CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The Heretaunga Plains and southern Hawke's Bay (Fig. a) infill a basin (Heretaunga depression-Kingma 1970) about 150 km west of the converging Australian and Pacific plates at the Hikurangi subduction zone (Fig. 1.1). Contrasting tectonic and sedimentation processes during the Quaternary (last 2 million years) are reflected in folding and thrust faulting, changes in sediment sources as rivers adjusted to tectonic processes, and sedimentation response to global climate cycles and related sea-level changes.

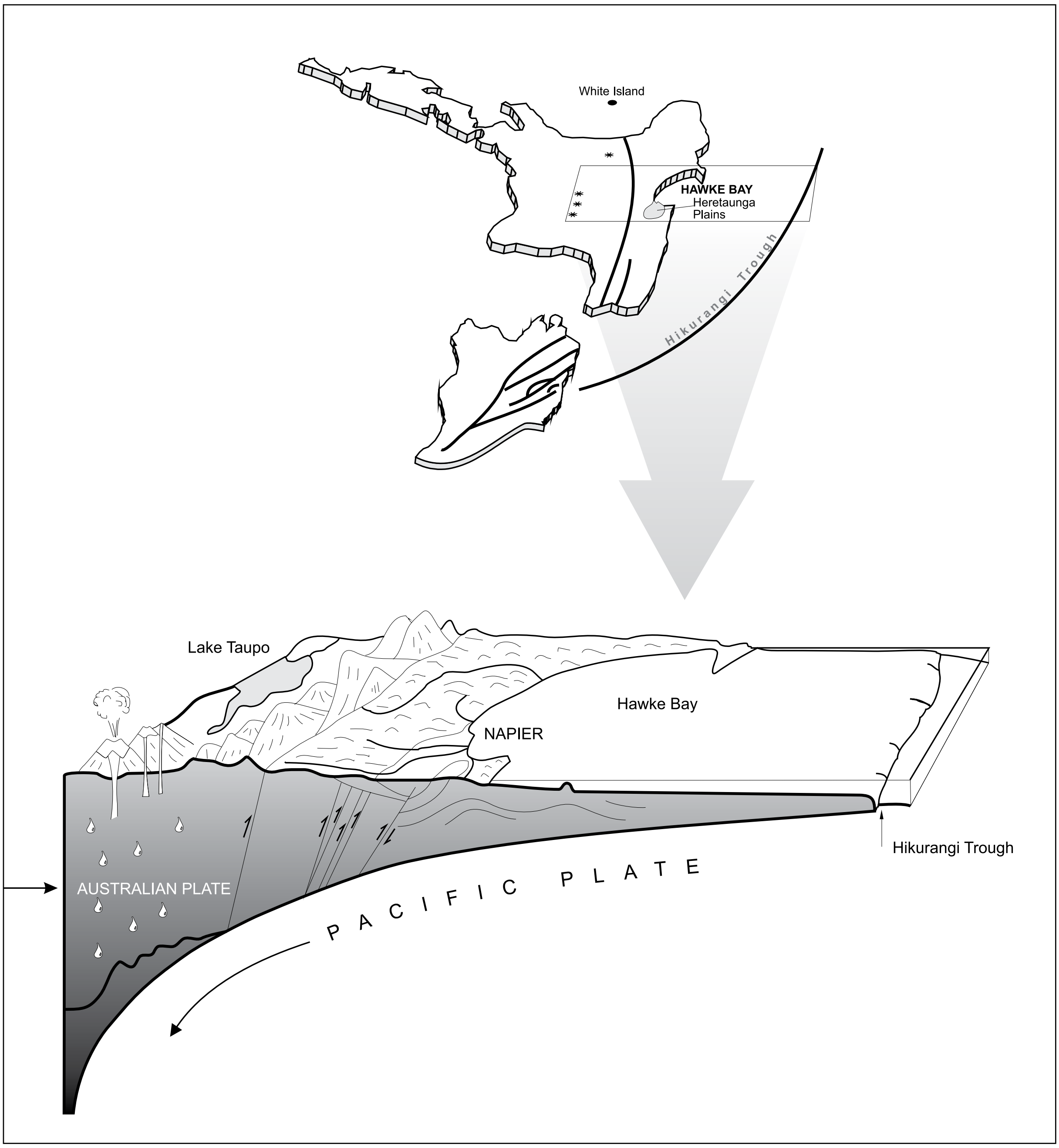

Figure 1.1: Plate tectonic interpretations

The Heretaunga Plains comprise an area of 300 km^2 on the east coast of the North Island of New Zealand (Fig. a). The Plains were formed during the last 250 000 years by river sediments deposited by the Tutaekuri, Ngaruroro, and Tukituki rivers together with coastal lagoonal, estuarine and embayment deposits. The Heretaunga Plains are underlain by sequences of fluvial gravel, sand and silt, interbedded with beach gravel and sand, and lagoon-estuary silt. There is a general layered structure with coarse permeable gravel beds alternating with fine impermeable beds. The permeable gravel beds form aquifers which in plan reflect their formation as meandering river channels.

The first well was drilled at Meanee[1] in 1866. This was unsuccessful and stopped at 45.4 m. A second well was drilled at Meanee on 18 February 1867 and water was struck at 46.1 m. Since then about 9000 wells have been drilled on the Heretaunga Plains. Groundwater now provides about 85% of agricultural, industrial and domestic water requirements (Dravid 1992b) for the 143 000 people living on or adjacent to the Plains (including water supply for Napier (p. 53 500), Hastings (p. 58 000) and Havelock North (p. 9300) (NZ Statistics Department 1995).

The Plains are traversed by three main rivers; the Ngaruroro, Tutaekuri and Tukituki. An aquifer system recharged primarily by the Ngaruroro River underlies most of the Plains. The Tutaekuri and the Tukituki rivers recharge a relatively shallow aquifer system in the northern and southeastern parts of the Plains. A clue to the recharge source for the main aquifer system was the former Ngaruroro River channels crossing the Heretaunga Plains in the area between Maraekakaho and Fernhill (Fig. a). The link between the river and groundwater was established by observing that floods in the river caused well water levels to rise. River gauging in the bed of the Ngaruroro River show a loss of 500 000 m^3/day occurs between Maraekakaho and Fernhill (see 6.2.1, Table 6.1 and Fig. 6.1) for the river flow of up to 30 m^3/s at the Fernhill Bridge. This river water enters the unconfined aquifer mainly through south-easterly trending former river channels that cross and underlie the floodplain between the river, Flaxmere and Bridge Pa (see 5.2 and Figs. 1.2 and 5.1).

The combination of temperate climate, fertile soil and groundwater for irrigation, enable the production of about 50% of the total New Zealand harvest of fruit, vegetables, and grapes on the Heretaunga Plains. In the last 20 years there has been a considerable increase in the production of crops, fruit, vegetables and grapes on the Heretaunga Plains to meet the requirements of expanding markets both in New Zealand and overseas. This has been accomplished by irrigation using groundwater to maintain plant growth during dry periods when soil moisture levels are low. The strategic importance of the Heretaunga Plains groundwater resources to the Hawke's Bay region and New Zealand makes the establishment of a groundwater management programme a high priority for the Hawke's Bay Regional Council (HBRC).

1.2 PRE EUROPEAN HISTORY

Legend, folklore and stories passed on from one generation to the other provide information about the settlement and earliest inhabitants of Hawke's Bay.

About 750 years ago during a canoe race at Tahiti, one of the islands of the Society Island Group, a sudden storm swept several canoes into the South Pacific Ocean. On one canoe was a young Polynesian called Whatonga. Toi, grandfather of Whatonga waited for many days, but Whatonga did not return. Toi became concerned and set sail in search of his grandson in a canoe called "*Te Paepae ki Rarotonga*". Sailing from one island to the other he eventually arrived at Aotearoa which had been discovered by Kupe years before. Toi landed near Auckland and did not find Whatonga, and set sail again and landed near Whakatane where he settled and established a pa known as "Kape-te-rangi".

In the meantime, Whatonga whose canoe had drifted to other islands of the Society Group, eventually returned to Tahiti. After his return to Tahiti, Whatonga and his friends made a canoe that they named *"Kurahaupo"* and set sail in search of Toi. They eventually landed at Aotearoa and their enquiries confirmed that Toi was living at Whakatane and finally Whatonga found his grandfather. Later Whatonga sailed to Mahia at the northern edge of Hawke Bay where he settled permanently. Many years later, Whatonga's two sons Tara and Tautoki sailed south across Hawke Bay and landed near the outlet of Te Whanganui a Orotu (the "Great Lake of Orotu" Fig. 1.3) now known as the Ahuriri Lagoon near Petane. Tara and Tautoki lived

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[1] The spelling of Meeanee was originally Meanee. The extra E was added in the late 1880's to emphasise the sound of the Indian word in English phonetic spelling. The spelling was changed in New Zealand on 1 January 1888 (Knight 1995). In this report Meanee has been used in its original form until 1888 and since then in its present form Meeanee.

Figure 1.2: Heretaunga Plains looking east from the Ngaruroro River towards Flaxmere and Hastings. Former Ngaruroro River courses can be seen extending from the river across the plains to Hastings *(photo : Lloyd Homer, IGNS CN 17683/14)*.

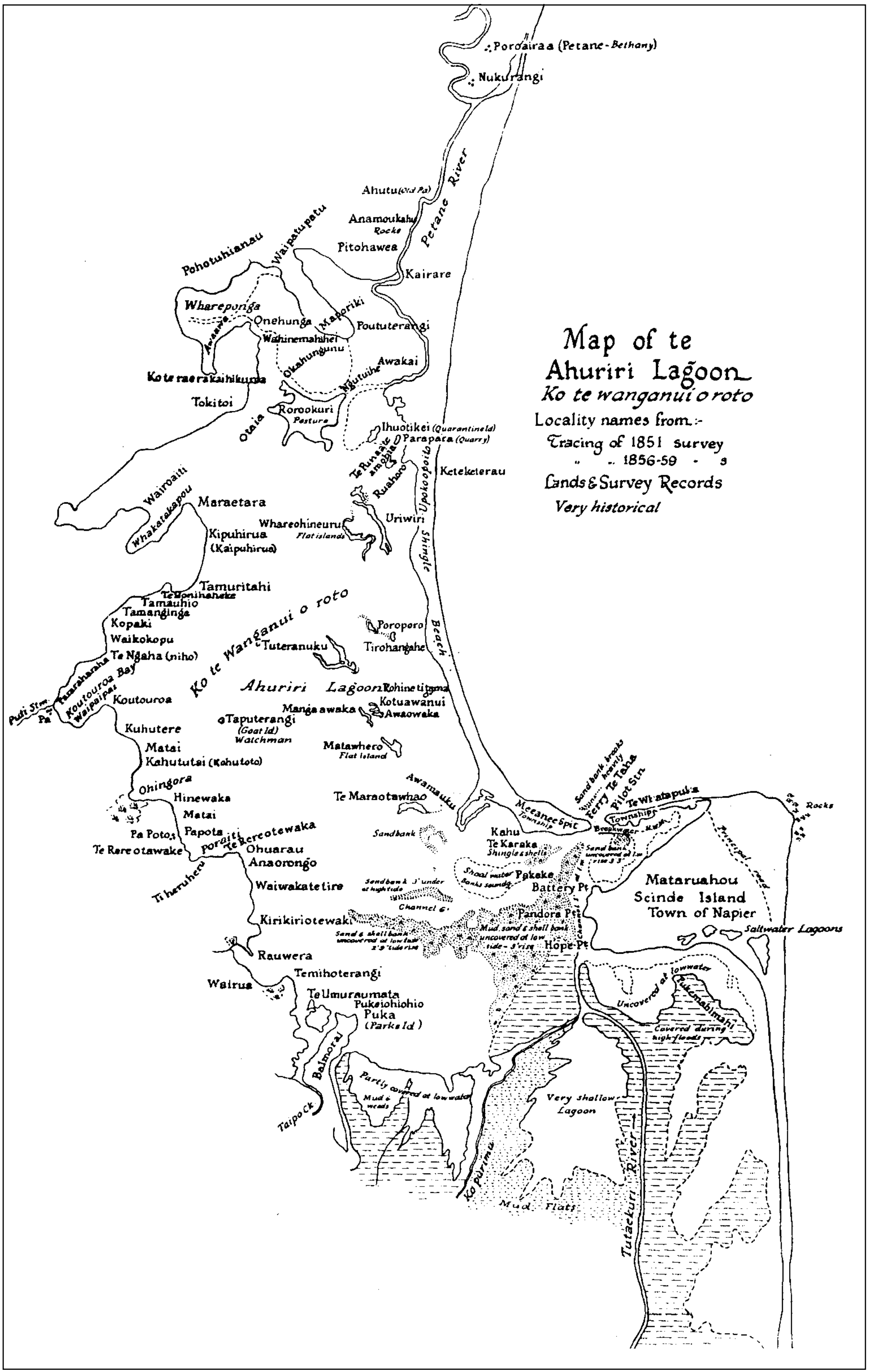

Figure 1.3: Map of Te Whanganui a Orotu, the Ahuriri Lagoon. Locality names from tracing of 1851 and 1856-59 surveys and former NZ Department of Land and Survey records *(Department of Survey and Land Information).*

a while on the Heretaunga Plains, before migrating to Wairarapa and Wellington, where their descendants become known as Ngati-Tara and Ngati-Rangitane.

Two ancient tribes associated with Te Whanganui a Orotu are Ngati Whatumamoa, who descended from Mahu Tapoanui, and Ngati Awa who descended from Awanuiarangi, son of Toi Kairakau (Parsons 1994). These two tribes are regarded as the tangatawhenua or original inhabitants of Te Whanganui a Orotu.

Kahungunu, a grandson of Tamatea who commanded the sacred canoe *Takitimu* on the voyage from the ancestral homeland of Hawaiki to Aotearoa, moved from place to place on the east coast of the North Island and married several times uniting various tribes and creating sub-tribes. He was regarded as a "playboy" but his exploits provided the ancestral structure of the east coast tribes.

Another noteworthy figure in Hawke's Bay Maori history is Kahungunu's grandson Taraia, who migrated to Hawke's Bay from Gisborne with his father about 1450. Taraia fought at and conquered many Hawke's Bay pas as he moved south. Te Whanganui a Orotu is named after Te Orotu a descendant of Manu of Ngati Whatumamoa who lived at Lake Waikaremoana. Turauwha, a high chief at Otatara the pa near Taradale at the time of the Kahungunu conquest, was Ngati Awa descent on his father's side and his mother was Ngati Whatumoana. Through a mixture of conquest and intermarriage with tangatawhenua, the three tribal groups were amalgamated. The mana rangitira of Te Whanganui a Orotu resides in the descendants. Ngati Kahungunu were now well established in the Heretaunga area.

By the early 1700's there were many organised tribal settlements on and adjacent to the Heretaunga Plains in Hawke's Bay. These pas and kaingas were large enough to accommodate hundreds of people. The pa at Ohiti is typical (Fig. 1.4).

Te Whanganui a Orotu was a source of kaimoana, providing a plentiful supply of shellfish, flounders, eels and other fishes. Kainga were located at Tiheruheru which was on the mainland at Poraiti and on the island Tuteranuku at the northern end of the present day Hawke's Bay airport.

The value attached to Te Whanganui a Orotu by the Maori is illustrated in a lament composed by Ngati Mahu ancestor Te Whatu for a beloved grandchild :

Kia horo te haere nga taumata ki Poraiti,
(Go quickly to the heights at Te Poraiti)
Ko te keinga tena I pepehatia e o tipuna.
(That island in a proverb by your ancestors).
Te rua te paia ko Te Whanga,
(The storehouse that never closes is Te Whanga),
He kainga to te ata
(A meal in the morning)
He kainga ka awatea
(A meal at noon)
He kainga ka ahiahi, e tama e I.
(A meal in the evening, my son)

(Parsons 1994).

1.3 EUROPEAN HISTORY

On 13 October 1769, the *Endeavour* captained by Lieutenant James Cook sailed into Hawke Bay. Cook

Figure 1.4:
Ohiti Pa looking across the Ngaruroro River from Roys Hill.
A pre-European Ngati Upukoiri hilltop pa site. Stories about this pa go back to the 15th century and the occupation of the district by Ngati Kahungunu. The name Ohiti means river crossing (photo : Hawke's Bay Museum, Napier 7113).

named the bay in honour of Sir Edward Hawke, First Lord of the Admiralty. In his journal Cook described the land in his typical laconic style:

"The southernmost land in sight and which is the south point of the Bay SEBS distant 4 or 5 leagues, and a bluff head lying in the SW Cod of the Bay, SBW 2 or 3 miles, on each side of beaches and the main land is a pretty large lake of salt water as I suppose; on the SE side of this head is a very large flat which seems to extend a good way inland to the westward, on this flat are several Groves of straight tall trees".

The inner harbour ("lake of salt water") at that time was about 8 km long and 3 km wide. Te Waiohinganga, the Esk River, discharged into it from the north and the Tutaekuri River from the south. The harbour was dotted with islands such as Roro o Kuri, Te Iho o te Rei (Quarantine Island) and Tapu te Ranga (Watchman Island). The outlet to the sea was at Keteketerau, north of the Beacons. Sometime after Cook's visits to Hawke Bay a storm blocked the Keteketerau outlet and the rising waters of Te Whanganui a Orotu threatened to flood the Maori cultivations on its shores. A visiting ancestor named Tu Ahuriri assisted in digging a new outlet near Scinde Island. The escaping water gouged out a permanent opening which was named Ahuriri in recognition of his services.

Flax traders and whalers arrived in the early 1800's and trade of guns, axes, tobacco, blankets, clothes, grain and fruit seeds, for flax, pigs, labour and land began. The Heretaunga Plains area was waterlogged and swampy and was unsuitable for farming without drainage. The early European settlers lived and farmed on the hills adjacent to the Plains. In December 1844 the botanist-missionary William Colenso settled at Waitangi (Awatoto). His descriptions of the plant species of New Zealand later formed the basis of New Zealand botanical studies. The Catholic missionary Father Lampila settled at Pakowhai in 1851 and with the Marist Brothers, made altar wine from the grape vines they planted around the mission.

Hill (1905) describes the Heretaunga Plains at the time of arrival of the first Europeans.

"The plain between Farndon and Pakipaki was covered with raupo, flax, tea-tree, scrub, and bush, and so ramified by overflow and swamp channels as to make it impassable to man or beast. The lower country about Meeanee, and between it and Napier, was an area of fairly deep water, and long after Europeans had begun to settle in the district large 5-ton boats plied between Napier and Pakowhai by way of Awatoto."

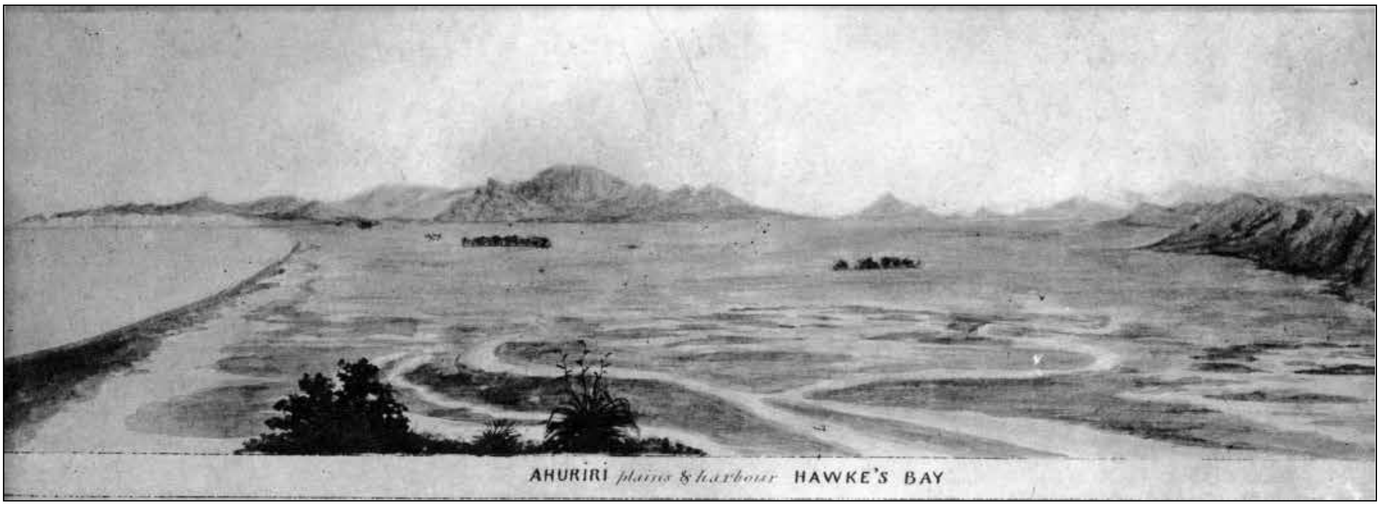

Figure 1.5: Heretaunga Plains in 1851.
Water colour of Ahuriri Plains by Charles Rudston Read, February 1851, taken from the headland Scinde Island (Napier), showing the Tutaekuri River and mud flats in the fore, with stands of bush at Whakatu and Mangateretere. The prominent Havelock North Hills dominate the centre skyline, following the shoreline to Cape Kidnappers on the left *(drawing: Hawke's Bay Museum, Napier T2846)*.

Figure 1.6: Meeting of settlers and Maori at Whakairo Pa (Waiohiki) near Napier in 1863.
The meeting was called on 20 July 1863 to celebrate the completion of a large flour mill erected by the natives of the district, with the assistance of the Government, at the Pawhakairo village. The gentleman with head uncovered is Donald McLean, Superintendent of the Province. *(photo: print donated by George Willan, Hastings).*

Organised European settlement of the Heretaunga Plains began after 1850. In 1851 Crown Commissioner, Donald McLean, negotiated the purchase of the 106 000 acres Ahuriri block. Te Whanganui a Orotu was excluded from the purchase but the Crown assumed title to it by legislation in 1874 and vested it in the Napier Harbour Board. Within 20 years most of the Maori land was bought or leased by European settlers. Draining of the swamps began, forests were felled for timber and scrub areas cleared for farmland. Besides sheep and cattle farming, wheat, corn, potatoes, peaches and grapes were soon planted or cultivated.

In April 1855, McLean concluded the purchase of the 1000 acre Tutaekuri block giving Government title to all land on the north side of the Tutaekuri River from Meanee to Napier. Half of the purchase price of £200 (pounds) was paid at purchase date with the final £100 being paid on 13 November 1856. In 1857 the Tutaekuri block along with part of the Ahuriri block, was subdivided into blocks ranging from 20 to 80 acres and named the River Meanee District. The settlement Meanee (Napier), was named after the battle of Meanee in 1843 on the River Indus in the province of Scinde, India by Alfred Dommett, along with other Indian names given in the area during 1854-1855. Land access to the interior and to Auckland for Napier was via Meanee. Napier and Clive townships were surveyed in 1855 and 1857 (Knight 1995).

