka catchment. Historic extent (in blue) and current extent (in pink) are sourced from FENZ and HBRC Wetland Inventory, respectively.

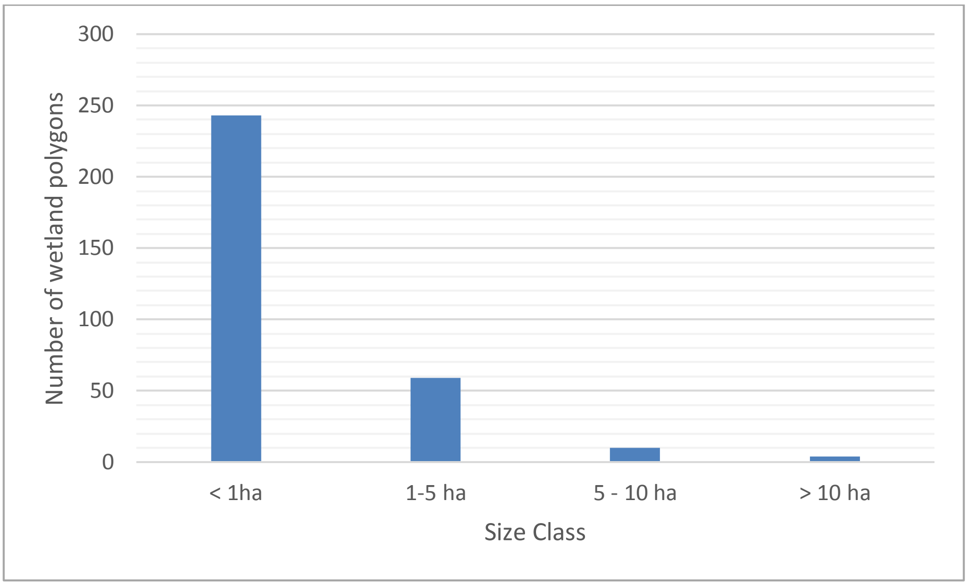

Figure 7-2: Size distribution of remaining wetlands in the Mohaka catchment. Polygons of the HBRC Wetland Inventory are divided into size classes. Some of the wetlands may form a single wetland system, but for this analysis, each polygon is regarded as an independent wetland.

7.2 Summary and conclusion

The catchment has lost most of its wetlands. The conditions of remaining wetlands requires targeted investigation, together with examination of the reasons for loss, in order to determine how further decline may be halted. There is very low representation of wetlands in existing protected areas. This, and the degree of loss leave wetlands as one of the most acutely threatened ecosystems in the Mohaka catchments.

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Appendix A Threatened Environment Classification

Each of the Land Environments of New Zealand (Level 4) classes are assigned with 1 of the 6 threat categories based on past loss of indigenous vegetation and extent of current legal protection within a class (Walker et al, 2007).

Threat Category	Criteria
Acutely Threatened	< 10% indigenous vegetation left
Chronically Threatened	10 – 20% indigenous vegetation left
At Risk	20 – 30% indigenous vegetation left
Critically Underprotected	>30% left, < 10% protected
Underprotected	>30% left, 10 – 20% protected
Less Reduced and Better Protected	>30% left, > 20% protected

Appendix B Wetland Types

Table B-1: Hydrosystems of wetlands identified in the Tukituki Catchment. Hydrosystem is based on broad hydrological and landform setting, salinity and temperature (Johnson and Gerbeaux, 2004). There are nine hydrosystems recognised by Johnson and Gerbeaux (2004), of which four subsystems are present in Tukituki Catchment (Forbes et al., 2011).