In 1861 Clive and Napier both had 250 inhabitants. Havelock North was surveyed in 1860, and Hastings (Karamu) in 1871 had 200 residents. Two of the immediate water problems were flood protection and the establishment of clean reliable water supplies for these settlements.

1.4 EARLY RIVER CONTROL AND FLOOD PROTECTION WORKS

In 1867 the Ngaruroro River, which originally flowed to the south of Hastings along the Karamu Stream, changed course to flow directly from Fernhill to the sea at Waitangi and flooded the Plains and the settlements of Napier, Meanee and Clive. The flood deposited 0.3

to 0.5 m of silt over most of the Plains area and the settlers demanded flood protection. Parliament passed the Hawke's Bay and Marlborough Rivers Act in 1868 which allowed property owners to construct their own stopbanks. This included the railways department who in 1876 built a short stop bank above Roys Hill (on the right bank) to protect the Napier - Palmerston North railway line from flooding. These flood protection works often only directed flood flows towards other properties.

It soon became apparent that a co-ordinated river control scheme was necessary and the Hawke's Bay Rivers Act was passed in 1876 repealing the earlier act. In 1877 a comprehensive flood control scheme for the Heretaunga Plains area (the "Knropp" report) was presented to the Minister of Public Works by Superintending Engineer Charles Knropp. Knropp came to New Zealand in 1873, from India where he had completed major irrigation canal and distribution works in South India.

The Hawke's Bay County Council (HBCC) was established in 1876 and immediately became involved in river control works by planting willows at Clive initially, and then at many other places to protect roads. By 1885 the willows had become a problem and by 1894 it was reported that the Ngaruroro River bed was blocked by willows as far upstream as Fernhill. The clearing of bush was compounding the problems of flooding on the Plains by increasing erosion in the river catchments and downstream aggradation on the floodPlains. In 1898 four separate river boards were established for the Heretaunga Plains. The Clive River Board which was responsible for Ngaruroro River flood control, undertook willow clearing, river alignment and stopbank construction from the coast to Fernhill.

The Hawke's Bay Rivers Board was established in 1910 by the amalgamation of the four river boards. A 1911 report proposed construction of an overflow channel for the Ngaruroro River from Pakowhai to Awatoto, willow clearance and land purchase. Despite ratepayers voting

Figure 1.7: Damage caused to road and rail bridges by flooding of the Ngaruroro River at Waitangi in 1897. *(photo: Alexander Turnbull Library 61690 ½ - print donated by C. Athol Williams).*

against the scheme, land for the overflow channel at Pakowhai was bought in 1912. Construction also began in 1915 on a road and rail bridge linking Scinde Island with Westshore. Various schemes were re-examined after each flood, particularly in 1924 and 1928 but no direct action was taken. Public meetings and River Commission hearings continued, gaining momentum until the Hawke's Bay Rivers Board decided to proceed with the flood protection works. The Hawke's Bay River Bill was passed in 1929 authorising the works but only some of the proposed stopbank work was completed.

The changes of river course produced by the 1931 M7.8[2] Hawke's Bay earthquake prompted renewed agitation for action and in 1933 the Hawke's Bay Rivers Board approved schemes for the embanking of the Tutaekuri and Ngaruroro rivers over the whole of their courses across the Heretaunga Plains. Work commenced in 1934 and was partly completed in 1940.

1.5 HAWKE'S BAY CATCHMENT BOARD

In 1941 the Soil Conservation and Rivers Control Act was passed resulting in the formation of the Hawke's Bay Catchment Board (HBCB) in September 1943. The initial impetus for this Act was the devastating Esk River flood which occurred on 25 April 1938, causing major damage in the Esk River valley. The HBCB took over the responsibilities of the Hawke's Bay Rivers Board which was dissolved in 1950. Stopbanking of the lower Tukituki River was the first major job undertaken by the HBCB and in 1954 the Board presented a comprehensive scheme for flood protection control and the drainage of the Heretaunga Plains.

The Tukituki River stopbank construction work was completed in 1975 as was the reconstruction of stopbanks on the Tutaekuri and Ngaruroro rivers incorporating revised design discharges of 2830 and 4530 m^3/s respectively based on estimates of 100 year return period floods. Also the diversion of the Ngaruroro River into its overflow at Pakowhai and the diversion of the Tutaekuri into the Ngaruroro upstream of the State Highway 2 bridge was completed.

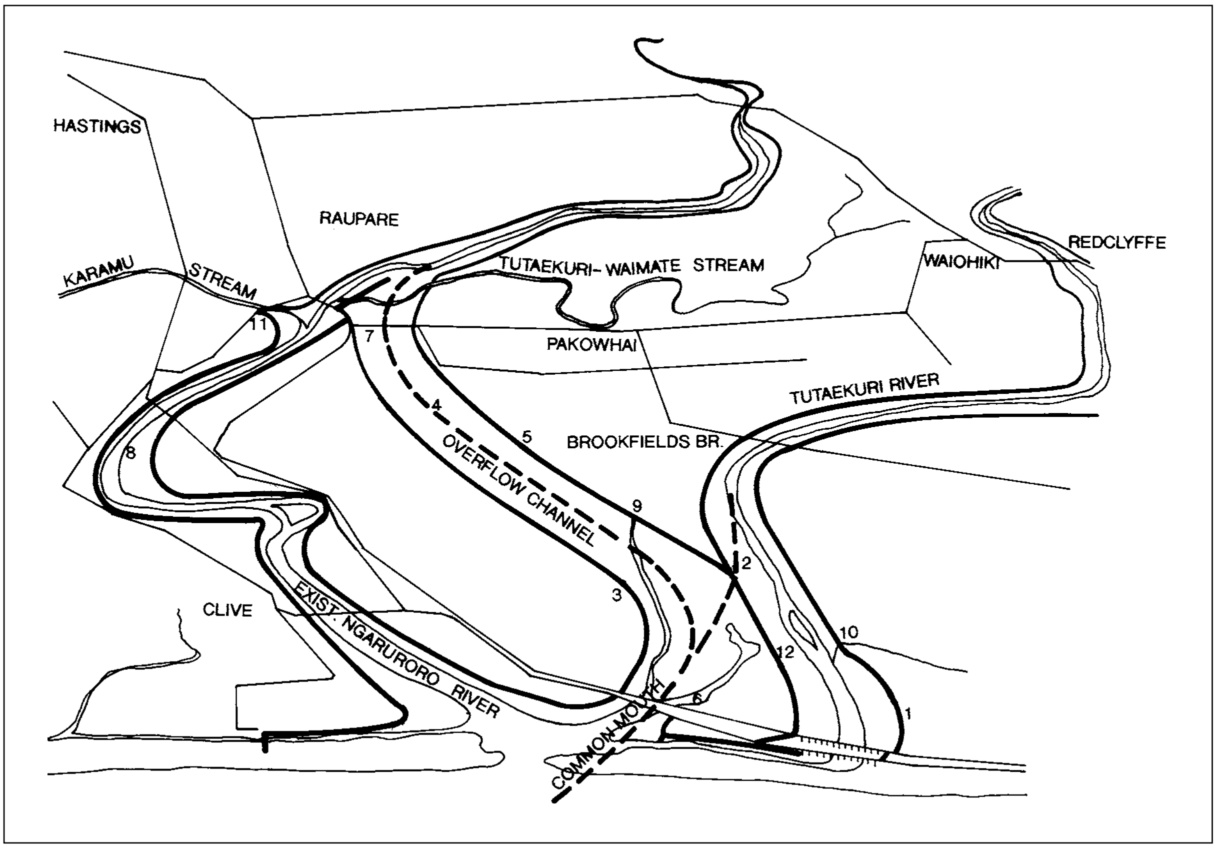

Figure 1.8: Heretaunga Plains river diversion and flood control works.

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[2] Richter scale earthquake magnitude intensity is measured on a scale from 0 to 9 where each number represents on energy release ten times that of the preceding number.

Figure 1.8 shows the HBCB scheme for river diversion and flood control in the Heretaunga Plains, as approved by Cabinet in April 1961. The black dotted line shows the planned diversion to the sea for the Ngaruroro and Tutaekuri rivers. Numbers on the map represent: (1) redesign of Tutaekuri River stop banks; (2) diversion of the Tutaekuri River to form a common mouth with the Ngaruroro River; (3) redesign of the stop banks of the Ngaruroro River; (4) diversion of the Ngaruroro River down the overflow channel; (5) double stop banks on the northern side of the overflow to discharge the flood waters of the Tutaekuri - Waimate Stream and protect Pakowhai; (6) extension of highway road and rail bridges; (7) new bridge over Pakowhai dip; (8) existing Ngaruroro River channel retained for Karamu and Raupare streams; (9) pump stations to drain Pakowhai - Waiohiki; (10) pump station to drain Brookfields - Awatoto area; (11) removal of Karamu flood gates; (12) removal of stopbank between Tutaekuri River and overflow to use existing Tutaekuri bridges.

From 1975 to 1989 diversion and flood control works were undertaken including lengthening of the overflow and rail bridges by 120 m to accommodate a combined river flow of 5650 m^3/s and the provision for pumping stations for draining low lying areas of the Heretaunga Plains at Pakowhai and Awatoto.

1.6 REGULATION OF GROUNDWATER ABSTRACTION

Hill (1923) "urged" that the flow of all artesian wells should be regulated to conserve groundwater. He also suggested that artesian pressures be monitored to provide information on response of water level to abstraction and suggested "a properly constituted authority should collect, monitor and analyse information on wells and groundwater". In the 1930's the concept of conserving water and groundwater began to be seriously considered. After the 1931 Hawke's Bay earthquake, concern as to the vulnerability of the Heretaunga Plains aquifers to leakage, overwithdrawal and wastage, resulted in R.J. Findlay, HBCC surveying Heretaunga Plains wells for earthquake damage. The results of the survey were never published but the original data has been retained and is now held by the Hawke's Bay Regional Council (HBRC). In 1937, M. Ongley of the NZ Geological Survey reviewed the knowledge of the Heretaunga Plains groundwater resources and noted, "this underground water has been hurriedly and somewhat irresponsibly developed." (Ongley 1937).

In June 1950, Dr J.T. Kingma, District Geologist, of the NZ Geological Survey, Napier warned that deforestation, erosion and pollution were threatening the underground water supplies of Napier. He also warned that water was flowing away wastefully from hundreds of disused artesian bores. In the same year the HBCB submitted a petition to the government suggesting that it be granted power to regulate and control the sinking of artesian bores as a means of conserving water. This resulted in the Underground Water Act, 1953. In December 1955 the Minister of Works appointed a Commission to inquire into the constitution of an underground water area in the provincial district of Hawke's Bay. The Commission recommended the setting up of an underground water authority in terms of the Underground Water Act 1953 and in July 1957 the Heretaunga Plains Underground Water Authority was established.

A survey of existing bores by the HBCC during 1956-57, reported that the indiscriminate issuing of permits could only cause chaos, and that the old bores were becoming a major problem, wasting millions of gallons of water daily, and should be sealed (Findlay 1955). In May 1959, Taradale Borough Council overseer Kenneth Burnett advised that uncontrolled and broken artesian bores discharged thousands of gallons of water onto land and into the Borough drains contributing to the poor drainage in some areas of the Borough. He reported that a number of bores in the Borough that were broken during the 1931 earthquake were still flowing.

In 1962, the Soil Conservation and River Control Act 1941 was replaced by the Water and Soil Conservation Act and the Heretaunga Plains Underground Water Authority was abolished and its powers and functions were transferred to the Hawke's Bay Regional Water Board (HBRWB). Taking and discharging of water were regulated by Water Rights with the cost of administering HBRWB activities financed from HBCB revenue. The passing of the Water and Soil Amendment Act in 1973, gave HBCB the right to levy water users on a formula based on the amount of water abstracted. During the opening of HBRWB office at Napier on 18 July 1970, Duncan MacIntyre, Minister of Lands and Forests emphasised the need for proper management of water - in particular the groundwater beneath the Heretaunga Plains. He foresaw spectacular expansion in fruit and vegetable processing industries in Hawke's Bay with better water management.

On 1 November 1989 the HBRC was established from the amalgamation of the Hawke's Bay United Council, HBRWB, HBCB, Hawke's Bay District Noxious Plant Authority and Hawke's Bay Pest Destruction Authority.

1.7 GROUNDWATER USE

1.7.1 Well Drilling and Water Supply History

The first European settlers on the Heretaunga Plains obtained their water supply from the nearest river, stream, pond or spring. Napier was established on and adjacent to Scinde Island which was joined to the mainland by shingle spits (tombolos), and the settlers initially relied solely on rainwater. Springs discovered on and around Napier Hill also provided a water supply source. A military barracks was built near a spring on Hospital Hill in the Botanical Gardens. Another spring in Battery Road near Shakespeare Road provided water for filling barrels for supplying water. The Europeans were not as careful as Maori to protect their water supplies from pollution and soon water borne diseases became a problem. Shallow wells were dug to obtain uncontaminated water but these too were prone to pollution. Many suggestions were made for the provision of a permanent water supply.

In 1865 a report to the Hawke's Bay Provincial Council suggested that water might be found as in Christchurch where artesian water had been discovered in aquifers underlying the coastal Canterbury Plains in 1858. In November 1866 a group of Meanee settlers funded the sinking of a trial well for artesian water (Knight 1995). The driller was a Mr Bennett from Christchurch. Drilling commenced on 6 December 1866 on a property in the vicinity of the Meanee Hotel. On 18 December drilling stopped at a depth of 45.4 m due to slow progress without encountering water. Another attempt was made at a site on the boundary of the Catholic Mission and the property of Mr Davies in Meanee Road, Meanee and on 18 February 1867 water was struck at 46.1 m. The artesian pressure produced a head of 6.1 m above ground level and flow of about 40 litres/min. On 11 July 1868 after 14 weeks of "incredibly difficult drilling," a 63.1 m deep well at Napier at the intersection of Hastings and Edwardes streets encountered artesian water (Knight 1995). The driller was Mr Garry of Napier. By 1887 Napier town was supplied with water from six artesian wells and another 300 wells had been drilled on the Heretaunga Plains (Hill 1923).

Figure 1.9:
Well drilling at Hastings in the early part of the century. Alfred Ferdinand Leipst (on right) drilling a well outside the Orange Lodge Hall, Warren Street, Hastings.
(photo: print donated by George Willan, Hastings).

By 1916 nineteen wells were used to supply Napier with water. Wells were located at Nelson Park, Sale Street and the junction of Munro and Raffles streets. The McLean Park well field and pumping system and the Thompson Road reservoir on Bluff Hill serving the Napier Hill area was installed in 1931. The Enfield Road reservoir was constructed in 1940 to supply water to development on the flat land raised in the earthquake. Taradale water supply was initially developed on the basis of individual and shared wells for normal domestic use. Some of these remain in use today. A public water supply was introduced in Taradale after the amalgamation with Napier in 1968. The system was designed on the basis that the bulk of the water would be supplied from Napier but this soon changed and water from Taradale was instead pumped to Napier. The Taradale reservoir built in 1989 and the Enfield Road reservoir are interconnected by pumps and a 300-375 mm diameter pipeline. Current work provides an additional pipeline of 450 mm diameter from the Taradale wells to the Enfield Road reservoir and the retirement of some of the Napier wells. The water quality from the underground source is excellent and no treatment is required.

In the 1870's artesian bores were being used for domestic water supply in Hastings. By 1882 there was a problem with leaking artesian bores which flooded low land and made drainage of the streets difficult. Although there was a water supply for most houses there was no water for fire fighting purposes. When the first fire brigade was formed in 1885, it was general practice to extinguish fires using dammed up sewage and storm water runoff. Two typhoid outbreaks and major fires in the 1880's and 1890's brought more calls for a reticulated water supply. The HBCC opted for the cheaper solution of making a new bylaw enforcing the construction of brick dividing walls between buildings in the business area. Also six water tanks were built of 10 000 gallons capacity at sites around town so that the fire engine with 1000 feet of hose could cover the Hastings town area. Over the next 10 years more studies were undertaken to develop a high pressure water supply. In 1901 a scheme to service Hastings with high pressure reticulated water at the cost of £30 000 ($60 000) was rejected. In 1907 County Engineer John Roque proposed a scheme which was a combination of water supply and a power station for generating electricity. This consisted of an artesian bore at Crosses Road on the northern perimeter of Havelock North, pumping water to a reservoir on the Havelock North hills for Hastings and Havelock North water supply. This was to be supplemented by piped water from the Maraetotara River which first would be fed through the power station. The scheme was never built. In 1909 County Engineer H. M. Climie, proposed a scheme that pumped water from wells in Eastborne Street East to a reservoir on the Havelock North hills. During 1911 and 1912 a reservoir, pumping station and 22 miles of pipe for a reticulated water supply was laid. Some of this water was sold to Havelock North residents at 1/6d per 1000 gallons (3.5 c per cubic metre). Havelock North water supply was extended with six wells drilled from 1921 to 1931 at the corner of Havelock and St Andrews roads. The supply is still supplemented by water from the Hastings water supply.

Figure 1.10: Well drilled by Tommy Willan about 1930 at Whakatu Freezing Works, Hastings *(photo: print donated by George Willan, Hastings).*

At present Hastings City is supplied by 24 bores at 11 pump stations and water is pumped to five reservoirs. In 1996 two new reservoirs of 20 000 m^3 capacity will be completed to replace the three old reservoirs and a new main will be built from the Eastbourne Street East pumping station to the reservoirs. This is to cope with growth of Hastings and Havelock North and anticipated increased water demand.

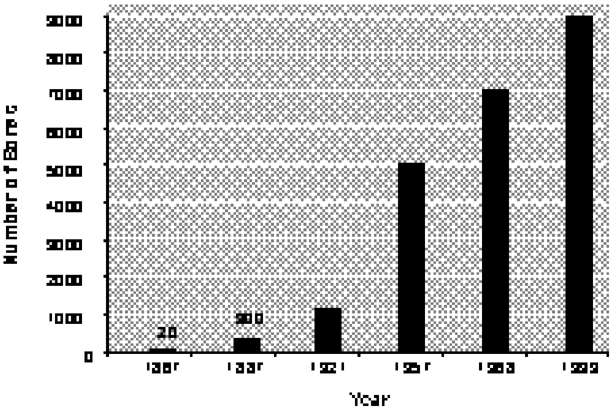

Figure 1.11: Growth in number of bores in the Heretaunga Plains since 1867.

Salient Features

1867 -	First artesian well sunk
1957 -	Bore Permits are issued by Hawke's Bay Underground Water Authority
1968 -	Water Rights are issued by Hawke's Bay Regional Water Board
1991 -	Bore Consent and Water Permit required by Hawke's Bay Regional Council

Fig. 1.11 illustrates the growth in number of wells drilled on the Heretaunga Plains since 1867. By 1995 there were about 9000 water wells drilled on the Heretaunga Plains. Many wells were damaged during the 1931 Hawke's Bay earthquake and these along with many others were sealed by grouting to prevent leakage from corroded or broken casing by the HBCB during the 1970's and 1980's. Groundwater provides 85% of all the water requirements for domestic, agricultural and industrial purposes for a population of 143 000 on the Heretaunga Plains.

Figure 1.12 shows the Heretaunga Plains groundwater use during the period July 1994 - June 1995. Approximately 63 million m^3 of groundwater was withdrawn during the July 1994 - June 1995 period for public water supply, irrigation and industrial uses (Fig. 1.12).

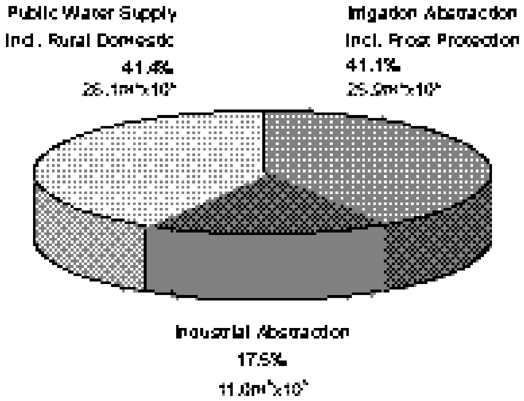

Figure 1.12: Heretaunga Plains groundwater use during July 1994-June 1995.

Public water supply including rural domestic abstractions used 26.1 million m^3 (41.4%) and irrigation water abstraction including farm and stock water supplies was 25.9 million m^3 (41.1 %). The balance 11.0 million m^3 (17.5%) was used by industries. Average daily per head abstraction for the cities of Napier (p. 53 500), Hastings (p. 58 000) and Havelock North (p. 9300) during the June 1994 - June 1995 period are shown in Table 6.6.

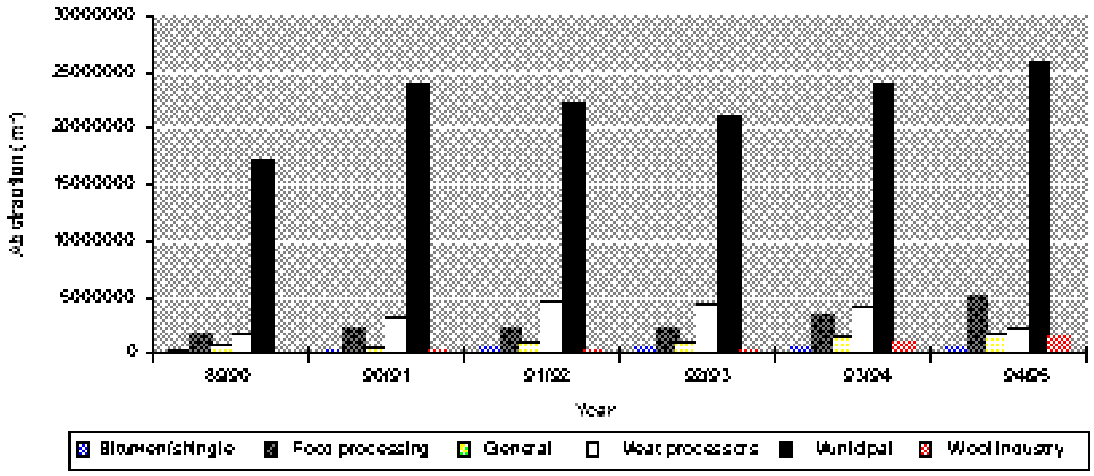

Figure 1.13: Annual abstraction (July 1989 -June 1995) by industry group and public and rural domestic supply.

Figure 1.13 illustrates annual abstraction by industry group and public water supply during July 1989 to June 1995 arranged according to hydrological (July-June) years. The plot suggests a trend of increasing groundwater abstraction for industry and municipal supply. Napier water supply abstraction for the 1990/91 period was estimated due to fragmentary water meter readings. The closure in 1994 of the freezing works at Tomoana is reflected in the decline in water consumption during 1994/95 period for the meat processing industry group.

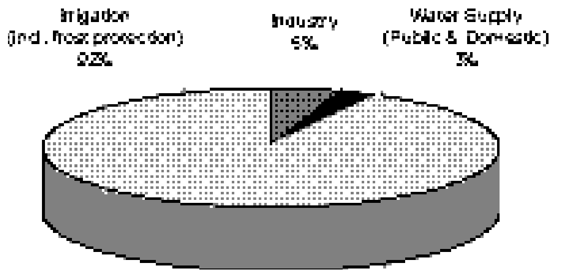

Figure 1.14: Groundwater take Resource Consent statistics.

Use of groundwater for irrigation has expanded considerably in the last twenty years for the production of crops, fruit, vegetables and grapes. During dry periods, agricultural and horticultural production is heavily reliant on irrigation from groundwater supplies to maintain production and growth. Currently there are 2178 consents for groundwater abstraction on the Heretaunga Plains, of which 2004 (92%) are for irrigation (Tim Waugh, HBRC, pers. comm. 1995). The balance of 174 consents are represented by industry 109 (5%) and public and domestic water supply 65 (3%) consents respectively (Fig. 1.14).

1.7.2 Well Drillers

From December 1866 to December 1867 the wells were drilled on the Heretaunga Plains by Messrs Bennett and Ashworth from Christchurch. However by 14 December 1867 these gentleman had “made themselves scarce, leaving a few creditors in the lurch,” (Anonymous 1868). Mr John Garry of Garry’s Foundry, Napier established a well drilling business in November 1867 and a Mr Lord began well drilling in December 1867. Other Hawke’s Bay well drillers included Gilberd (c.1891), A.F. Leipst (c.1904), Tommy Willan (c.1921 - 1947), H.A. McLean (c.1925 - 1960), Ernest King (1930’s), Harold Armstrong (c.1950 - 1970), G.A. Pearce (1950’s) and K. Rawlinson (1950’s). Also J.M. Stewart from Dunedin drilled 3 large diameter (216 mm) wells for the Napier Borough Council at McLean Park during 1924 and 1925. Other well drillers from outside Hawke’s Bay who have drilled wells on the Heretaunga Plains include Richardson Drilling from Palmerston North and Neville Webb & Sons from Levin.

Figure 1.15: Dick Baylis checking progress during drilling of the HBRC Flaxmere testbore (well no. 3698[3])
(photo: Len Brown, IGNS).

Today there are three Hawke’s Bay based drilling companies. The oldest of these is Baylis Brothers Limited which started drilling in 1947 having taken over the drilling business of Tommy Willan. Vic Boag & Sons established in 1930’s was purchased in 1968 by John Hill and renamed Hill Well Drillers Limited. The third drilling company Honnors Well Drillers Limited began drilling in 1964.

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[3] A unique well number is allocated by the HBRC during the issue of a well drilling permit. Well number links well drilling and other groundwater data bases.

1.8 Resource Management Act (1991)

In 1991 the Water and Soil Conservation Act (1962) was replaced by the Resource Management Act (RMA). One of the core functions of the HBRC under the RMA is to promote sustainable management of the physical and natural resources of the region. The RMA places specific emphasis on:

- Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonable forseeable needs of future generations.
- Safeguarding the life-supporting capacity of air, water, soil and ecosystems.
- Avoiding, remedying or mitigating any adverse effects of activities on the environment.

The objectives for attaining sustainable resource management in the Hawke's Bay region are stated in a Regional Policy Statement which provides direction for a comprehensive Regional Water Resources Plan (RWRP). The Heretaunga Plains groundwater study will provide additional technical input to future reviews of the RWRP.

1.9 Heretaunga Plains Groundwater Study

The groundwater resources of the Heretaunga Plains has been regarded with both curiosity and concern since discovery in 1867. In 1887, Henry Hill published his paper, "On the artesian well system of Hawke's Bay," summarising data and knowledge. Since then numerous groundwater investigations (see later 3.2 Review of Previous Work) have been undertaken to determine how the aquifers were formed, the sources and the flow of groundwater in the aquifers, estimation of safe yield and susceptibility to contamination. These sporadic investigations have extended the understanding of the Heretaunga Plains groundwater resource considerably. However, it was not until 1991 that a co-ordinated systematic regional investigation of all aspects of the Heretaunga Plains aquifers was begun. This investigation involved the HBRC and the Crown Research Institute, Institute of Geological and Nuclear Sciences (IGNS) in a five year (1991-95) project funded by the HBRC with research input by the IGNS under the Public Good Science Fund administered by the Foundation for Research Science and Technology (FRST). In 1992 it was decided that land and water use were also an essential component of the groundwater investigation and expertise in these aspects was gained by involving the Crown Research Institute - Landcare Research NZ (Landcare). In addition, a pesticide leaching study was initiated jointly by Landcare and Environmental Science and Research (ESR) with the HBRC in 1993.

The objective of the joint investigation was to utilise the multidisciplinary expertise and the specialised laboratory facilities of the Crown Research Institutes (specifically the IGNS and Landcare), in assisting the HBRC to investigate the Heretaunga Plains groundwater resource and develop management policies. Research has focused on obtaining an understanding of the extent, quality and quantity of groundwater in order to manage the resource sustainably through equitable allocation and efficient use.

It was originally intended that the results of the study be presented in June 1996. However, a severe drought in the summer of 1994-95 resulted in declining water levels in wells on the fringe of the Heretaunga Plains. Because of concern that the groundwater resource was being depleted, the HBRC made the decision to prioritise the Heretaunga Plains groundwater study, and report results a year earlier than originally proposed. This would enable appropriate planning decisions to be made immediately if required to prevent depletion of aquifers. Autumn and winter 1995 rain on the Heretaunga Plains ended the drought condition but the advanced reporting deadline remained in place and an Executive Summary of the Heretaunga Plains groundwater report was produced in December 1995 (Dravid & Brown 1995).

1.9.1 Objectives of the Groundwater Study

The objectives of the Heretaunga Plains groundwater study were (Dravid 1992a):

- Review and collate the existing groundwater information and identify the gaps in knowledge.
- To develop a comprehensive long-term (5 year) regional groundwater investigation strategy and undertake the necessary investigations.
- To assess the current state of the environment from existing water quality monitoring data and make appropriate recommendations for future monitoring.
- To review current groundwater management policies and practices in context of current environmental issues.
- To provide technical input to facilitate the development and implementation to enable sustainable development.

- ✏ To quantify sustainable yield of the Heretaunga Plains aquifer system.
- ✏ To review current groundwater allocation policies and suggest improvements for sustainable management of soil.
- ✏ To collate the findings in a study report to HBRC by June 1996.

1.9.2 Structure of the Study Report
The Heretaunga Plains groundwater study report is presented in the following format:

- ✏ An executive summary, including recommendations presented to HBRC, December 1995 (Dravid & Brown 1995).
- ✏ Volume 1 (this report) which provides:
  - . a description of the hydrogeology and geochemistry
  - . identifies management issues of the groundwater resource and
  - . makes specfic recommendations.

- ✏ Volume 2 contains reports that contributed to the study.

Figure 1.16 is a diagrammatic representation of the contents of each volume and shows the relationship between the different parts of the study report.

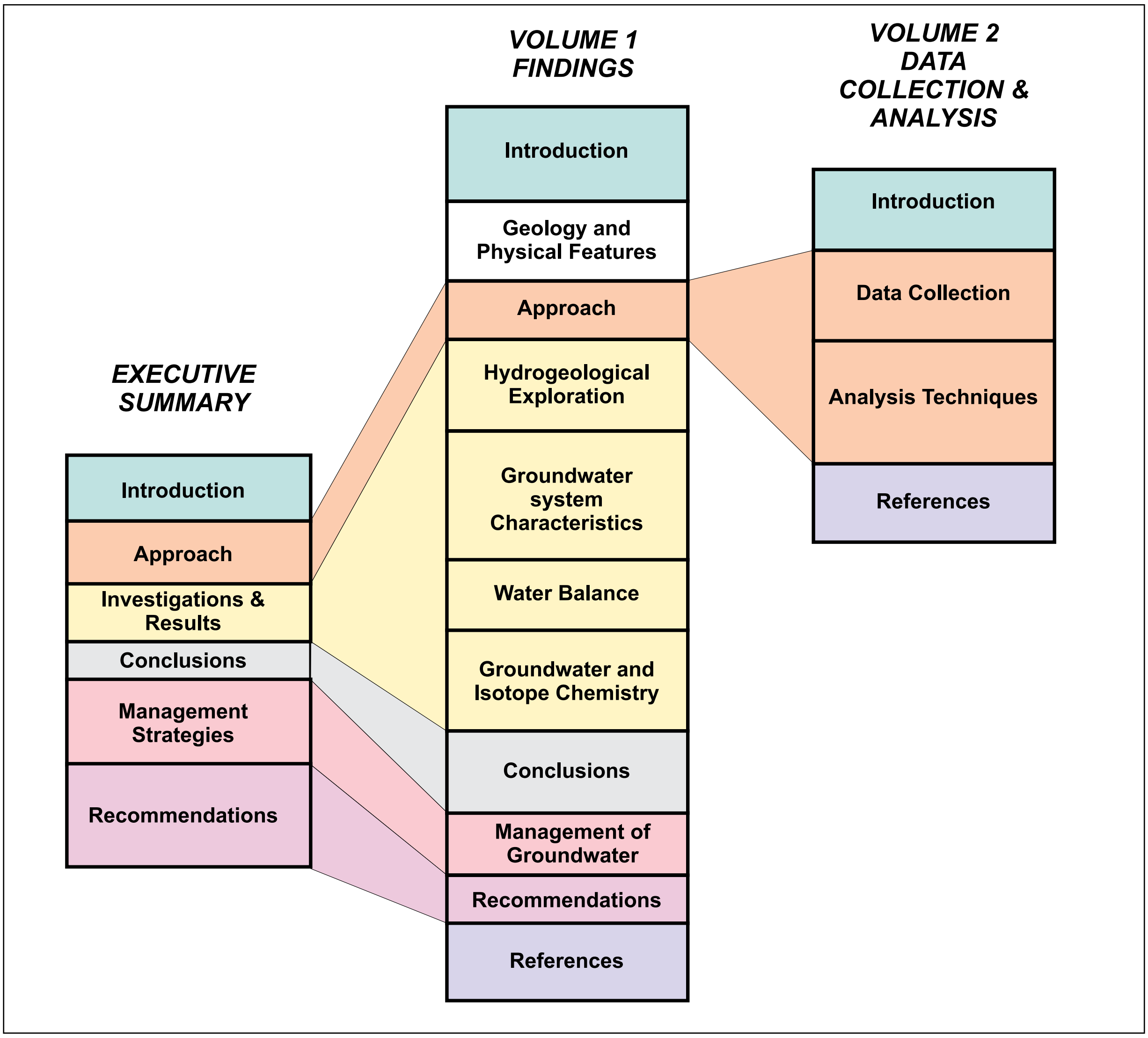

Figure 1.16: Structure of the Heretaunga Plains Groundwater Study Report.

CHAPTER 2

GEOLOGY AND PHYSICAL FEATURES

2.1 REGIONAL STRUCTURE

New Zealand is located across one of the major tectonic plate boundaries of the world. Southwest of the South Island the Pacific plate is pushing over the Australian plate, while under the North Island the Pacific plate is being thrust beneath the Australian plate (Fig. 1.1). Between these two opposing subduction systems, the New Zealand landmass is being twisted and torn by complex horizontal movement (faulting) and vertical movement (folding). Hawke's Bay is on the margin of the Australian plate and is an area of compressional stress from the westward directed thrust of the Pacific plate. 150 km offshore from Hawke's Bay the Pacific plate subduction zone is at the Hikurangi Trough (Fig. 1.1) which extends along the east coast of New Zealand to the Marlborough coast. Oil exploration seismic surveys show gently folded anticlines and synclines with northeast striking axial planes and northwest dipping thrust faults to a depth of 3 km in Hawke Bay. The northeast-southwest oriented "basin and range" topography, and faults of Hawke's Bay are the onshore products of the interaction of the plates. The Heretaunga Plains infill a basin formed by buckling and fault dislocation. The infilling sediments are a product of paleoenvironments associated with glacioeustatic sea level changes in the range of a few metres above to 150 m below present sea level and subsidence of the basin at a rate of about 1 m/1000 years over the last 250 000 years.

On the Heretaunga Plains, seismic surveys from Bridge Pa to Pukahu (Figs. 2.5 and 4.4) suggest a 900 m deep basin structure with the deepest part below Bridge Pa (Ravens 1990). The offshore seismic surveys for oil exploration suggest that the basin structure extends at least 30 km off the coast in a northeast direction (American Exploration 1991). The basin structure beneath the Heretaunga Plains has been variously described as a tear apart structure (drag-graben), a fault-angle depression, and a syncline (Kingma 1971, Ravens 1990). This report adopts the term Heretaunga depression as proposed by Kingma (1970).

High resolution continuous seismic profiles obtained by NZ Oceanographic Institute, DSIR in southern Hawke Bay show four seaward-tilted unconfirmities which are identified as wave-planed surfaces on which late Quaternary (penultimate glacial to postglacial) sediments have accumulated during eustatic sea level fluctuations.

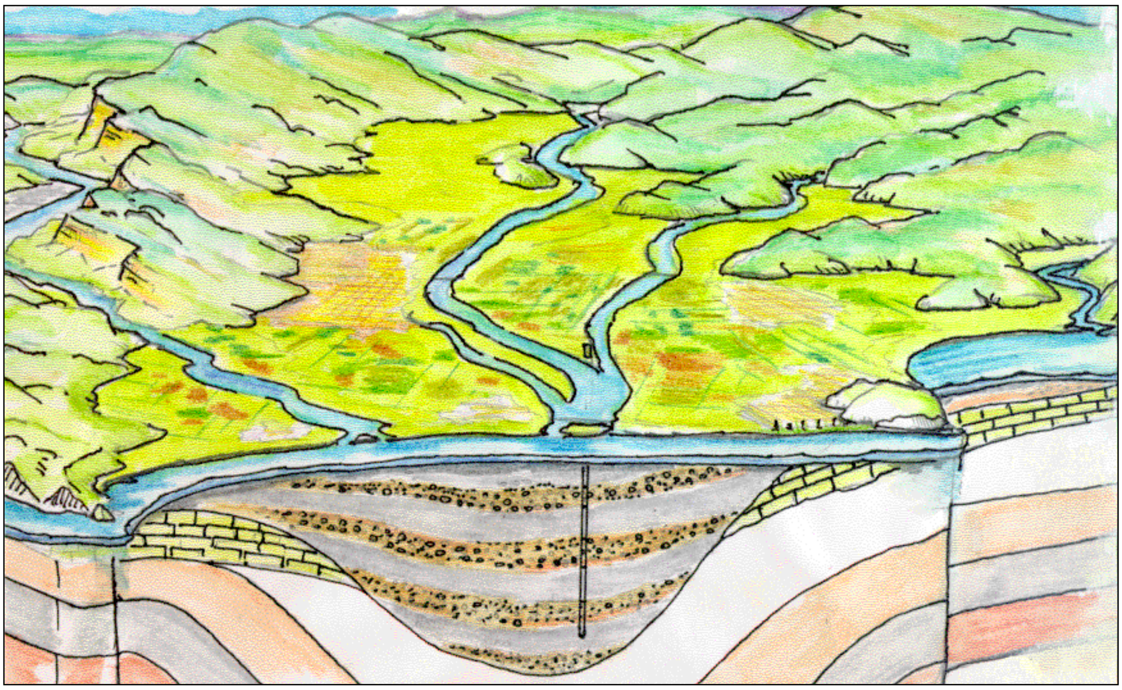

Figure 2.1:
A drawing showing the landscape and a slice through the Heretaunga Plains at the Hawke Bay coast.
The Heretaunga depression is infilled with young deposits (<500 000 years BP) including gravel forming aquifers which overlie limestone and older sediments. The HBRC Awatoto testbore (well no 3699) is shown penetrating the aquifer/ aquiclude sequence to a depth of 250 m.
(drawing:Bruce Churchhouse, HBRC).

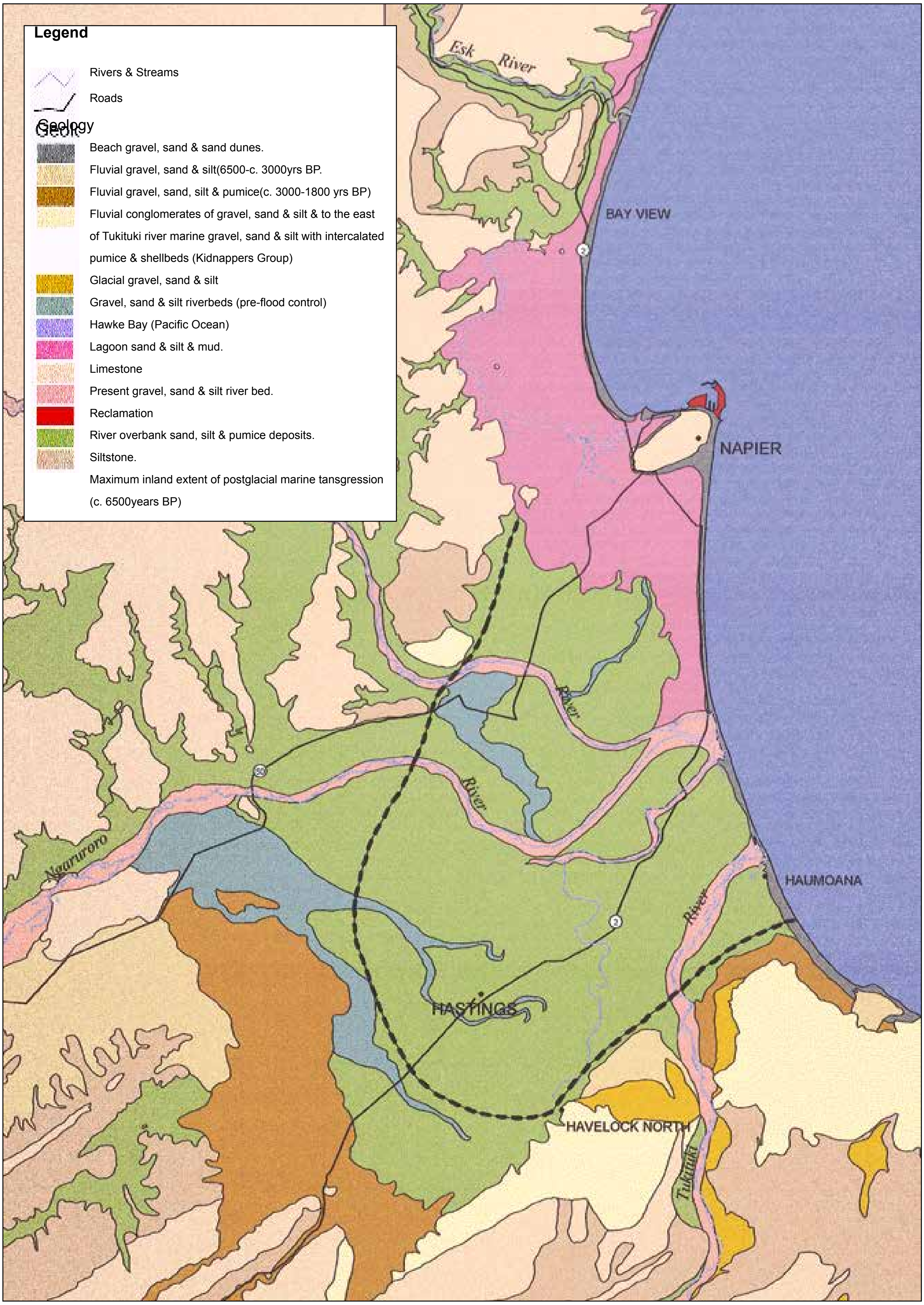

Figure 2.2: Geological map of the Heretaunga Plains.

These late Quaternary beds become thinner towards the Lachlan Ridge and tilt westwards into the Lachlan depression of the eastern margin (Lewis 1973b).

The present Hawke's Bay geology and landscape began to take shape about 2 million years ago with the onset of a series of global climate cycles of glacial climate followed by temperate climate periods. This was the beginning of the Quaternary period.

Figure 2.2 is a geological map of the Heretaunga Plains and adjacent areas. The various rock types and river and marine sediments which form the present landscape have been delineated. The maximum inland extent of the postglacial marine transgression is marked by the 6500 years BP[4] shoreline.

2.2 SEDIMENTATION

The deepest groundwater exploration testbores on the Heretaunga Plains were drilled as part of the HBRC - IGNS Heretaunga Plains groundwater study. Testbores at Awatoto on the Hawke Bay coast and at Tollemache Orchard near Hastings penetrated to 250 m and bottomed in penultimate interglacial deposits. Below this the sediments that fill the Heretaunga depression probably include part of the sequence of strata exposed in the sea cliff between Clifton and Black Reef at southern Hawke Bay (Fig. 2.3). These were mapped by Kingma (1971) and are called the Kidnappers Group. The deposition and probable preservation of the Kidnappers Group in the Heretaunga depression and the deposition of the overlying late Quaternary sediments is the result of tectonism (folding and faulting) producing predominantly subsidence, and climate cycles with changing sea level, interacting with river and coastal erosion and deposition processes.

Kidnappers Group sediments include alternating layers of gravel, silt, peat with buried tree trunks, volcanic ash, and dune, beach and near-shore sand. The age of these deposits range from about 500 000 years BP near Clifton to about 1 million years BP (Castlecliffian) in the east near Black Reef (Black 1992). There are breaks in the sequence where sediments have been eroded. Subsequent uplift in the east with a component of westward tilting (Fig. 2.3) has resulted in the preservation and exposure of the strata at the southeast Hawke Bay coast, and probable burial beneath the adjacent Heretaunga Plains to the west.

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[4] Before present.