Hydrosystem	Description
Estuarine	Wetlands influenced by salinity, associated with intertidal, and supratidal processes. Types of wetlands in this classification include saltmarshes, intertidal mudflats, and coastal lagoons. Clarkson et al (2003) indicated that salinity values in these wetlands at the inland limit should be at a dilution level of 5‰
Riverine	Wetlands directly associated with rivers. They may be flood associated wetlands of river flood plains or old meanders of the river that have been cut off from the main river channel i.e., ox bow lakes.
Lacustrine	Wetlands associated with the waters, beds and immediate margins of larger standing water bodies. These are large enough to be influenced by the associated processes that drive the characteristic lake features such as wave action and water level fluctuations.
Palustrine	Freshwater wetlands with inputs from groundwater, surface runoff or rain. These are not directly associated with river, coastal or estuarine systems. Examples of palustrine wetlands are seepages, swamps, marshes, fens, shallow water etc. and these make up the majority of wetlands in New Zealand.

Table B-2: Wetland classes (Johnson and Gerbeaux, 2004). Wetland class is defined by substrate factors, water regime and consequent factors of nutrient status and pH.

Wetland Class	Description
Swamp	Wetlands located on peatland or mineral soils that have a moderate flow of surface water and/or groundwater. The drainage of these systems is poor and the water table remains above ground surface in places, usually characterised by open water areas and permanent wetness. Swamps have a moderate to high nutrient status with pH values between 4.8 and 6.3. Vegetation associated with swamps includes rushes, sedges, reeds, tall herbs and scrub types.
Marsh	Wetlands located on mineral soils with a slow to moderate flow of surface water and groundwater. Drainage in these systems is better than in the swamps and the water table is usually just at or below the surface of the ground. Marshes experience high water level fluctuations and experience temporary wetness or drying throughout the year in response to climatic conditions. Nutrient status of these systems is high and the pH ranges are neutral to slightly acidic.
Seepage	Wetlands associated with groundwater inputs with some surface water and have a steady to moderate flow of water. These types of wetlands occur where there is a change of slope or a change in the permeability of the underlying geology which forces the water table to the surface. Vegetation associated with these types of wetlands includes low growing turf species, bryophytes and cushion plant species.
Shallow water	Wetlands associated with standing water bodies with a maximum depth of 2m and a water surface above ground level for all or most of the year. Farm dams were classified under this category as they were most closely related to this wetland class although their maximum depth may be deeper than the limits specified in Johnson and Gerbeaux (2004)
Ephemeral wetland	Ephemeral wetlands receive inputs of groundwater and rain only and have nil to slow water movement through them. They are characterised by marked seasonal drying and wetness and can have water table levels well above or below the ground surface. There is usually a marked zonation of vegetation communities due the fluctuation of water levels. Ephemeral wetlands are important due to the rare or specialist species that may use this system.
Bog	A peatland which receives its water supply only from precipitation, receiving neither groundwater nor any nutrients from adjacent or underlying mineral soils. It is oligotrophic, poorly aerated and usually markedly acid. It occurs on hill crests, basins, and terraces. Vegetation types are wide-ranging, dominants including mosses, lichens, cushion plants, sedges, grasses, ferns, shrubs and trees.
Fen	A wetland with a predominantly peat substrate that receives inputs of groundwater and nutrients from adjacent mineral soils. It is low to moderate acidity and oligotrophic to mesotrophic. It mainly occurs on slight slopes such as fans and toes of hillsides where they may grade downslope to swamp. Vegetation is often composed of sedges, restiads, ferns, tall herbs, tussock grass or scrub.
Pakihi/Gumland	Wetland characterised by ultra-infertile acidic soils with an impervious horizon, prone to temporary drought. It is frequently saturated with water but seasonally dry, occurring on level to rolling or sloping land in districts of high rainfall, the soils are old and severely leached of most nutrients. Vegetation is often dominated by heathland species.
Saltmarsh	A wetland class embracing estuarine habitats of mineral substrate in the intertidal and subtidal zones, but also including those habitats in the spratidal zone. It includes non-vegetated habitats such as mudflats, and where vegetated, it can be herbfield to rushland, scrub and mangrove scrub or low forest.