Figure 2.3: Westward tilted Kidnappers Group strata dipping beneath the Heretaunga Plains. *(photo: Lloyd Homer, IGNS CN 29227)*

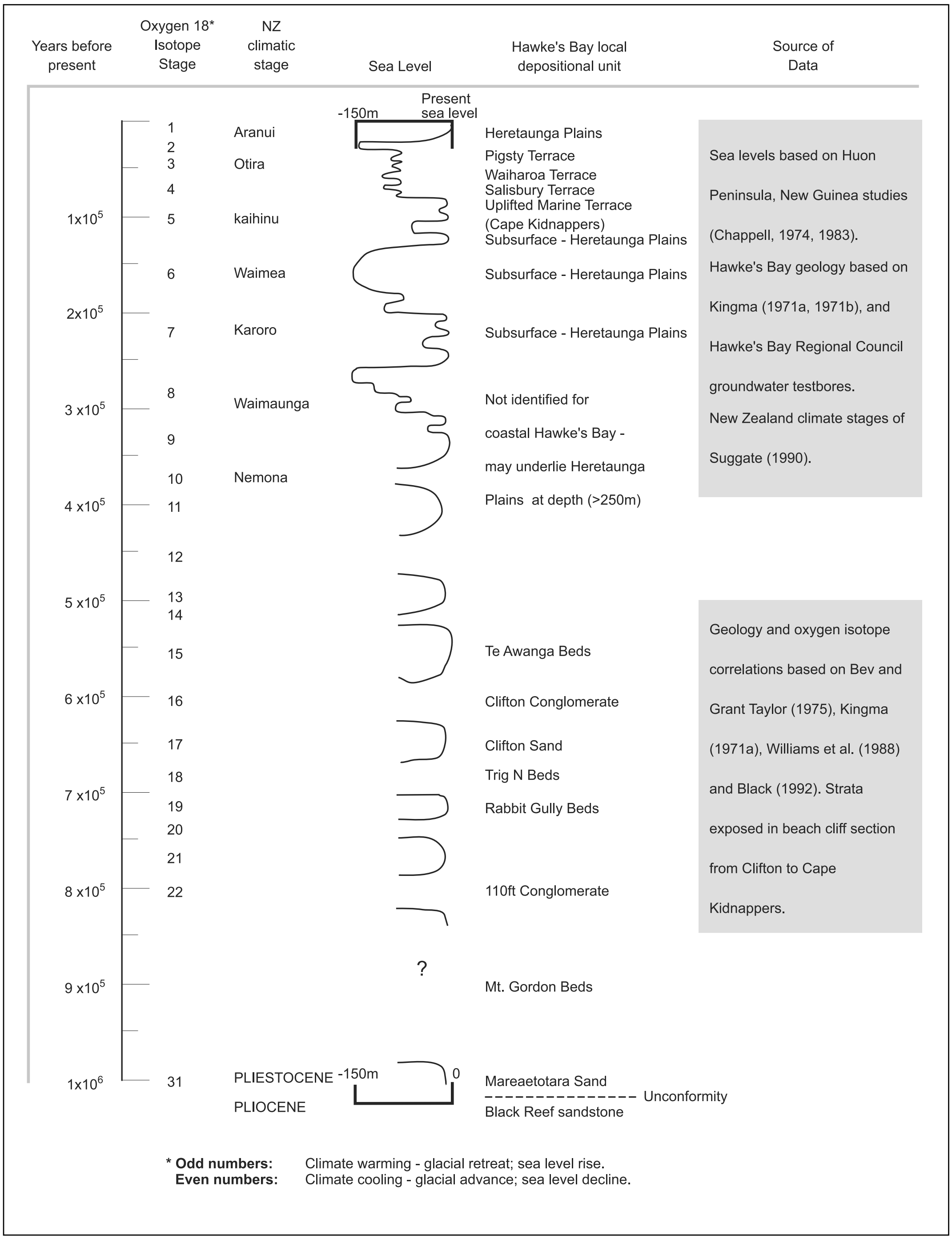

Figure 2.4: Diagrammatic representation of the climatic changes during the last 1 million years.

During the glacial periods there was build-up and retention of ice as ice sheets on mountain ranges, and as glaciers in valleys to the west of Hawke's Bay. There was less water in the oceans, with sea level declining as much as 150 m below present levels (Chappell 1983), onto exposed former sea bed. Hawke's Bay rivers flowed eastwards into the bay depositing gravel, sand, and silt eroded from the mountain ranges to form an alluvial plain extending about 50 km offshore from the present Hawke Bay coast.

The warming of climate during the temperate interglacial periods, caused the ice to melt and glaciers to retreat. The warmer climate resulted in the establishment of vegetation at higher altitudes on the mountains reducing erosion. Sea levels rose and coastal swamp, estuarine-lagoonal, and beach deposits accumulated over the alluvial plain. The geologic record provides evidence of at least ten glacial-interglacial episodes during the Quaternary period. The Kidnappers Group includes sediments deposited during glacial and interglacial periods.

The onshore seismic surveys suggest Kidnappers Group strata could underlie the Heretaunga Plains as could Nukumaruan late Pliocene and early Pleistocene strata penetrated by an oil exploration drill hole at Mason Ridge (Leslie 1971) near Maraekakaho (Fig. 2.5).

These correlations suggest ages for the structure and infilling sediments of the Heretaunga depression (see inside covers - Geological history of the Heretaunga Plains and Hawke's Bay). The Heretaunga depression is a synclinal structure in late Pliocene and early Pleistocene sediments which have undergone uplift, warping, tilting, and subsidence over the last 1 million years. In the middle Pleistocene, tectonic uplift and deposition associated with alternating cold and temperate climate resulted in the accumulation of the terrestrial and coastal sediments of the Castlecliffian Kidnappers Group. In the Heretaunga depression these deposits probably unconformably overlie the late Pliocene and early Pleistocene marine sediments. The erosional unconformity is a regional reflector which the seismic surveys have identified (Ravens 1990) and may represent the deepest and antepenultimate glacial offshore wave-planed surface identified by Lewis (1973b). About 500 000 years BP, subsidence of the Heretaunga depression began and continues to the present day.

A groundwater testbore at Tollemache Orchard (well no. 3697) on the southern boundary of Hastings city (Fig.a), was drilled to a depth of 256.5 m and terminated in a beach gravel correlated with the penultimate

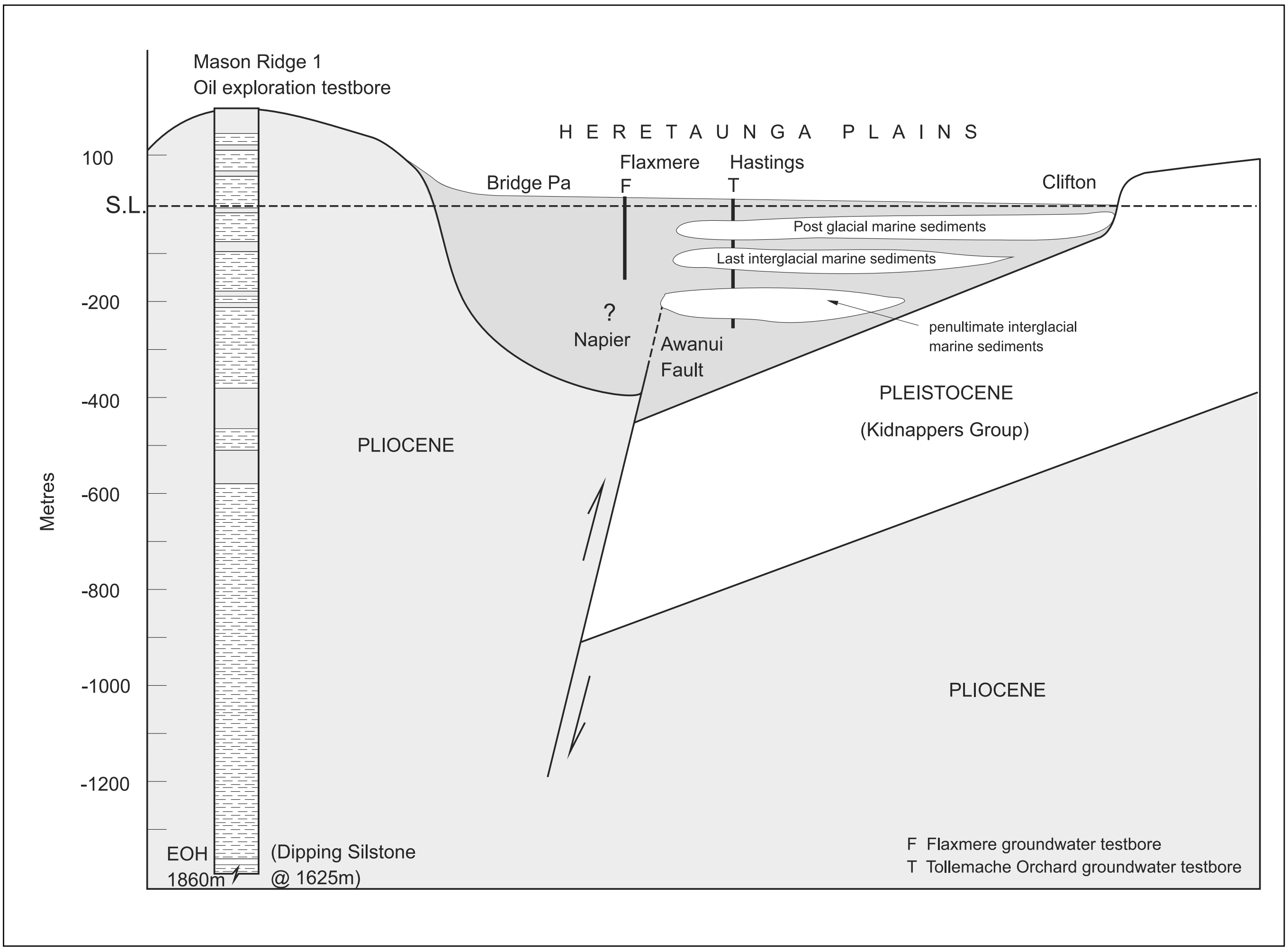

Figure 2.5: Seismic correlation with the Mason Ridge oil exploration testbore.

Karoro Interglacial (Suggate 1985) of 200-250 000 years BP. The sediments penetrated by the testbore were “tight” at 225 m and this combined with “sand heave” forced drilling to stop at 256.5 m (Brown 1993). A groundwater testbore at Awatoto near the Hawke Bay coast, encountered “tight” and difficult drilling conditions at 224 m and drilling finally stopped in a terrestrial gravel at 254 m. This testbore penetrated penultimate interglacial marine deposits from 187 to 233 m (Brown & Gibbs 1996). The deposition of penultimate interglacial marine deposits is a result of the sea transgressing over the land during the high sea level (similar to that of the present) associated with the temperate climate. The maximum inland extent of sea produced an embayment with the coastline at Havelock North, Flaxmere and Taradale (Fig. 2.6). Subsidence of these deposits to 200 m suggests a subsidence rate of about 1 m/1000 years and this has resulted in their burial and preservation from subsequent erosion.

The groundwater testbores at Flaxmere (well no. 3698), Tollemache Orchard (well no. 3897) and Awatoto (well no. 3699) all penetrated last interglacial Kaihinu Interglacial (Suggate 1985) of 70 -120 000 years BP marine deposits in the depth range 90-110 m (Brown 1993, Brown & Gibbs 1996). Well logs from several other water wells on the Heretaunga Plains drilled deeper than 100 m also show marine deposits at this depth range. The last interglacial Hawke Bay shoreline on the Heretaunga Plains extended inland to a similar position to that of the penultimate interglacial shoreline (Fig. 2.6).

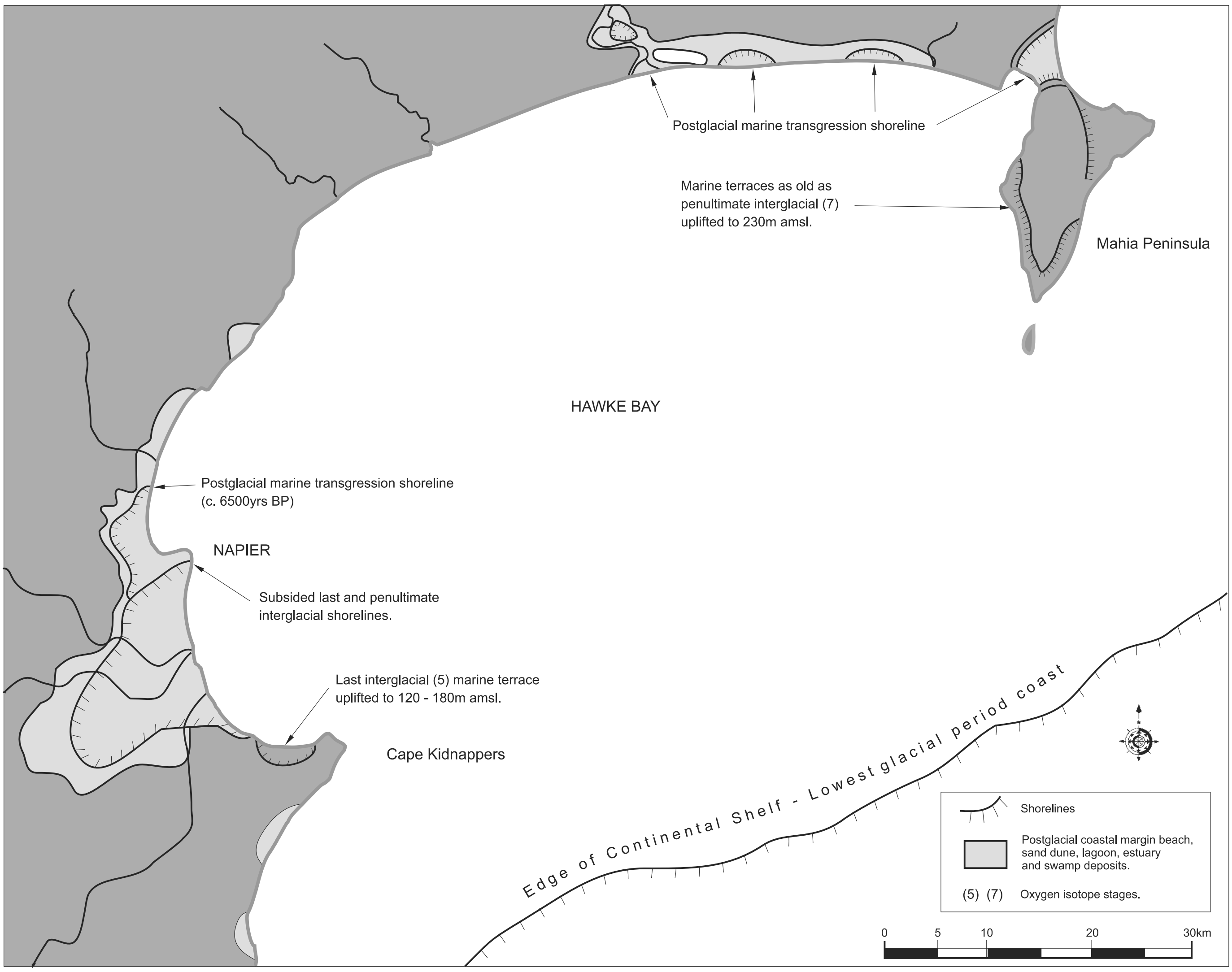

Figure 2.6: Position of minimum sea level during the last glaciation and maximum sea level of interglacial and postglacial periods.

During the last glacial period sea level fluctuations resulted in changes in the location of the coast on the continental shelf. When the sea level was at the lowest level of 150 m below present sea level, the coast would have been at or near the edge of the continental shelf (Fig. 2.6) 50 km offshore of the Hawke Bay coast.

About 14 000 years BP, the present temperate climate period began and sea once again transgressed over the land. The Hawke Bay 6500 years BP shoreline was at a similar position to the interglacial period shorelines (Fig. 2.14). Estuaries, lagoons and swamps occupied the Hastings, Pakowhai and Napier areas. Coastal outbuilding or progradation began after sea level stabilised at about the present level 6500-6000 years BP and a succession of juxtaposition beach deposits including beach gravel, dune sand, estuarine, lagoon, and swamp, silt and peat accumulated as progradation proceeded. Also incursions by the Tukituki, Ngaruroro and Tutaekuri rivers into the area deposited sand, silt and gravel. Ages for the accumulation of these deposits are established by radiocarbon dating.

From the groundwater resource point of view the predominantly fluvial gravel deposits that accumulated as gravel river channels during and immediately after the glacial periods are important, as these form permeable high yielding aquifers. The aquifers are interbedded with interglacial silt, clay, peat, and shelly sand and clay down to explored depths of 250 m. The fine grained sediments separating gravel aquifers form aquicludes and aquitards which impede vertical groundwater flow.

2.3 QUATERNARY PALEOGEOGRAPHY

In order to provide a regional overview of the Heretaunga Plains depositional environments, the areas of sedimentation and the tectonic influences in the context of aquifer configuration, a sequence of seven paleogeographic snapshots during the Quaternary period (2 million years BP to present) are presented (Figs. 2.7 to 2.14). From the groundwater point of view, the paleogeographic changes during the last 300 000 years are most relevant. For the division and tentative correlation of the surface and subsurface late Quaternary terrestrial and marine deposits, this report adopts the north Westland, South Island climatic stages of Suggate (1985).

2.3.1 Quaternary/Pleistocene (c. 2 million years BP)

At the beginning of the Quaternary period the climate in New Zealand was temperate and most of the Hawke's Bay area was below sea level except for uplifted coastal land south of Cape Kidnappers (East Coast Highlands - Beu et al. 1980). Limestone units which occur from Hawke's Bay southwest to Wairarapa were deposited when the sea occupied the East Coast Inland Depression (Kamp 1982). Detailed mapping and descriptions of the limestones of Hawke's Bay are given by Beu (1995).

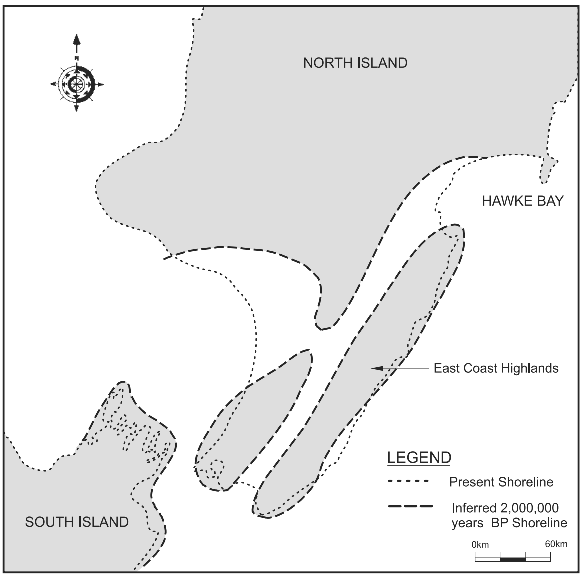

Figure 2.7: Central New Zealand coastline about 2 million years ago.

A seaway in the vicinity of the Manawatu Gorge connected Wanganui and Hawke's Bay. During the early Quaternary period climate cooled and the shoreline receded. Also tectonic uplift of the Mt Bruce block to the south of Hawke's Bay in the early Quaternary (Vella 1962) and the main uplift of the Ruahine Range about 1 million years BP (Grant-Taylor 1978) displaced the seaway. The shoreline receded and the East Coast Inland Depression was filled with gravel, sand and silt eroded from the Ruahine Range and deposited by the rivers flowing into the seaway. These were the Tukituki (and tributaries), Ngaruroro, Tutaekuri, Esk and Mohaka rivers.

2.3.2. Middle Quaternary/ Middle Pleistocene (c. 1 million to c. 500 000 years BP)

Kamp (1990) suggests that the middle to upper part of the Kidnappers Group ranges in age from isotope stage 13 (c. 500 000 years BP - Mt Gordon Beds) to stage 5 (c. 100

000 years BP - Te Awanga Beds) based on constraints offered by the macropaleontology, magnetostratigraphy and especially fission track ages of volcanic tuff beds (tephra). The Tollemache Orchard and Awatoto exploration bores penetrated postglacial, last and penultimate interglacial deposits to a depth of 250 m beneath the Heretaunga Plains. This should overlap with the Kidnappers Group beds. The macro and microfauna and the microflora assemblages of the subsurface Heretaunga Plains climatic stratigraphic beds cannot be definitely correlated with the Kidnappers Group beds. Also it is difficult to reconcile a late Quaternary time range with the tectonic tempo necessary to tilt the Kidnappers Group beds 8-13° NW dip, and form and subsequently uplift the last glaciation marine cut terrace at Cape Kidnappers (Fig. 2.3). This suggests that the Kidnappers Group may be older than Kamp's (1990) time range.

An older time range has been proposed by Black (1992) for the Kidnappers Group sediments exposed in the cliff section between Clifton and Black Reef based on magnetostratigraphy. This suggests deposition over a period of c. 500 000 to 1 million years BP. Black's (1992) oxygen isotope stage correlations are adopted for Figure 2.4 of this report. The layers of sediments in the cliff section include sandstone deposited in shallow sea water close to the shore, bluish-grey beds of estuarine silt and fluvial gravel, sand and silt. Thin layers of peat beds containing fossil leaves, tree trunks, thick beds of white volcanic ash, and white calcium-rich shell layers also occur. The sediments arise from a series of paleoenvironment cycles of high and low sea levels during which, marginal marine swamp, lacustrine and fluvial sediments were deposited.

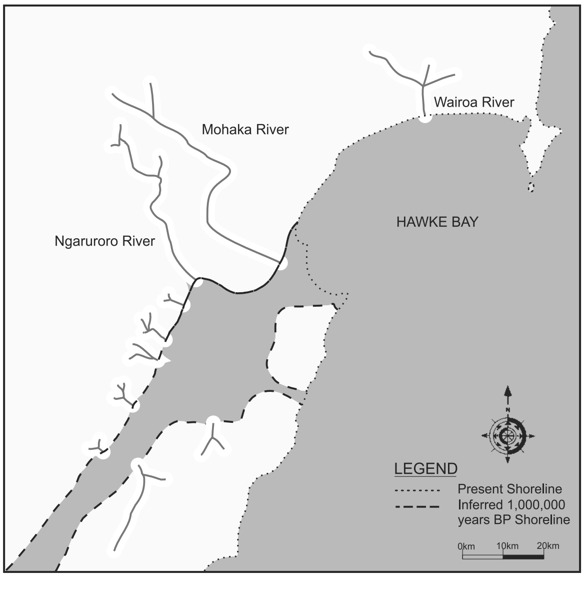

Figure 2.8: Hawke Bay coastline about 1 million years ago.

Besides wind blown deposits of volcanic ash there are two ignimbrite volcanic units in the Kidnappers Group. These were also derived from volcanic eruptions in the Taupo Volcanic Zone of the central North Island but were emplaced by pyroclastic flows which crossed the mountain ranges. The presence of ignimbrite, a pumice like rock which flows away from the eruptive centre until it cools and solidifies, indicates that river valleys probably provided a route to the east for these flows. The ignimbrite is similar in composition to ignimbrite observed at Waipunga Falls in the headwaters of the Mohaka River (Grindley 1960). Isolated remnants of river gravel containing ignimbrite have been found at several places between Cape Kidnappers and the main northward bend of the Mohaka River near Puketitiri (Beu and Grant-Taylor 1975). Therefore it seems likely that valleys of the Mohaka River and tributaries provided the route whereby ignimbrite flows reached Hawke's Bay. The ignimbrites are dated between 730 000 and 910 000 years BP (Black 1992) and these dates suggest that significant uplift of the mountain ranges has occurred since the deposition of volcanic material in Hawke's Bay. It seems likely that the Mohaka River course has been diverted to the north after about 700 000 years BP as ignimbrite pebbles do not occur in gravel beds above the Rabbit Gully Beds in the Kidnappers Group.

2.3.3 c. 500 000 - 250 000 years BP

This time range encompasses three climatic cycles of glacial and temperate climate. No sediments or surfaces are known onshore that can definitely be related to deposition during this period. Groundwater testbores (Tollemache Orchard and Awatoto - see 4.4) terminated at a depth of 250 m (below ground surface) in sediments correlated with marine deposition during the high sea level (similar to present day) Karoro Penultimate Interglacial period. Sediments deposited during the 250 000 - 500 000 year BP time period may be deeper than 250 m and overlie Kidnappers Group sediments under the Heretaunga Plain. Their preservation and burial would be a result of continuing subsidence of the Heretaunga depression over the last 500 000 years.

Offshore in Hawke Bay, Lewis (1973b) correlates the deepest of four seismic reflectors with an antepenultimate glacial (Waimaungan Glacial) wave planed surface.

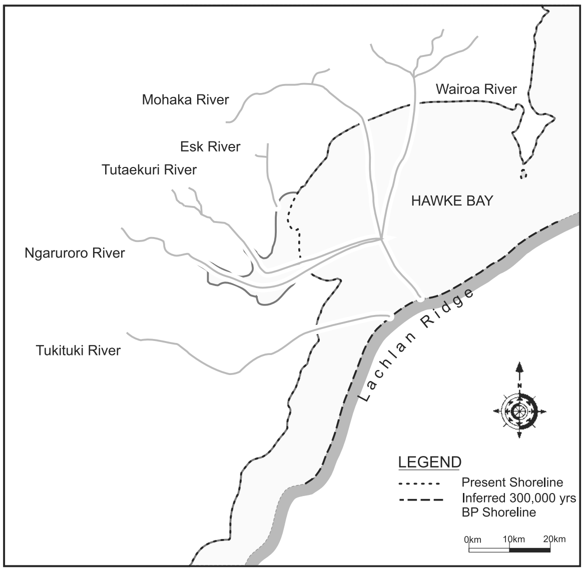

Figure 2.9: Hawke Bay coastline about 300 000 years ago

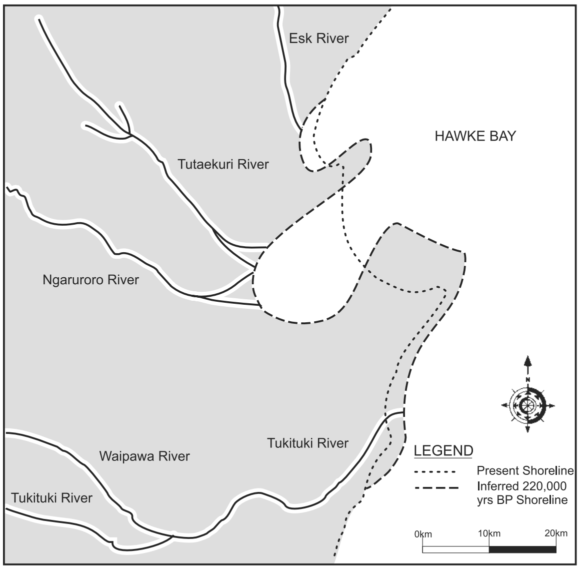

Figure 2.10: Hawke Bay coastline about 220 000 years ago.

If this is correct a sequence of Karoro Penultimate Interglacial to Holocene sediments forms the near surface deposits on the Hawke Bay sea floor.

2.3.4 Karoro Penultimate Interglacial (200 000 - 250 000 years BP)

The only deposits on or surrounding the Heretaunga Plains which can be correlated with the Karoro Penultimate Interglacial period are marine deposits intersected by the Tollemache Orchard and Awatoto deep exploratory groundwater testbores. Figure 2.10 shows the shoreline at Hawke Bay 220 000 years BP when the sea level was similar to the present and these deposits accumulated. Penultimate interglacial deposits were penetrated from 154 to 256 m below ground level by the Tollemache Orchard testbore and from 132 to 254 m below ground level by the Awatoto testbore (see 4.4). Lithologies are predominantly blue and blue-grey gravel, sand, silt and clay with interbedded shell, carbonaceous and wood layers. Deposition occurred during rising or high sea level in shallow water offshore, beach, estuarine, lagoonal, swamp and coastal floodplain environments. Preservation and burial is a result of subsidence.

2.3.5 Waimea Glaciation (120 000 - 200 000 years BP)

During this cold climate period sea levels were as low as 150 m below present level (Chappell 1983) and the coast would have been near the edge of the continental shelf. Penultimate glacial deposits were penetrated from 144 to 154 m below ground level by the Tollemache Orchard testbore and from 117 to 132 m below ground surface by the Awatoto testbore. Lithologies are predominantly grey gravel with a matrix of sand, silt and clay and carbonaceous material, and represent deposition at the inner Plains margin of the Ngaruroro and Tutaekuri rivers.

2.3.6 Kuhinui (last) Interglacial (70 000 - 120 000 years BP)

The relatively flat surface on top of the cliff at Cape Kidnappers (Fig. 2.3) is a remnant of an old shore platform cut during the last interglacial period about 125 000 years ago on Pliocene mudstones and the older units of the Kidnappers Group (Kamp 1990). It has been preserved after tectonic uplift. Looking towards Clifton from Cape Kidnappers, the terrace height increases and then decreases (Fig. 2.11).

This is the result of folding in response to continuing tectonic pressure in the earth's crust. In the Cape Kidnappers area there is gap in sediments from about 500 000 years BP (Te Awanga Beds) to the last interglacial period. This could be a result of deposits in

Figure 2.11: Shore platform at Cape Kidnappers *(photo: Lloyd Homer, IGNS CN 29227)*.

that time range having accumulated at the coast further north of the present Cape Kidnappers coastline, which have subsequently been eroded by the sea as the coast retreated to the south.

Beneath the Heretaunga Plains at a depth of about 120 m marine deposits of the last interglacial period are intersected by wells. Figure 2.12 shows the shoreline at Hawke Bay 120 000 years BP when sea level was similar to the present. Lithologies are predominantly blue and grey-brown gravel, sand, silt and clay with interbedded shell, carbonaceous and wood layers. Deposition occurred during rising or high sea level in near shore, beach, estuarine, lagoonal swamp and coastal floodplain environments. Preservation and burial is a result of subsidence.

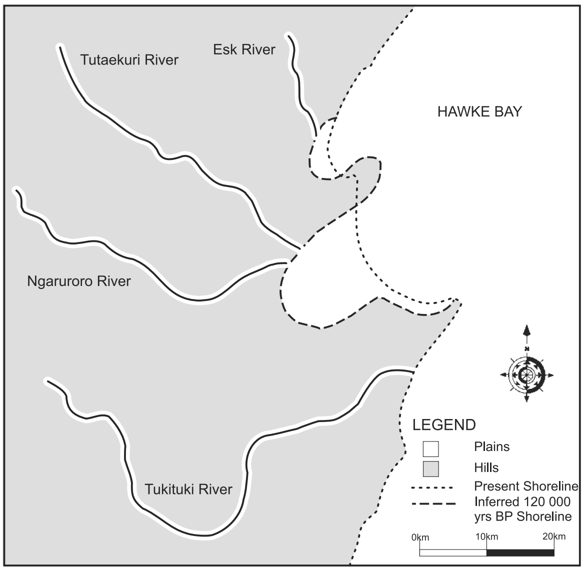

Figure 2.12: Hawke Bay coastline about 120 000 years ago.

2.3.7 Otiran Glaciation (70 000 - 14 000 years BP)

With cold climate and sea levels as low as 150 m below present level during the last (Otiran) glaciation at about 23 000 years BP, the coast would have been about 60 km offshore not far from the edge of the continental shelf.

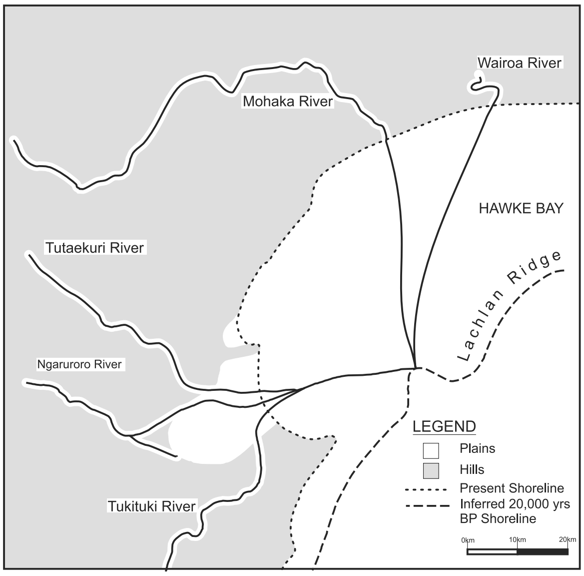

Figure 2.13: Hawke Bay coastline about 20 000 years ago.

Also with the onset of glacial climate, erosion of the greywacke mountain ranges would have intensified and the Ngaruroro and Tutaekuri rivers with their mountain catchments would have river valleys and floodPlains that were often filled with fluvial gravel deposits. The late Quaternary terrace deposits (Salisbury, Waharoa, Pigsty and Maraekakaho terraces - Kingma 1971) in the Maraekakaho area are the depositional products of erosion associated with cold climate. Kingma (1971) does not directly correlate these terrace deposits with the climatic stages of Suggate (1965). However he describes a radiocarbon dated wood sample from Hospital Hill, Napier in a weathered pumiceous clay which unconformably overlies the Brickyard Clays which unconformably overlie Nukumaruan strata in Brickyard Quarry (V21/454826)[5]. The Brickyard Clays as the sequence is known, are overlain by pumice with an interbedded tree stump. The wood sample was radiocarbon dated at 20 550 +/- 300 years BP (Table 4.2 NZ12)[6]. Kingma (1971) concludes "the erosion interval between the clays and the Nukumaruan is considerable, and it seems reasonable to place the Brickyard Clays and their overlying pumice in the H1 part of the Hawera Series". H1 is equivalent to the Salisbury and Waharoa terraces early to middle Otiran, Pigsty terrace late Otiran, and Maraekakaho terrace of early postglacial deposition.

This correlation has other implications for Kingma's (1970) geological map and the Tukituki River paleogeography. Terrace remnants at Houpouri on the Ocean Beach Road and in the Maraetotara River valley, would also be correlated with last (Otiran) glaciation deposition. Correlation of the Ocean Beach Road terrace deposits and the Salisbury and Waharoa terraces, suggests the Tukituki River was still flowing to the east with an outlet south of Cape Kidnappers possibly up to about 20 000 years BP. Westward tilting of the Kidnappers block and rising postglacial sea level would have resulted in the Tukituki River forming a new course to the north into Hawke Bay.

While this correlation of Salisbury terraces with last (Otiran) glacial fluvial deposition can only be regarded as speculative, it demonstrates that the Salisbury and Waharoa terraces in the Maraekakaho area may include fluvial deposits as young as last glaciation. Kingma (1971 - p. 103) noted that for the Salisbury and Waharoa terrace deposits, pumice is intermixed with relatively fresh greywacke gravels, compared to Castlecliffian terrace deposits where the pumice occurs in bands and the gravels are more weathered.

The Salisbury gravel lithofacies of Kelsey et al. (1993) is a composite fluvial deposit with an age ranging from late Nukumaruan to early Castlecliffian (early Pleistocene). Salisbury and Waharoa terraces of Kingma (1971) have an age range extending to late Pleistocene. Detailed mapping of terrace deposits in the Maraekakaho area has the potential to produce finer division related to climatic stages and correlation with the Heretaunga Plains surface and subsurface fluvial deposits.

During the Otiran Glaciation on the western margin of the Heretaunga Plain, fluvial depositional processes would have been constantly adjusting to uplift at the Puketapu Fault Zone (Kamp 1990), fluctuations in river flow and sediment supply, and sea level changes. The Tutaekuri and Ngaruroro rivers would be depositing fans of gravel, sand and silt to build out a fluvial plain from the Scinde Island ridge (Fig. 2.12) in the north to the

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[5] Grid references are based on the national 1000m grid of the 1:50 000 topographical map series (Infomap 260) of the Department of Survey and Land Information.

[6] All radiocarbon dates are conventional Radiocarbon Age as defined by Stuiver and Polach (1977) in years BP (1950 A. D.).

hills south of Bridge Pa and at Pakipaki. These gravel fan deposits were constantly reworked and redeposited so that channels of permeable gravel with minimal fines (silt) content criss-crossed the Plains. Poorly sorted gravel, sand and silt formed "islands" where the original fluvial deposits were not reworked and fines, principally silt, accumulated as overbank flood deposits adjacent to the channels. The permeable gravel channels predominated in the central area of the plain, while less permeable fluvial deposits were more likely to be on the margins of the plain. These fluvial processes were typical of the build up of the Heretaunga Plains during the Otiran Glaciation.

About 14 000 years BP when climate warming began, rivers carried less sediment as catchment erosion declined with increased forest cover, and rising sea level shortened the Plains reaches of the river courses. On the Heretaunga Plains the Ngaruroro and Tutaekuri rivers adjusted by downcutting into and reworking the gravel fan and channel deposits. The net result of glacial and early postglacial river deposition and reworking was that the Heretaunga Plain was built up and out with an underlying "spaghetti" of criss-crossing interconnected gravel channels.

2.3.8 Aranuian Postglacial (c. 14 000 years BP - present day)

About 9000 years BP the rising transgressing sea reached the present day coast - sea level was about 25 m below present sea level (Fig. 2.20). Sea level continued to rise until about 6500 years BP when the present level was attained. At this time the Hawke Bay coast was inland as far as Pukahu, Longlands, Frimley, Twyford, Taradale and north as marked by the sea cliffs on the western side of Ahuriri Lagoon (Fig. 2.14).

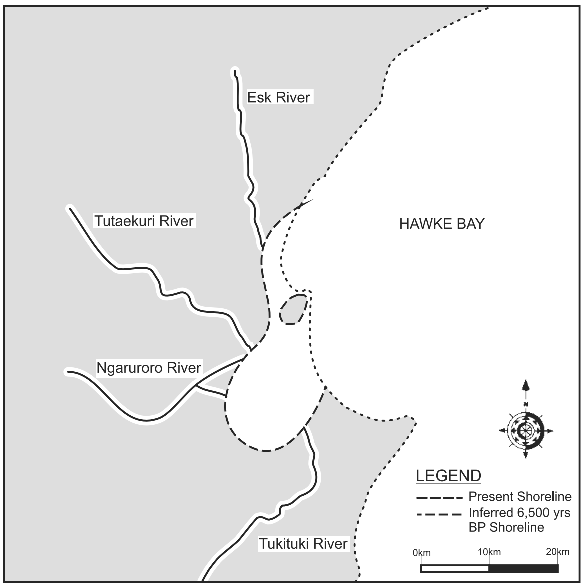


Figure 2.14: Hawke Bay coastline about 6500 years ago.

The sandstone and limestone promontory connecting Scinde Island to the mainland had been eroded and Scinde Island along with other smaller islands were present in a bay offshore from Taradale and Bay View. The marine transgression deposited a wedge of marine beach, estuarine and lagoonal sediments and marginal marine swamp deposits over the permeable gravel channel deposits of the last glacial period. At Awatoto this wedge forms a confining strata for the underlying artesian gravel aquifers and is about 30 m thick.

From 6500 years BP to the present, the coast has prograded (built out). About 4500 years BP gravel and sand tombolos had formed to reconnect Scinde Island to the mainland and enclose a large lagoon into which the Tutaekuri and Esk rivers flowed. The Ngaruroro and Tukituki river mouths were at the Hawke Bay coast not far from their present outlets.

For the last 4500 years the lagoon was slowly filled with sediments brought in by the Tutaekuri and Esk rivers and also periods of sediment input by the Ngaruroro River during floods or changes of course. The process was hastened this century by the 1931 earthquake and reclamation by man.

To the south of the Ahuriri Lagoon the Ngaruroro River continued depositing gravel, sand and silt on the Plains in channels changing position in response to tectonic influences and flood events. The Heretaunga Plains has been periodically mantled by tephras originating from the Taupo Volcanic Zone. This has occurred both as airfall deposits and as pumice deposits washed down the Ngaruroro and Tutaekuri rivers. These volcanic deposits are intersected by wells drilled on the Heretaunga Plains. Taupo pumice derived from the Taupo eruption about 140 AD, centred on what is now Lake Taupo is overlain by up to 10 m of fluvial deposits. A former Ngaruroro River course in the Bridge Pa - Pakipaki area was clogged with Taupo pumice shortly after the eruption and adjacent areas of the Heretaunga Plains were capped by pumice overbank flood deposits.

2.4 TECTONIC INFLUENCE ON HYDROLOGY & SEDIMENTATION

Besides the Mohaka and Tukituki rivers other Hawke's Bay rivers including the Ngaruroro, Tutaekuri and Esk rivers have undergone course adjustment in response to tectonic deformation. For the last 250 000 years this deformation has been a major influence on the hydrology of the Hawke's Bay rivers and the deposition of the aquifer/aquiclude sequence of the Heretaunga depression.

Terrace remnants underlain by predominantly greywacke gravels have been mapped by Kingma (1971) at Houpouri on the Ocean Beach Road and in the Maretotara River valley. This suggests the Maraetotara River valley was once traversed by a river (?Tukituki River) with a mountain range catchment. Kingma (1971) correlates these terrace remnants with the late Quaternary Salisbury, Waiharoa, Pigsty and Maraekakaho terraces of the Maraekakaho area. Based on these terrace correlations, the present Tukituki River course downstream of the Waimarama Road bridge would be a relatively recent (?last 10 000 years) positioning.

Beu & Grant-Taylor (1975) have identified a former Tukituki River course flowing eastwards from Patangata to the coast south of Kairakau through a broadly open valley presently occupied by small streams and oxbow lakes. Another change in the Tukituki River course has occurred since the river flowed into Hawke's Bay. Originally the river flowed into Hawke's Bay at Te Awanga before shifting eastwards to its present course at the eastern margin of the Heretaunga Plains. These changes of river courses are probably in response to uplift of the Cape Kidnappers area and the progressive westward shift of the axis of the syncline.

The Ngaruroro River crosses the northeast-southwest trending Puketapu Fault Zone at Maraekakaho. Uplift to the east of the fault zone and the occurrence of relatively hard cemented limestone (Petane Group - Beu, 1995) from Maraekakaho to Napier appears to have impeded the eastward flow of the Ngaruroro River into the Heretaunga depression. The Otiran terrace deposits (Salisbury, Waharoa, Pigsty and Maraekakaho terraces) in the Maraekakaho area are the result of upstream aggradation as the Ngaruroro River adjusted to downstream tectonic uplift, reducing the gradient of the river course.

Changes in the Ngaruroro River course in part due to tectonic adjustment to late Quaternary uplift along the Puketapu Fault Zone can also be recognised on the Heretaunga Plains. The river course was originally between Maraekakaho and Roys Hill, then between Roys Hill and Fernhill, and then north of Fernhill. Uplift of the Puketapu Fault Zone also caused the gradient of some small streams adjacent to the Heretaunga Plains to flatten, or even reverse in their lower reaches. In the Okawa district to the west of the Puketapu Fault Zone, alluviation of the Okawa depression is a result of folding producing uplift in the east to reduce the gradient of Okawa Stream (Kingma 1971). Lakes Oinga and Runanga are also a product of eastern uplift obstructing drainage.

The Tutaekuri River, the other major river flowing onto the Heretaunga Plains, has also undergone changes of course as a result of uplift during late Quaternary and Holocene periods. Gravel deposits in the Moteo Valley suggest fluvial deposition by the Tutaekuri River. Uplift, possibly in conjunction with stream capture of an old Omarunui Stream, diverted the Tutaekuri into its present course (Kingma 1971). In 1931, compression of the Hawke's Bay area associated with Hawke's Bay earthquake, produced a sudden uplift of 2 m of the Ahuriri Lagoon and caused the Tutaekuri River to change its course and flow into the sea at Awatoto instead of the Ahuriri Lagoon (Fig. 2.15). The new Tutaekuri River course was through an area not affected by the uplift which extended from Bridge Pa northeast to Awatoto. To the southeast adjacent to Hastings subsidence of up to 1 m occurred, and the total area of onshore warping was smaller than that of uplift (Hull 1990).

Tectonic uplift at the Puketapu Fault Zone would affect Ngaruroro River sediment transport and downstream depositional processes. The capacity of the river to carry sediment would be reduced by uplift of the river course and less fluvial derived sediments would be available to infill the Heretaunga depression. The Tutaekuri River is likely to have been similarly affected by uplift. The supply of fluvial gravel infilling the Heretaunga depression would be reduced while the rivers downcut to adjust to the change of gradient of their course imposed by the uplift. Other influences on fluvial deposition in the Heretaunga depression would be local subsidence and eustatic level fluctuations associated with the climatic changes from temperate interglacial to glacial climate conditions. Upstream of the Pukatapu Fault Zone, Ngaruroro and Tutaekuri river degradation and aggradation processes adjusting to eustatic sea level fluctuations would be insignificant

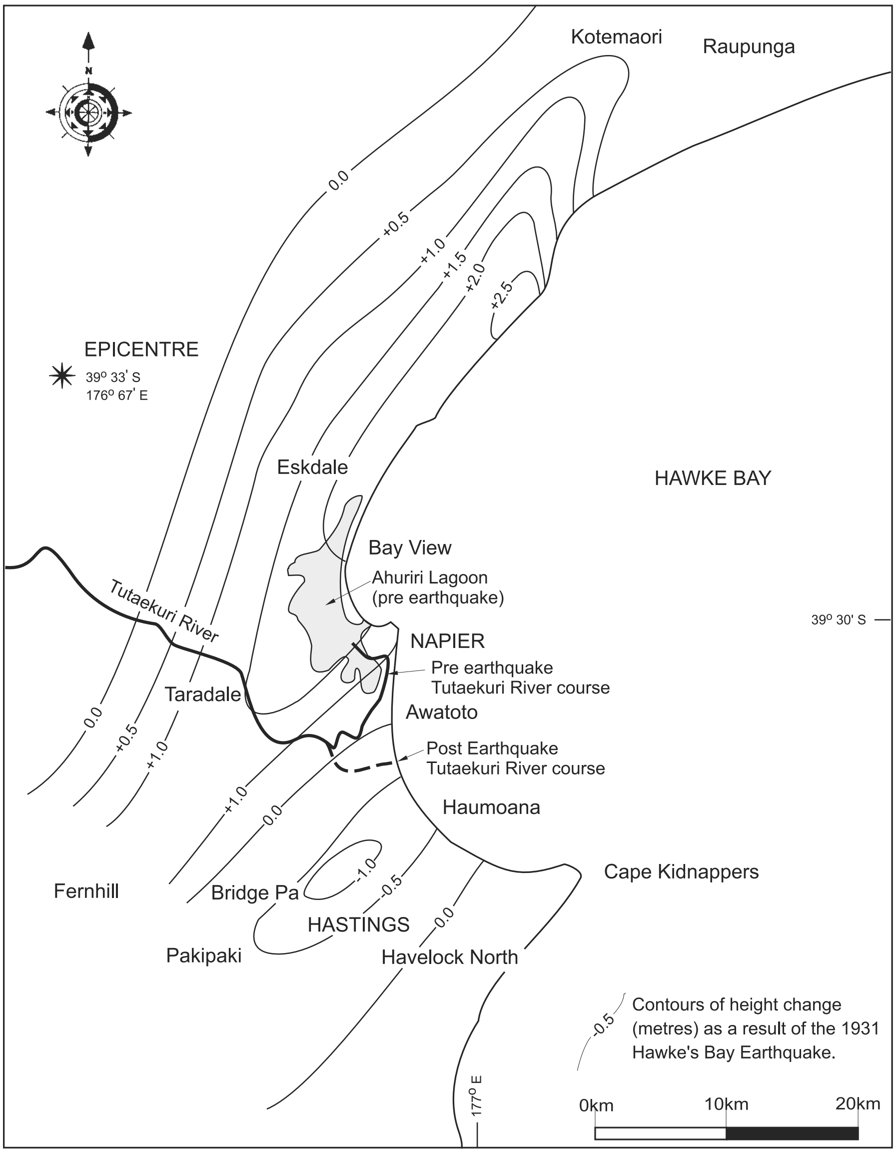


Figure 2.15:
Surface deformation after
1931 earthquake
(from Hull 1990).

compared with adjustment of sedimentation processes over the Heretaunga Plains reach of the rivers.

Additional, but relatively short-term influence on sedimentation have been volcanic eruptions in the Taupo Volcanic Zone. These have mantled the Hawke's Bay area with airfall volcanic debris (tephras). A series of shallow hand and rig augured and cored holes located in and adjacent to Lake Poukawa identified seven Holocene (last 10 000 years) and 3 late Pleistocene tephras over about the last 22 000 years (Howorth et al. 1980). In the Kidnappers section 6 tephra have been identified for the period 500 000 to 1 million years BP (IGNS 1993). In the catchments of Hawke's Bay rivers adjacent to the Taupo Volcanic Zone, volcanic eruptions and mantling with airfall debris would have locally destroyed vegetation to accelerate erosion, and clogged rivers with pumaceous material that was deposited downstream on floodPlains. On the Heretaunga Plains in the Bridge Pa - Pakipaki area a former Ngaruroro River course is indicated by pumice debris that originated from the Taupo eruption about 1850 years BP and was carried down the Ngaruroro River and deposited along the channel and on the adjacent Heretaunga Plains as overbank flood deposits.

Cyclonic storms producing brief but severe erosion in mountain catchments and downstream flooding in rivers, caused changes to the landscape and depositional processes. Grant (1985) has identified eight major periods of erosion and alluvial sedimentation on the east coast of the North Island during the last 1800

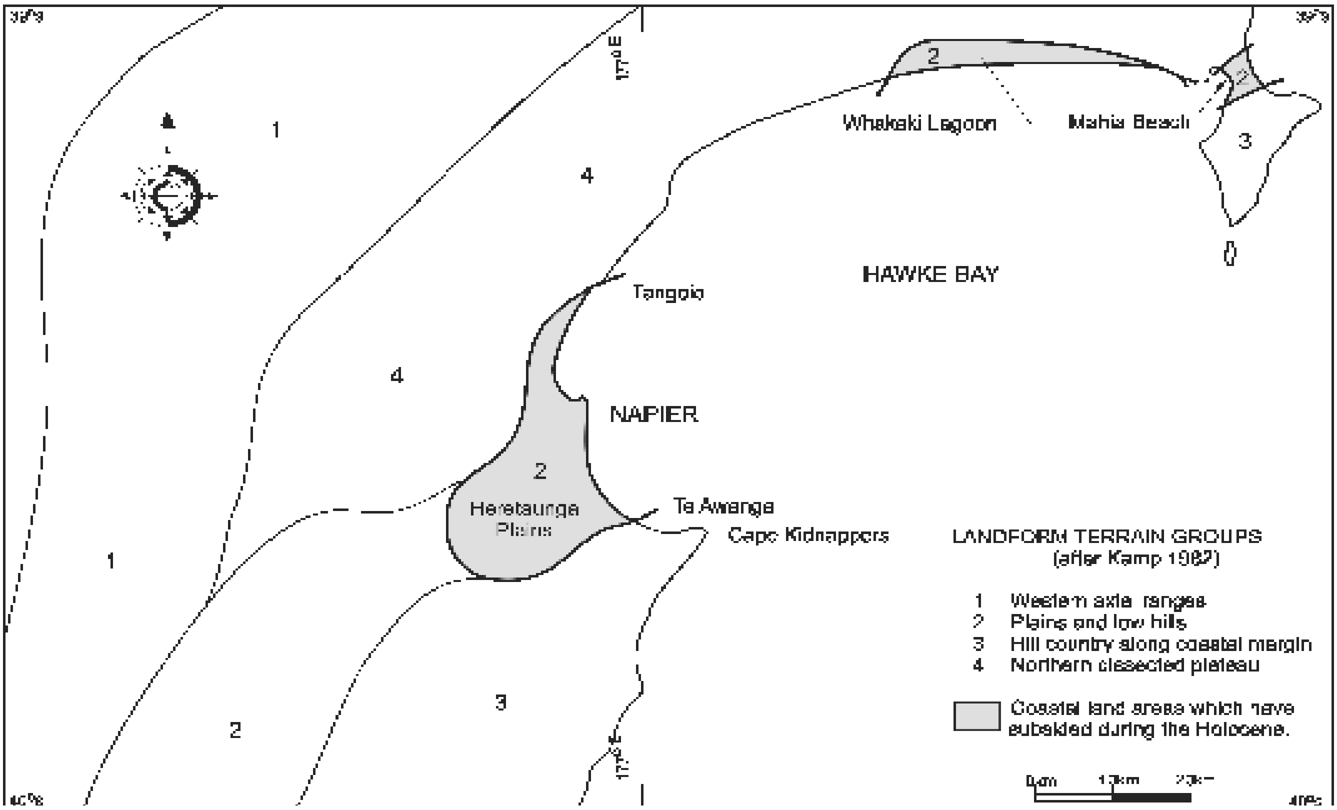


Figure 2.16: Hawke's Bay characteristic land terrain groups.

years. These may have produced pulses of downstream river aggradation that could have temporarily affected depositional processes on the Heretaunga Plains and at the Hawke Bay coast. Detailed studies of the Heretaunga Plains geomorphology for flood hazard prediction and prevention may tie specific storm events in with particular flood channel deposition.

2.5 GEOMORPHOLOGY

The Hawke's Bay region consists of distinct landforms aligned along northeast - striking axial planes. On the basis of topography four distinct landform suites have been identified in Hawke's Bay (Kamp 1990). These are:

- axial ranges in the west
- Plains and low hills
- hill country along coastal margin
- dissected plateau in the north.

These landform terrain groups are shown in Figure 2.16. The Heretaunga Plains and adjacent areas are part of the Plains and low hills landform and can be grouped into four physiographic units on the basis of geomorphology.

2.5.1 Napier Hill and Margin

Napier Hill (also known as Scinde Island) is a limestone promontory (Fig. 2.17) of three lithologic units. A capping limestone (upper Scinde Island limestone - Kingma 1971), a sandy siltstone and a lower limestone (Scinde Island Limestone - Beu 1995). An underlying siltstone strata is not exposed at Napier Hill but was penetrated by a testbore drilled in the Napier harbour breakwater.

Napier Hill was part of mainland until about 7000 years BP when the rising postglacial sea eroded the connecting ridge. It remained an island for about 3000 years until 4000 years when tombolos once again connected it to the mainland.

The countryside to the west and south of the Heretaunga Plains is a series of gently rolling hills broken by ridge escarpments and river valleys. The topography is relatively subdued ranging from 300 m above sea level

Figure 2.17: Napier Hill, the 1931 uplifted Ahuriri Lagoon and former inner harbour, and the industrial areas of Pandora and Onekawa *(photo: Lloyd Homer, IGNS C/N 12798/16)*.

in the northwest where a former plateau has been folded and dissected, to a maximum of 200 m above sea level in the southwest. To the west of the Heretaunga Plains the uplifted, gently dipping and dissected plateau is of late Pliocene and early Pleistocene limestone and mudstone overlain by remnants of a formerly more extensive sheet of fluvial gravel and silt. The strata and plateau surface dip uniformly at 5^0 to 10^0 in towards Hawke Bay (Kamp 1990). Hard recrystallised, horizontally lying, early Pleistocene limestones outcrop as prominent bluffs.

The southeastern boundary of the Plains is formed by a range of limestone hills, the Kohinurakau Range, which dips westward at 26^0 under the Plains. These are composed of marly and sandy mudstone with occasional limestone beds forming prominent topographical features. In the south is a series of tilted fault blocks of limestone and siltstone. In the Havelock North area at the north end of the Kohinurakau Range, a thick sequence of eustuarine gravel, mud and silt of mid-Pleistocene age overlies limestone. Te Mata Peak is a spectacular cuesta of Upper Pliocene barnacle-rich limestone (Awapapa Limestone - Beu 1995) which dips to the west.

From the hydrogeological perspective it is significant that when local disruption of strata by faulting and flooding is disregarded, the general regional trend is for strata enclosing the Heretaunga depression to dip inwards towards and possibly under the depression. This suggests that limestone in particular may underlie the infilling sediments and form aquifers contributing groundwater to mix with groundwater of the overlying late Quaternary gravel aquifers of the Heretaunga Plains aquifer system.

2.5.2 Plains

The Heretaunga Plains have been formed by fluvial deposition by the Tutaekuri and Ngaruroro rivers over the last 6500 years. In the sector of the Plains north of the present Ngaruroro River course, fluvial sediments deposited by the Ngaruroro, Tutaekuri and Esk rivers have been gradually infilling the Ahuriri Lagoon since it was formed about 4500 years BP when Scinde Island was reconnected to the mainland by tombolos extending both north and south of the island. In the southern sector of the Plains the Ngaruroro River flood channels have built the Plains out to the northwest with contributions of fluvial sediments from the Tutaekuri River at the northeast margin, and the Tukituki River at the southeast coastal margin.

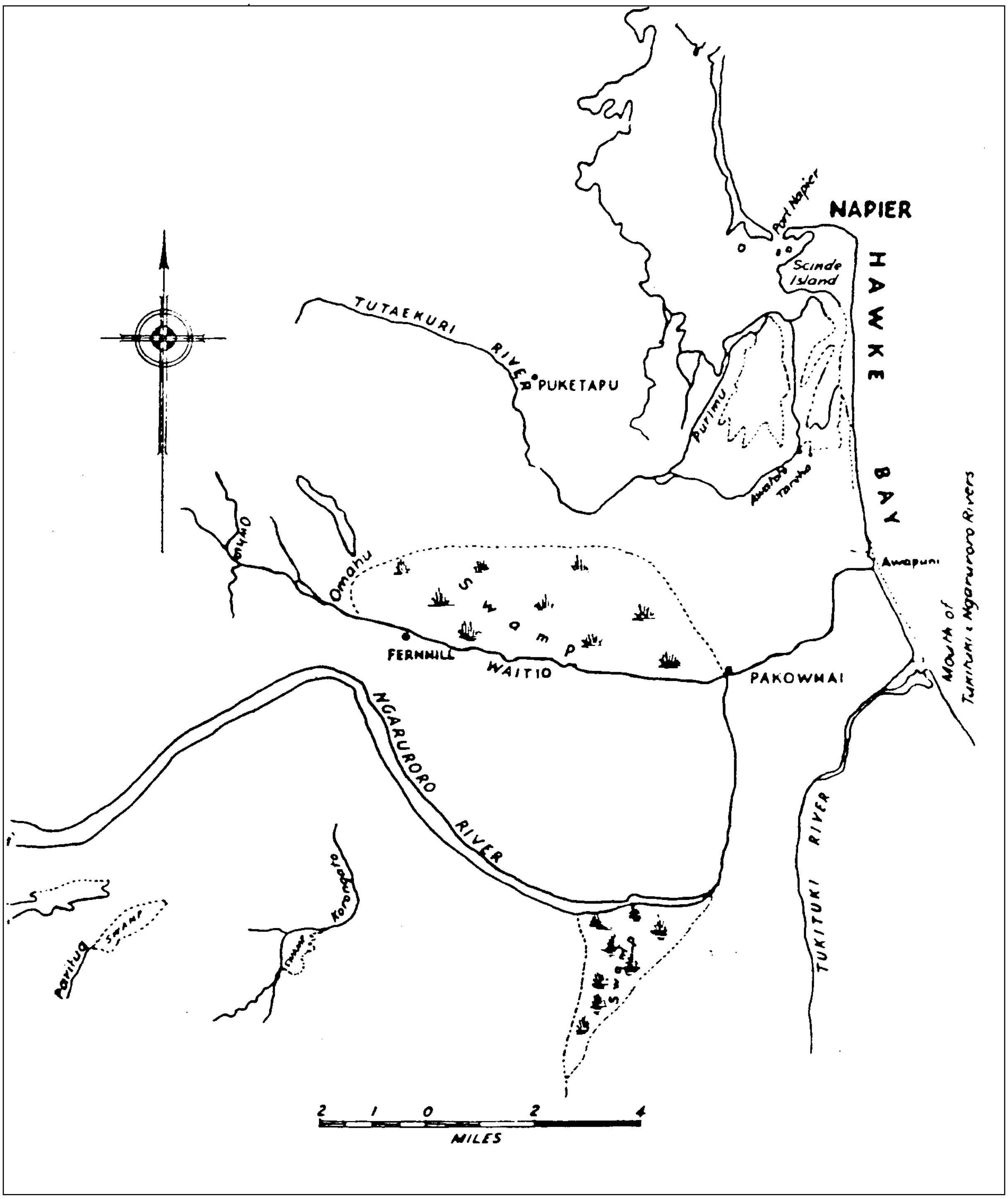


Figure 2.18: Heretaunga Plains rivers about 1854. *From survey by R.M. Skeet*

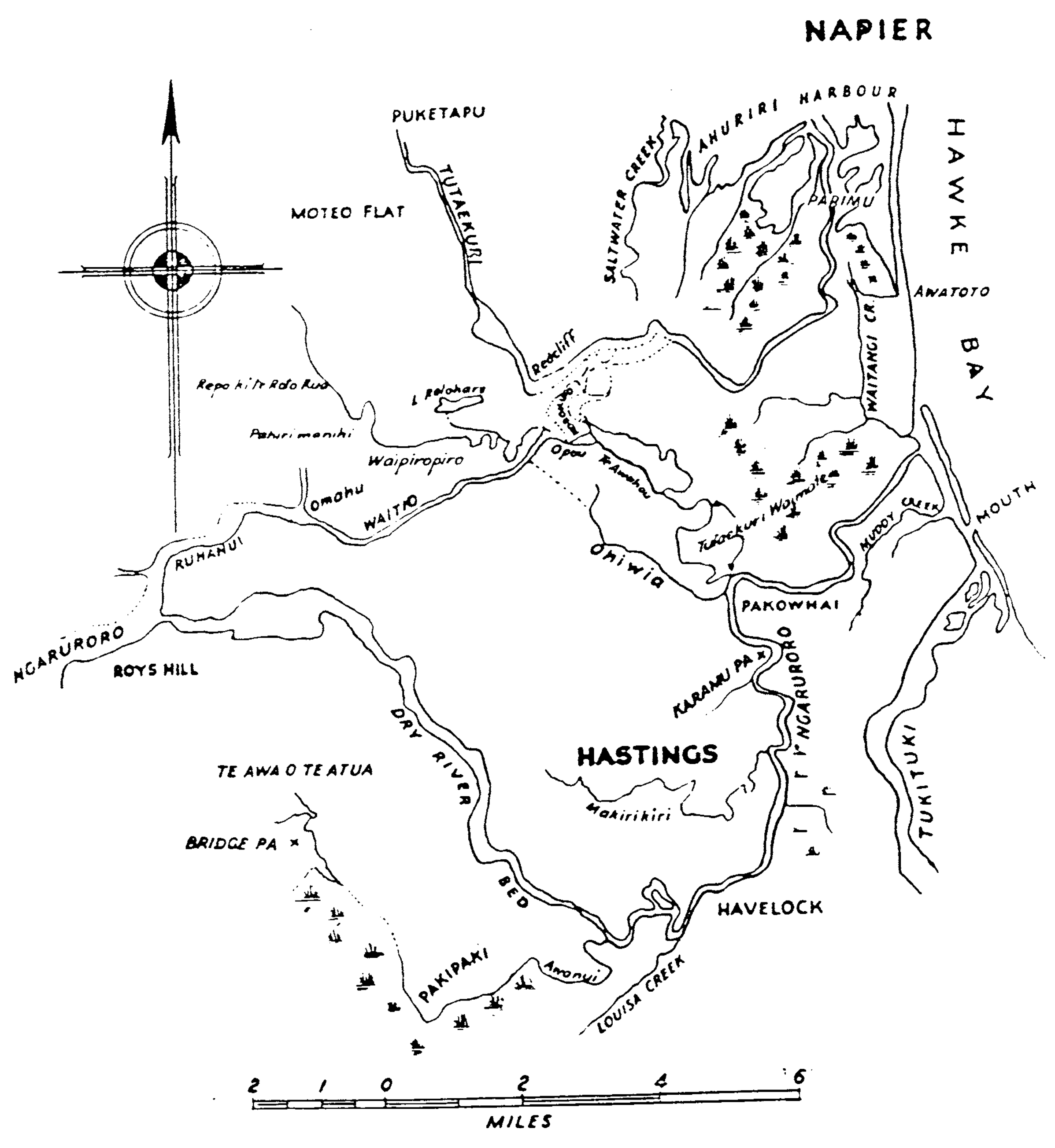


Figure 2.19: Heretaunga Plains rivers about 1875. *From drawing by J. Rochfort*

Former river channels on the present day Heretaunga Plains surface extend eastwards from the Ngaruroro River (Fig. 1.2). An example is the channel extending southeast of the river between Fernhill and Roys Hill towards Flaxmere and Hastings. The spring-fed Irongate Stream - Southland Drain mark the extension of this channel into a more recent (1867) Ngaruroro River channel occupied by Awanui and Karamu streams (Fig. 2.19).

The present Heretaunga Plains river, stream and creek pattern is very different to what it was when the first settlers arrived in the 1850's. This is a result of local drainage, diversion of courses for flood prevention and the 1931 Hawke's Bay earthquake.

In the area of the Heretaunga Plains adjacent to the 6500 year BP shoreline, local streams, creeks and drains are formed from spring sources. These springs are mainly fed from groundwater that is flowing through near surface gravel channels from the Ngaruroro River towards Hastings and the coast, and former Tutaekuri River channels extending northeastwards towards Napier. The springs occur where the gravel unconfined aquifer is interbedded with the lagoon and estuarine fine sediments and where the gravel channels extended into the coastal swamps. The volume of flow of these springs has been spasmodically measured since 1960 (see 6.4.5).

Swamps developed in low-lying areas where the water table reaches ground surface. High water tables occur for a variety of reasons including high spring flows, overbank floods from the meandering courses of local streams and creeks, heavy local rain and poor drainage. Along the coastal sector of the Heretaunga Plains 21 pumping stations abstract 3 million m^3/year of groundwater to prevent flooding of productive land and coastal communities.

2.5.3 Coast

The crescent shape coastline of Hawke Bay is a product of ongoing subsidence of the Heretaunga depression and uplift of the Cape Kidnappers emergent coastline. At Cape Kidnappers a last interglacial wave cut platform has been tectonically uplifted 200 m over the past 125 000 years (Fig. 2.3). There is decrease in the terrace height towards Clifton and the Heretaunga Plains, and Kidnappers Group sediments may dip under the Heretaunga Plains.

Hawke Bay coastal processes are a product of the interaction of sea level fluctuations, sediment input into the coastal regime and adjustment to tectonic movement. In very recent time the activities of man in constructing breakwaters for Napier Harbour and in changing river channels and river sediment transport, have become important influences. Coastal outbuilding or progradation began after the present sea level became established about 6500 years BP (Gibb 1986). Radiocarbon ages of shell material and water well logs show that at this time the sea extended inland with the coast a maximum distance of 12 km inland to the west of Hastings (Fig. 2.6). Napier Hill (Scinde Island) was an offshore island and sea cliffs were formed at the coast from Taradale to Tongoio Bluff.

Radiocarbon ages are listed in Table 4.2 , while Figure 4.8 plots age and depths of burial of the samples, and compares them with the theoretical curve of Gibb (1986) for postglacial sea level in New Zealand.

A succession of beach gravel and sand deposits, estuarine and lagoonal silt, and interbedded swamp (peat deposits) accumulated as progradation proceeded. Also, the Tutaekuri and Ngaruroro rivers were depositing gravel, sand and silt during flood incursions into the embayment. Figure 2.20 shows Hawke Bay postglacial marine transgression and progradation shorelines for the Heretaunga Plains based on radiocarbon dates.

Today the remnants of the Ahuriri Lagoon are still a conspicuous geomorphic feature of the Hawke Bay coastal environment (Fig. 2.21). The lagoon has been formed for at least 4500 years (Hull 1986) and is the result of the exclusion of the sea from part of the Hawke Bay coast by tombolos connecting Scinde Island to the mainland both north and south of the island. These tombolos are formed from beach gravel and sand deposited during storms and reworked along the beach during calmer intervals. When Europeans settled in Hawke's Bay in 1850, Ahuriri Lagoon was about 8 km long and 3 km wide at the widest part west of Scinde Island (Figs. 1.2 and 2.22).

Several islands of erosion resistant harder sediments were in the lagoon. These were originally sea stacks and near shore islands from when the area was open to the sea. In 1850 the Esk River discharged into the lagoon from the north and the Tutaekuri River from the south. The Ngaruroro River would also have intermittently flowed into the lagoon.

In 1931 the Hawke's Bay earthquake resulted in the uplift of 1300 hectare of Ahuriri Lagoon above sea level.

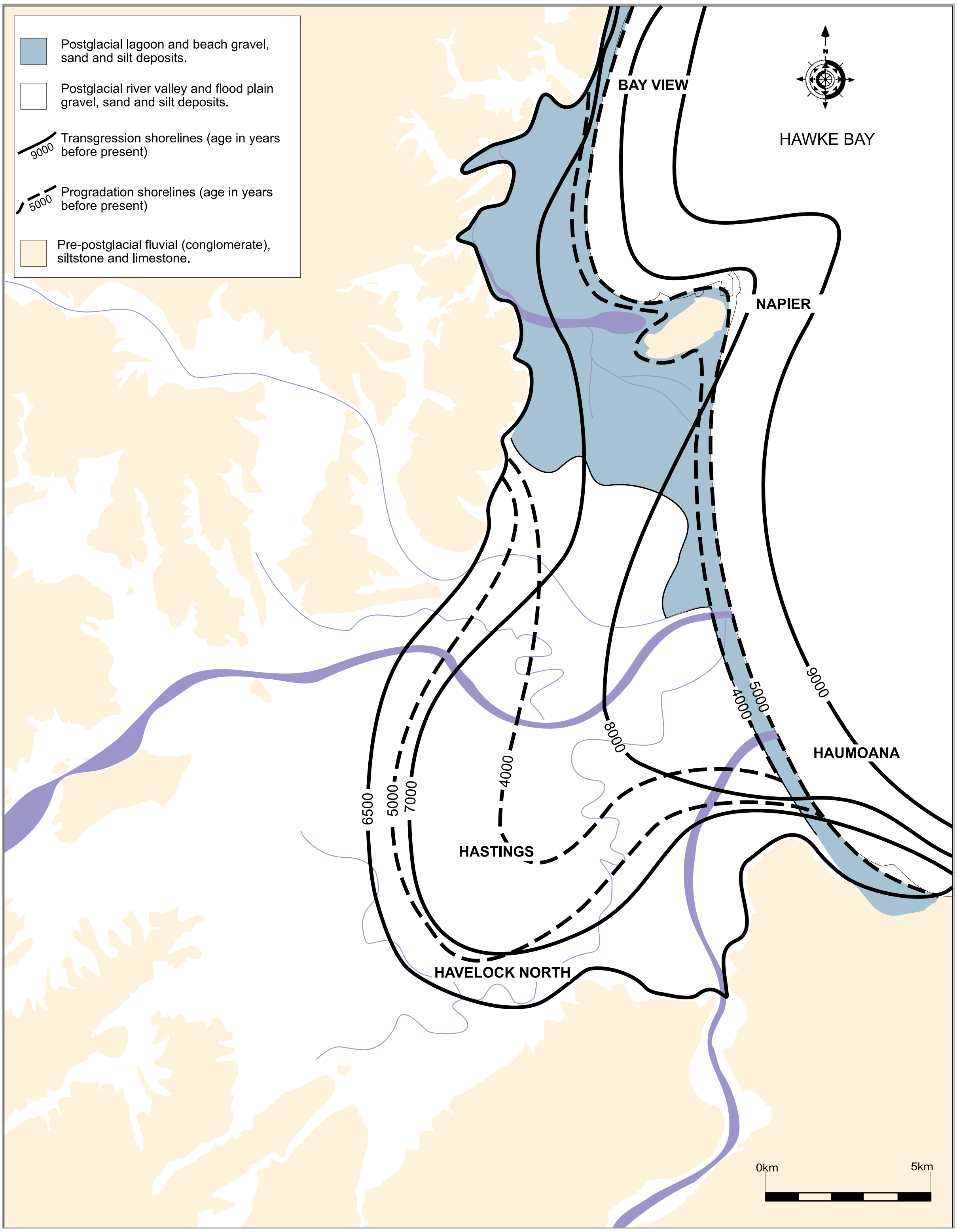


Figure 2.20: Hawke Bay shorelines for the last 10 000 years based on radiocarbon data.

Figure 2.21: View of inner harbour at mouth of former Ahuriri Lagoon *(photo: Lloyd Homer, IGNS CN 17719/37).*

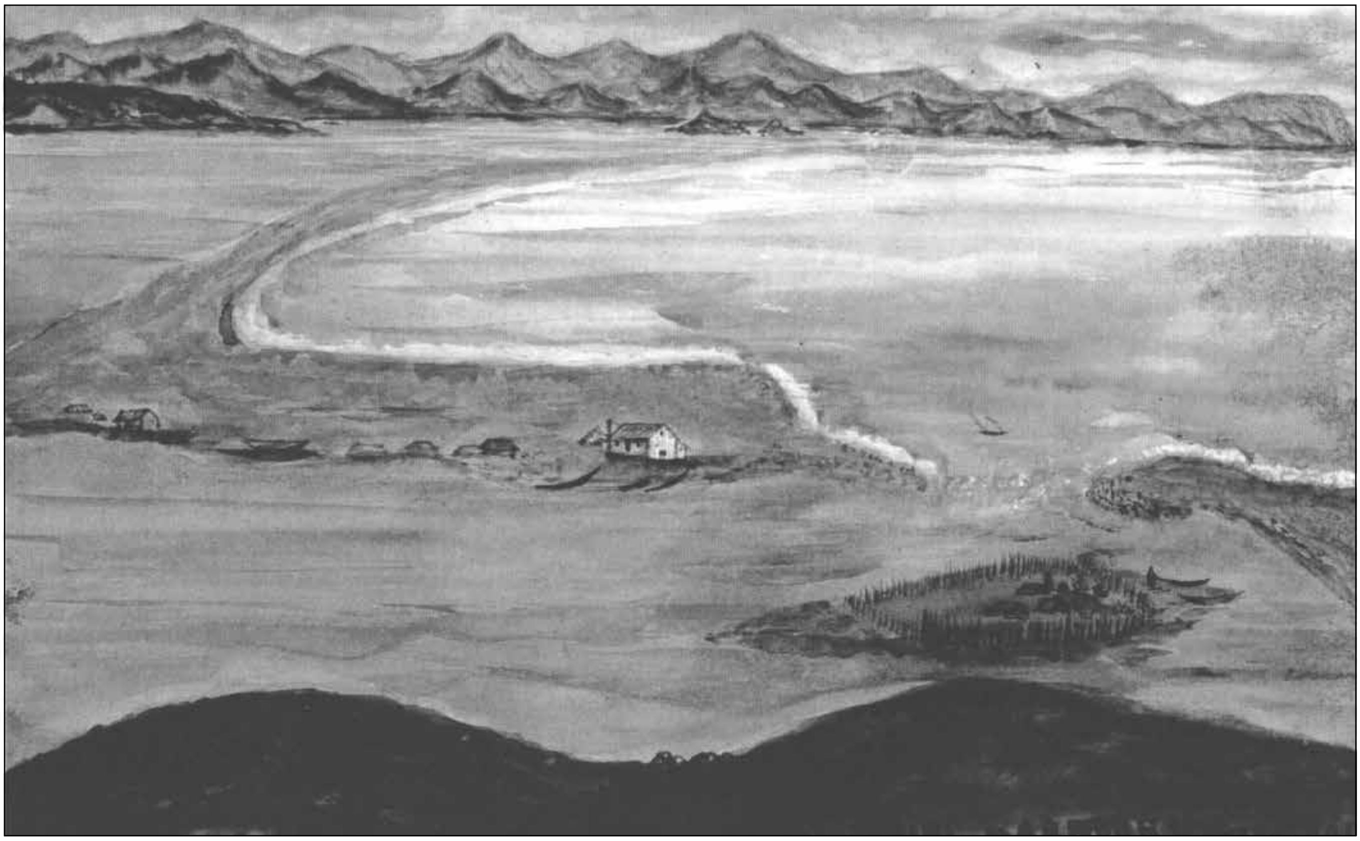


Figure 2.22: The Ahuriri Lagoon in 1850's from drawing by Joseph Rhodes.
Pakake pa is visible in the right foreground. The large building in the centre may be the accommodation house built by William Villers in 1850 (Knight 1995) *(photo: Alexander Turnbull Library F954.56 ½).*

The entire western margin of the lagoon was uplifted 1m, and the Westshore gravel spit at the eastern lagoon margin rose 1.5 m (Fig. 2.15) (Hull 1986). As a result of the earthquake the Esk River flowed directly into the sea opposite the Esk Valley and the Tutaekuri River formed a new course with an outlet near Awatoto.

Until the 1931 earthquake Napier Hill was partly isolated from the mainland by marshes and lagoon, and this gave rise to the name Scinde Island. Access to Scinde Island from the south was along the gravel and sand beach ridges forming the tombolo, and from the north along the tombolo and across the Ahuriri outlet by boat. The beaches at Napier prograded by about 20 m in the two weeks immediately after the earthquake (Marshall 1933) and access to Scinde Island become much easier.

Napier Hill is an outlier that has persisted because a sandy siltstone unit is underlain and capped by more resistant cemented limestones. Wells at Westshore and Onekawa penetrate Holocene lagoonal silts, beach sand, swamp, peat and shell bed deposits overlying Tertiary sediments suggesting that Napier Hill was part of the mainland at the time of the postglacial marine transgression.

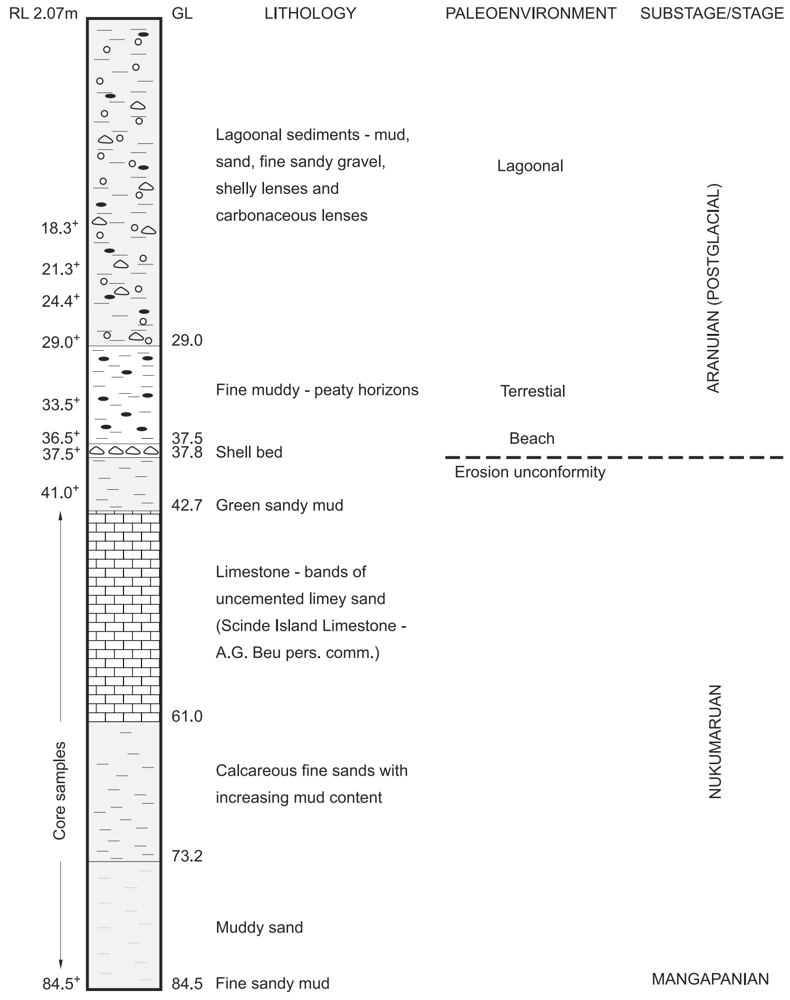
Figure 2.23: Napier Hill showing former sea cliff cut into Scinde Island Limestone *(photo: Lloyd Homer, IGNS CN 17691/10).*

Figure 2.24 shows the graphic log of the Rehabilitation League exploratory well (well no. 749), Onekawa. The Tertiary age sediments at 37.8m below ground surface are the eroded subsurface remnant of the promontory which connected Scinde Island to the mainland. The link to the mainland would have been eroded by the time Ahuriri Lagoon had formed 4500 years BP. Also postglacial coastal erosion has reduced the size of Scinde Island.

The beach from Whirinaki to Napier Hill has no obvious source of sediment supply apart from a possible small input from the Esk River. The beach is gravel and sand with a small area of predominantly sand at Westshore. Analysis of 5 profiles between 1937 and 1975 of the beach from Westshore to Bay View show there has been little or no nett change over the 38 year period and suggests this section of the beach is in a state of dynamic equilibrium (Knowles 1976).

The beach from Clifton to Napier Hill has been built from gravel and sand from the Tukituki and Ngaruroro rivers and the Tutaekuri River since 1931, and from sediments derived from erosion of the cliffs from Clifton to Cape Kidnappers. The near shore current flow in southern Hawke Bay is from north to south (Ridgeway 1960). However during storm events, waves and high winds produce a nett northward drift (Knowles 1976).

The steep cliffs exposed beneath the gannet colony at Cape Kidnappers, and the reef and shore platform cut by the sea, are Tertiary siltstone and sandstone which is more resistant to erosion than the younger Kidnapper Group sediments forming the cliffs from Black Reef to Clifton. These younger sediments are eroded by the sea, wind, rain and the small rivers draining the immediate hinterland.



+ Drill cutting and core samples studied by Paleontologists.

Figure 2.24: Rehabilitation League, Onekawa exploratory well log (well No. 749).

2.5.4 Hawke Bay

Hawke Bay is a conspicuous re-entrant with a coastline ranging from high sea cliffs to gravel spits, beaches and sand hills, to lagoons and estuaries. The whole of Hawke Bay lies within the continental shelf (<200 m below mean sea level Fig. 2.25). The bathymetry (sea floor topography - Fig. 2.25) and floor sediments (Fig. 2.26) have been studied by Pantin (1966) and Lewis (1973a), and the submarine stratigraphic sequence is described and mapped by Lewis (1973b).

Over most of the bay, the sea bed is nearly smooth, with isobaths conforming in shape to the general crescent outline of the coast, and gradients varying from 1:150 to 1:700. A zone of irregular topography is the Lachlan Ridge (Fig. 2.25) located between a 20 000 years BP shoreline (Lewis 1971) at c. 150 m below mean sea level and the edge of the continental shelf. The Lachlan Ridge extends for 21 km southwest from 13 km south of Portland Island to about 20 km east of Cape Kidnappers. The topography of the ridge is within a 25 m relief range.

A series of 10 submarine seismic profiles across the continental shelf from Hawke Bay to Castlepoint showed prominent unconformities of wide geographical extent, that pass seawards into conformable units (Lewis 1973b). These layers bounded top and bottom by unconformities, are mapped as lithostratigraphic units and correlated with the Waimaungan Glaciation climate stage and the subsequent penultimate and last glaciation, and the intervening interglacial and postglacial periods (Lewis 1973b).

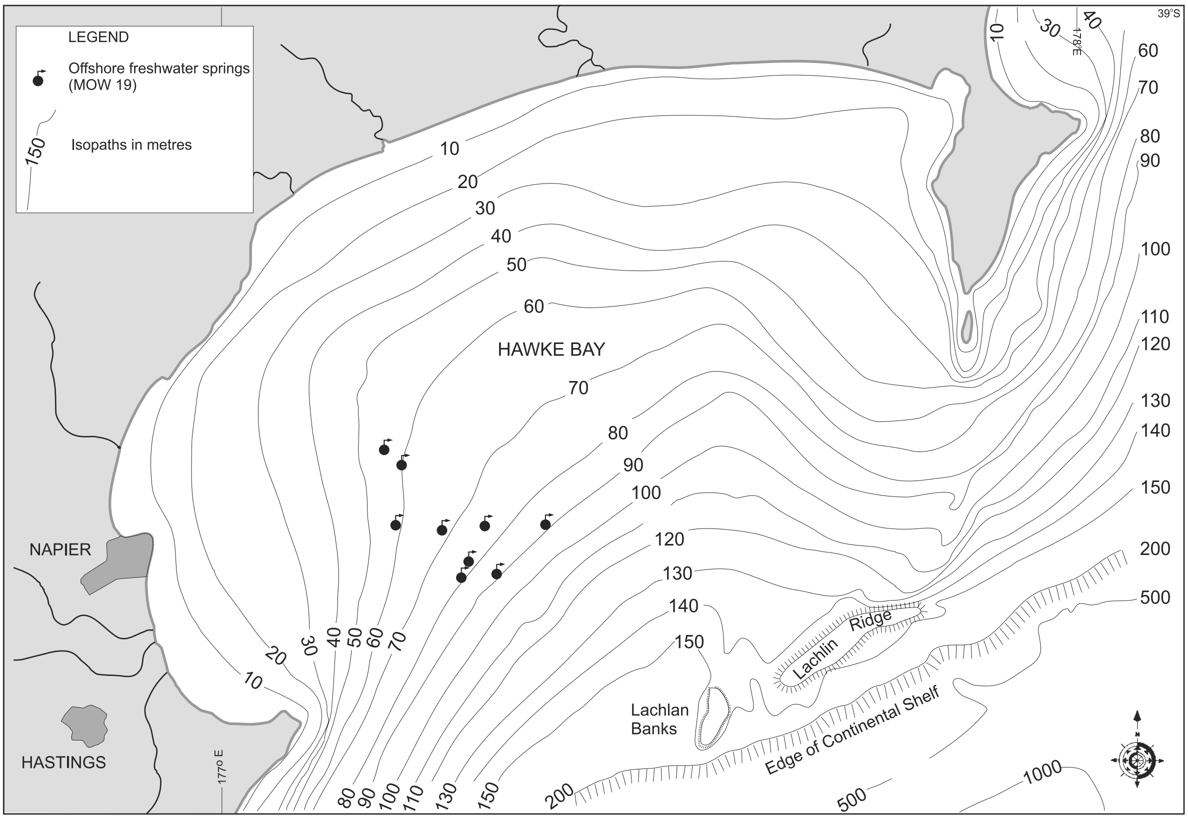


Figure 2.25: Sea floor topography *(from Pantin 1966)*.

Figure 2.26 is from Pantin (1966) and shows bottom sediments in Hawke Bay. Sand size particles occur adjacent to the coast and there is an area where gravel predominates opposite the Tukituki River mouth to about 27 m below mean sea level. Nearly all the clasts (2 to 10 cm diameter) are subangular to rounded, and usually somewhat flattened. Pantin (1966) considered these gravels were a product of fluvial deposition during the low sea levels of the last glaciation and were reworked by the rising postglacial sea into beach gravel. The Tukituki River bed and mouth would have been in the Haumoana - Te Awanga area for about the last 20 000 years.

The Lachlan Ridge is overlain in part by angular gravel comprised of Tertiary mudstone and sandstone clasts probably derived from near-shore deposition during low (glacial) sea levels. It is likely that the ridge consists of the parent material for these gravels, and is overlain by a thin covering of late Quaternary sediments (Pantin 1966).

2.6 CLIMATE

Anticyclones and intervening troughs of low pressure dominate the weather in Hawke's Bay. The majority of anticyclones passing over New Zealand have their centres over or to the north of Hawke's Bay and the prevailing wind flow in the lower atmosphere is from a westerly quarter. The Hawke's Bay region is to the east of mountain ranges which are over 1675 m high, and is relatively sheltered from the predominantly westerly winds which blow across New Zealand. The result is a sunny temperate climate with warm summers and mild winters. On the Heretaunga Plains temperatures frequently exceed 27^{0}C in summer and frosts are relatively frequent in autumn and winter. The eastward facing aspect of the Hawke's Bay means that it is also affected by weather systems accompanied by easterly winds.

The sheltered position of Hawke's Bay in the lee of mountain ranges results in high sunshine hours and

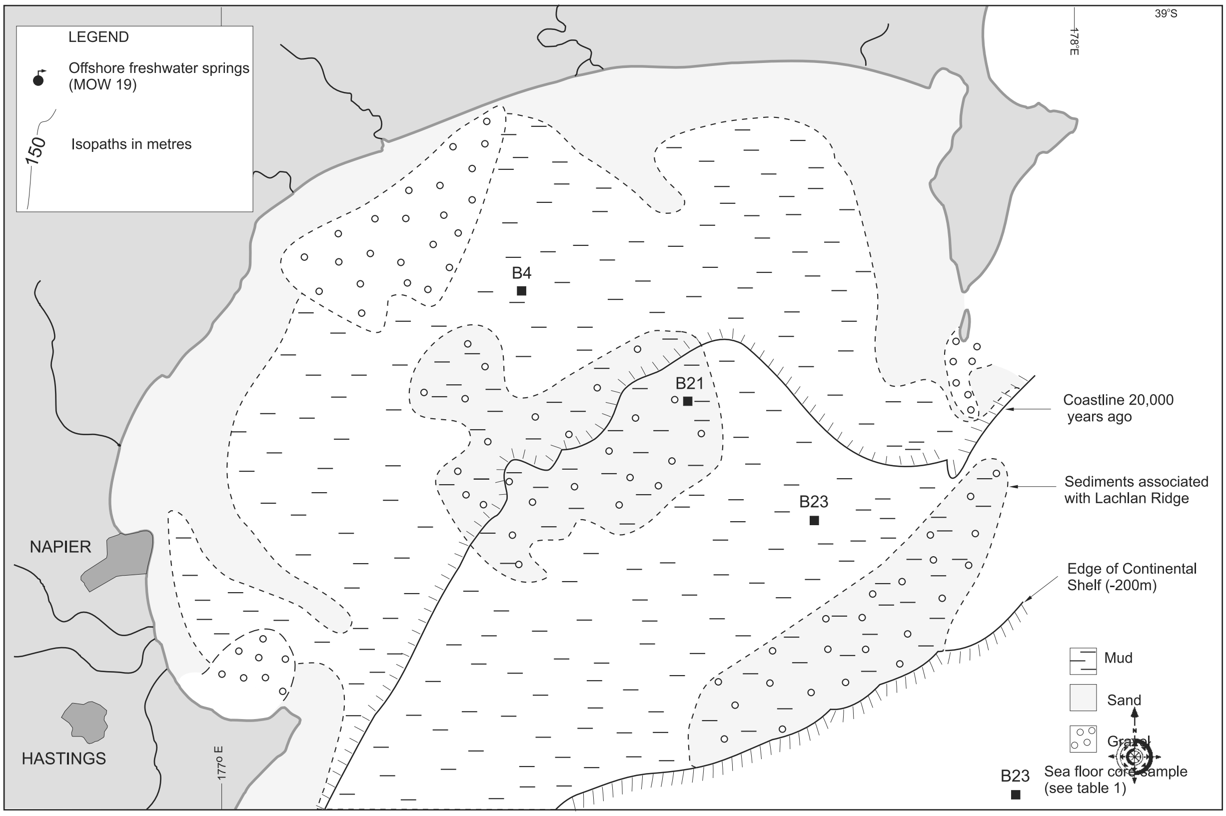


Figure 2.26: Bottom sediments in Hawke Bay *(from Pantin 1966).*

radiational cooling at night giving rise to a large daily range of temperature. Figure 2.27 shows mean daily and mean monthly maximum and minimum temperatures for each month for Napier and Havelock North. The average summer temperature is about 17°C and average winter 10°C.

Because of the sheltering effect of the mountains, most of the rainfall on the Heretaunga Plains and coastal districts is a result of weather systems associated with winds from an easterly quarter.

Figure 2.28 shows a plot of annual rainfall departure from the long-term mean rain measured at the Nelson Park, Napier rain gauge during January 1900 - January 1995 period. The mean annual rainfall during the period is 818 mm. The plot shows the distribution of annual rain above and below the long-term mean rainfall. The use of annual rainfall data masks the extremes experienced within any one year. However the tendency for Hawke's Bay weather patterns to be dominated by wet and dry climatic cycles means that a general pattern can be observed. There is some evidence of an overall drying of the Hawke's Bay climate since 1945 with fewer of the very wet years, such as 1938, which caused major flooding across the region. At the same time the worst recorded drought, in both severity and duration is still the 1913-1916 event. What is most evident is the variable nature of the rainfall pattern with a range this century of from 420mm to1500mm.

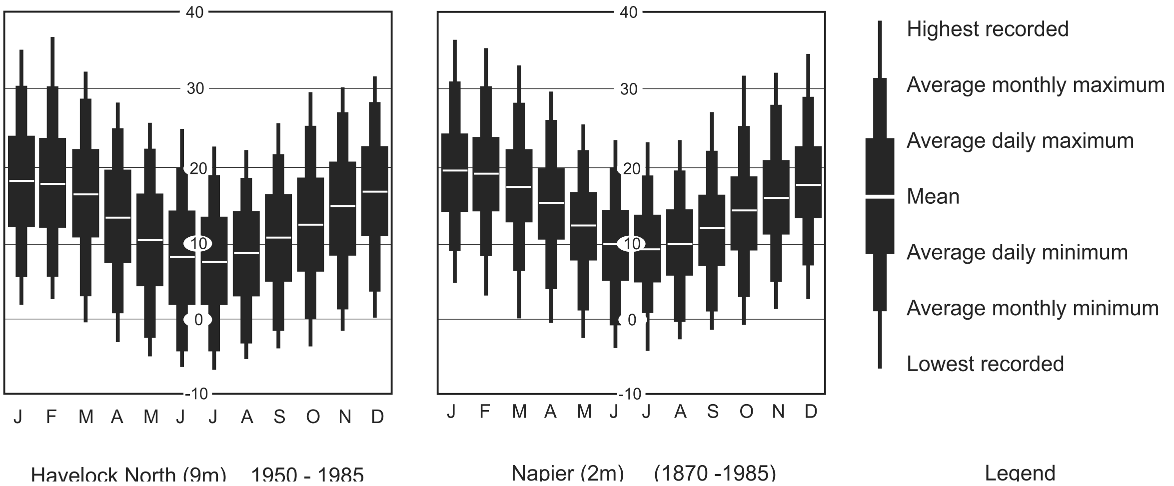


Figure 2.27: Mean monthly temperatures for Napier (1870 - 1985) and Havelock North (1950 - 1985).

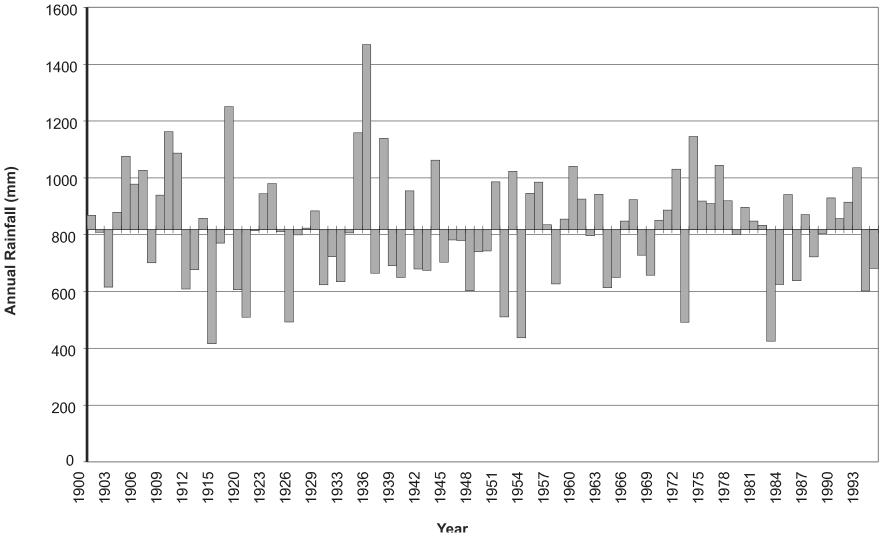


Figure 2.28: Annual Rainfall departure from long-term record at Nelson Park, Napier (1900 - 1995).

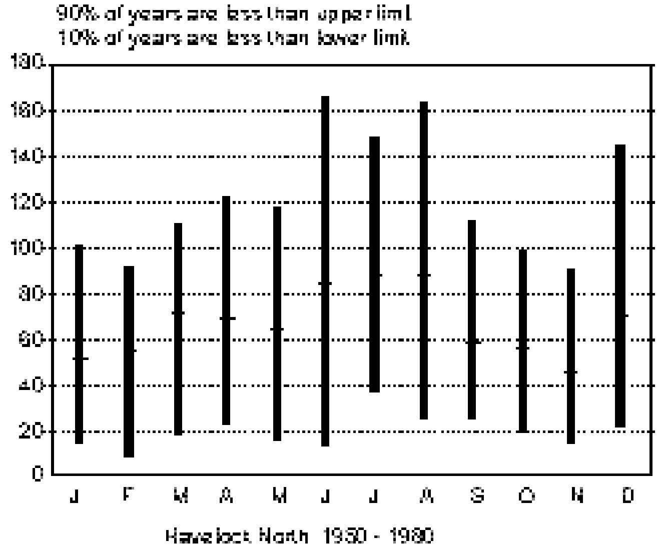


Figure 2.29: Variability of monthly rainfall at Havelock North (1950 - 1980)

The short term nature of this variability can be seen in Figure 2.29 which presents the variability of monthly rainfall at Havelock North during the period 1950-80. For each month the long term mean is represented by the horizontal dash and the vertical lines indicate the spread of values within which lie 80% of observed monthly totals. Thus 10% of monthly totals are higher than the vertical line while a further 10% of monthly totals have been lower. Although greater variability may be seen in the wider spread of winter values, June and August in particular, it is the effect of dry summer weather and consecutive spring and summer months that has the greatest impact within the region. On average one year in ten will have less than 15mm rainfall in January although the thirty year average is 50mm. February can be even drier - one year in ten rainfall for the month may be less than 10mm although the mean is higher at about 55mm. It is when the seasonal accumulation of rainfall is less than average that a drought is considered to have occurred.

The total annual rainfall if spread evenly throughout the year would nearly always be sufficient to supply the water needs of soil and plants. However, the monthly distribution and the variability of the rainfall are such that moisture deficits occur, and the soil water reserves are drawn upon to support plant growth. The amount of water required depends upon the soil and plant types. In the early spring the plant water requirements are nearly always met by the rainfall and dew and any deficit is small. From November to April rainfall on the Heretaunga Plains is often too low to meet the water requirements of the soil and plant types, and pasture growth is retarded. The dry conditions will occur in one year out of two, and on average last for at least four months. In extreme cases, such as existed during the drought of the 1936 - 37 season, rainfall can be deficient for 7 consecutive months on the Heretaunga Plains.

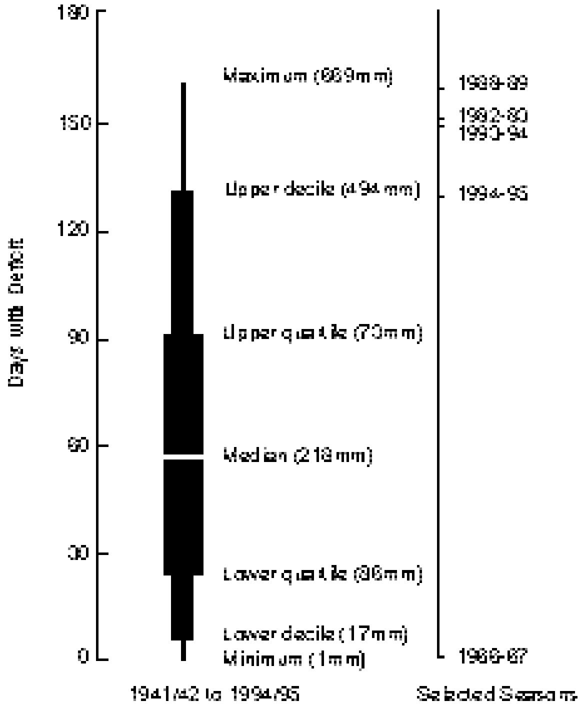


Figure 2.30: Variability of growing season soil moisture deficit, Nelson Park, Napier (1941-1995).

Figure 2.30 shows the graph derived from a daily water balance for pasture, for a soil of 100 mm storage, and Penman potential evapotranspiration (PET) calculated at the same station as the rainfall (Nelson Park). A deficit accrues when the storage is depleted to zero. Years with low growing-season rainfall have high deficits; years with high growing-season rainfall have low deficits. The deficit distribution is expressed as maximum (the greatest deficit experienced), minimum (the smallest deficit experienced), median (50% of years fall above and below this value), deciles and quartiles (the upper decile value is 130 days (494 mm) which means that 90% of seasons have deficits less than this value). The right hand axis identifies where specific years rank in the overall run - 1988/89 was the highest deficit of all years in the 1941 - 1995 period.

Some of the most intense rainfalls recorded in New Zealand have occurred in the mountain ranges of inland Hawke's Bay, producing high flood discharges. Grant (1985) presents evidence of storm events in geologic time while Hill (1896), Cowie (1957) and others document major historical flooding especially during the 1890's. The damaging effects have been increased by erosion of unstable soil and rock on the mountain ranges and hills. Thus on the Heretaunga Plains there are two opposing water problems produced by climate. These are droughts which during times of rainfall deficit require conservation of water and irrigation using groundwater, local rivers and streams, or water races to maintain soil moisture levels for plant growth and water supply for stock, to mitigate the affects, and control of floodwaters, and soil erosion during times of excess rain.

2.7 HYDROLOGY

The three Hawke's Bay rivers which flow across the Heretaunga Plains all have the major part of their catchments in the western mountain ranges and have high flows when there is heavy rain in the catchments. Since 1867 there have been 8 major floods in these rivers that caused significant damage on the Heretaunga Plains.

2.7.1 The Ngaruroro River

The Ngaruroro River rises on the northeast flank of the Kaimanawa Range and flows along the southwest side of the Kaweka Range. It has a catchment area of 2500 km^2 and a design flood flow of 4500 m^3/s. The largest historical flood in the Ngaruroro River occurred in 1867 when the river broke its banks near Fernhill and deposited 0.3 to 0.5 m of silt over most of the Heretaunga Plains area. As a result of this flood the Ngaruroro River changed course, leaving its former river bed (Fig. 2.2) now occupied by the Awanui and Karamu streams to the south and east of Hastings, to take the new course to the north that it still follows today.

The minimum flow measured in the Ngaruroro River at Ohiti is 4.4 m^3/s of which almost half infiltrates into the aquifers of the Heretaunga Plains to provide the main source of groundwater recharge. Low flow measurements undertaken since 1957 on the Ngaruroro River have demonstrated that losses of river water takes place between Maraekakaho and Fernhill. Along the left bank, facing downstream, there is a temporary loss of about 0.5 m^3/s of water infiltrating from the river toward Ohiti to feed Waitio Stream which then enters the river opposite Roys Hill rifle range. Along the right bank larger quantities of water leave the river in two zones. Between Roys Hill and Fernhill and between Maraekakaho and Roys Hill the mean flow loss of 4.2 m^3/s and 0.8 m^3/s respectively have been measured for river flow of up to 30 m^3/s. It has not been possible to gauge the river losses for flows greater than 30 m^3/s using conventional survey methods.

A comparison of the Ngaruroro River, Ohiti, Fernhill and Chesterhope stages shows similar fluctuations in the Ngaruroro River stages at Fernhill and Chesterhope (Figs. 5.13 and 5.14) and contrasts in the Ngaruroro River stage at Ohiti compared with the downstream Fernhill and Chesterhope stages. The underflow losses to groundwater between Ohiti and Fernhill probably contributes to the changing stage along with other factors such as the unstable nature of the river channel near Ohiti. This aspect is discussed in greater detail in 5.3.3.1.

2.7.2 The Tutaekuri River

The Tutaekuri River catchment of 900 km^2 is located on the western and southern faces of the Kaweka Range and flows southeast to the coast at the Heretaunga Plains. The present river mouth near Clive, common both to the Ngaruroro and Tutaekuri rivers, is the product of river control work since the Hawke's Bay earthquake of 1931. The Tutaekuri River originally flowed into the Ahuriri Lagoon from the south along a course through Meanee and Napier adjacent to Sandy Road and Riverbend Road. In 1873 the Taradale Road was built as a causeway across the lagoon and reclamation of the southern part of the lagoon commenced. The Tutaekuri River mouth was ponded to ensure that its load of sediment would be deposited to assist reclamation rather than be washed into the main lagoon and out to sea. Various diversions designed to aid the reclamation of Ahuriri Lagoon resulted in the Tutaekuri River mouth in 1879 being an area of lagoonal - swamp. This posed a health problem and in 1891 a diversion known as Carr's cut was completed and the river flowed down the new channel skirting Wellesley Road, past Pandora and into the lagoon. In 1897 silt deposited during flooding filled Carr's cut and the river formed a new natural course along Georges Drive. Uplift associated with the 1931 Hawke's Bay earthquake added over 1300 hectares of former lagoon to the Heretaunga Plains and diverted the Tutaekuri River to its present course with the river mouth near Clive.

Flooding by the Tutaekuri River both before and after the earthquake has been a regular occurrence. In 1867 the combined Ngaruroro and Tutaekuri rivers' flood inundated the low-lying parts of Meanee and Napier. In 1897 and 1917 Napier, Taradale and Greenmeadows were again flooded. Flooding occurred in February 1936 when the flow of the Tutaekuri River was 2265 m^3/s and the flow of the Ngaruroro River was 1700 m^3/s. In April 1938, the Tutaekuri flow was 2350 m^3/s. In June 1963 the Tutaekuri River rose to within 80 mm of the top of the stopbank at Awatoto before cutting a new outlet to the sea. The design flood flow of the Tutaekuri River is 3000 m^3/s. The estimated maximum flow on 24 January 1938 was 2730 m^3/s, while the minimum flow measured was 2.3 m^3/s on 6 February 1946. Other low flows measured are 2.7 m^3/s in March 1983 and January 1995.

Low flow gaugings have not indicated any losses from the Tutaekuri River between Puketapu and the coast (Table. 6.4), but losses have been measured from the river upstream of Puketapu in the order of 0.8 m^3/s. This loss is mainly into groundwater in a former southward flowing Tutaekuri River channel in the Moteo Valley. Groundwater from the Moteo Valley contributes to the flow of the Tutaekuri-Waimate Stream along the western margin of the Heretaunga Plains (Fig. 6.15).

2.7.3 The Tukituki River

The Tukituki River drains part of the eastern north and central Ruahine Range. It has a catchment area of 2473 km^2. The Tukituki River and its major tributary the Waipawa River flow across the Ruataniwha Plains which infill a synclinal basin. The active Otane Anticline is on the eastern margin of the Ruataniwha Plains and the two rivers have maintained their courses through this uplift area in the Waipawa and Tukituki gorges. Downstream of the Waipawa River confluence, the course of the Tukituki River turns to the northeast to flow into the sea at the southern end of Hawke Bay. Tectonic influenced changes to the Tukituki River course are outlined in 2.4. The Tukituki River mouth at Hawke Bay is a relatively recent feature. The river mouth and the course on the eastern margin of the Heretaunga Plains near Haumoana is likely to have been established in the postglacial period (Aranuian). In the early days of European settlement the Tukituki River was sufficiently deep for barges to transport goods upstream as far as Waipawa. Erosion and sediment deposition have since made the river too shallow. In 1893 the Tukituki River flooded the town of Clive while in April 1938, the Tukituki flowed at 5660 m^3/s the maximum measured flow. The minimum measured flow in the Tukituki River was 3.8 m^3/s in 14 February, 1979. The 100 year return period design flood flow at the coast for the Tukituki River is 4800 m^3/s.

Limited low flow gauging information suggests a loss of up to 2 m^3/s from the river channel between Red Bridge and Black Bridge. However, intermediate flow values varied considerably and it was noted that higher flow values were obtained where "basement" rock was evident in the channel (Grant 1974). These observations suggested the downstream decrease in surface flow was offset by increase of underflow through the deeper gravels.

2.7.4 The Esk River

Prior to the 1931 Hawke's Bay earthquake the Esk River flowed into the Ahuriri Lagoon from the north. The uplift associated with the earthquake resulted in the river cutting a new outlet to the sea through the sand beach ridge at Whirinaki. On 23-25 April 1938, after three days of heavy rain, the peak discharge was estimated to be 1347 m^3/s in the Esk River below the railway bridge. The river held its peak for only half an hour, but a flow of over 50% of this continued for nearly two days. The flood waters deposited silt over 700 hectares to an average depth of about 1.1 m but a depth of about 1.8 to 3 m was found over wide areas. At the Eskdale Railway Station the water depth over the floor was over 1.9 m with 1.5 m of silt. Within the well defined valley of the lower Esk River, the railway embankment confines floodwaters to a relatively narrow area of land up to a flood flow of around 900 m^3/s. This flow has an estimated frequency of exceedance of 2% per annum, or 87% in a 100 year period. The measured maximum flow in the Esk River during the July 1985 flood was about 725 m^3/s, while the minimum flow measured was 1.25 m^3/s on 6 February 1950. Another low flow measured was 1.3 m^3/s on 24 January 1994.

Although limited low flow gaugings undertaken on the Esk River do not indicate any losses from the river, it is likely that seepage from the Esk River bed recharges groundwater in a beach gravel aquifer along the Whirinaki - Northshore coastal area. A specific river flow gauging run may be necessary to establish sources and mechanism of recharge to the coastal Esk (Bay View -Whirinaki) aquifer system.

2.8 Springs, Springfed Streams and Drains

On the Heretaunga Plains there are seepage or spring areas, the flows from which combine to form sizable perennial streams (Figs. 2.31 and 6.2). In order of magnitude the largest of these streams are:

- Tutaekuri - Waimate Stream
- Karamu Creek
- Raupare Stream
- Irongate Stream
- Mangateretere Stream

Seasonal spring flows as shown by the surface flows vary considerably throughout year. Based on streamflow gauging data (January 1969 and February 1995) typical summer surface flows of the spring-fed streams, creeks and drains of the Heretaunga Plains are given in Figure 2.31.

Figure 2.31: Typical summer patterns of surface flows on the Heretaunga Plains.

Despite the seasonal variation in the spring-fed stream flows and inconsistency of data, the summer pattern of surface flows given in Figure 2.31 provides a basis for estimating the groundwater outflow from the Heretaunga Plains aquifer system.

The Tutaekuri - Waimate Stream derives water from both the Ngaruroro and the Tutaekuri rivers. As there has not been a significant loss of surface flow measured along the Tutaekuri River from downstream of Waiohiki to the coast, the maximum contribution the Tutaekuri River makes to the Tutaekuri - Waimate Stream, could be 0.8 m^3/s from Moteo Valley aquifer (see Tables 6.4). The larger proportion of the Tutaekuri-Waimate flow in the order of 1.2 m^3/s is derived from the Ngaruroro River upstream of Fernhill. The observation that in the absence of local rain the Tutaekuri - Waimate flow increases when the Ngaruroro River is in flood, substantiates that the Ngaruroro River is the significant supplier of water to the Tutaekuri - Waimate Stream.

As with the Tutaekuri - Waimate Stream, the Raupare Stream flow increases when a fresh occurs in the Ngaruroro River. The Ngaruroro River recharged groundwater is estimated to contribute a mean summer flow of 0.4 m^3/s to the Raupare Stream (see section 6.4.5).

The summer low flow gauging data suggests that the Mangateretere Stream discharges about 0.2 m^3/s to the Karamu Creek. The Mangteretere Stream originates from a series of spring seepage areas along the Tukituki River, which would suggest that the river is its primary source. However, the Mangateretere spring seepage area is perched above and hydraulically interconnected to the main aquifer system recharged by the Ngaruroro River. The possibility of upward leakage of the Ngaruroro River sourced water into the Mangateretere Stream cannot be discounted. It is likely that both the Tukituki and Ngaruroro rivers contribute to the flow of the Mangateretere Stream.

Irongate Stream follows an old course of the Ngaruroro River. The mean summer flow of the Irongate Stream is 0.1 m^3/s which is sourced from the Ngaruroro River.

At its outlet to the Ngaruroro River near Floodgate the mean summer flow of the Karamu Stream is 1.4 m^3/s. The Karamu Stream near Havelock North has a mean summer flow of 0.4 m^3/s. If the inflows coming into the Karamu Creek from the tributaries between Havelock North and Floodgate (0.32 m^3/s) are added to the flow of the Karamu Stream at Havelock North (0.4 m^3/s), a flow value of 0.72 m^3/s is derived instead of 1.4 m^3/s. The additional increment of 0.68 m^3/s has seeped into the Karamu Stream from the adjacent Plains area from excess irrigation drainage flowing through a shallow unconfined aquifer.

The seasonal variation in the surface spring flow (overflow) from summer to winter is a direct response to the changes in groundwater abstraction and the maintenance of through flow of groundwater in the confined aquifer to the offshore springs. If the abstraction is constantly exceeding recharge there would be a permanent decline of groundwater levels during the summer and a downstream movement of the headwater spring locations and consequently lower stream flows in the spring-fed streams and drains. In a typical summer, it is estimated that the Ngaruroro River recharge to the confined aquifer is about 1.2 m^3/s whereas the spring flow (overflow) component is about 3.8 m^3/s.

2.9 SOIL AND LANDUSE

Soils and landuse are closely related especially when water is available for irrigation. This has been recognised since the 1930's when the first land utilisation survey of the Heretaunga Plains was carried out (DSIR 1939). In the area adjacent to the river between Fernhill and Roys Hill to Flaxmere, the soils are predominantly Omahu series which are low fertility and moisture deficient but when water is available for irrigation are ideal for the production of wine grapes. Further to the southeast the floodplain soils are suitable for both dryland pastoral farming and intensive horticulture. In the area east of Omahu Road there are deeper Twyford and Pakowhai soils where orchardising and intensive horticulture are practised. In the Ngatarawa Valley extending from Maraekakaho to Pakipaki, pasture and stock farming predominates but there is rapid development of squash, stone fruit and horticultural applications. A new digital soil map (1 : 25 000) has recently been prepared by the Landcare New Zealand and held by the HBRC.

The area surrounding Hastings is principally intensive horticultural crops and orchardising. The urban areas (Napier, Hastings and Havelock North) make up about 18.5% (5546 hectares) of the Heretaunga Plains total land area. The principal industrial areas are along Omahu Road to the northwest of Hastings and Awatoto and Pandora located south and northwest of Napier. The total industrial area of Hastings and Napier is estimated

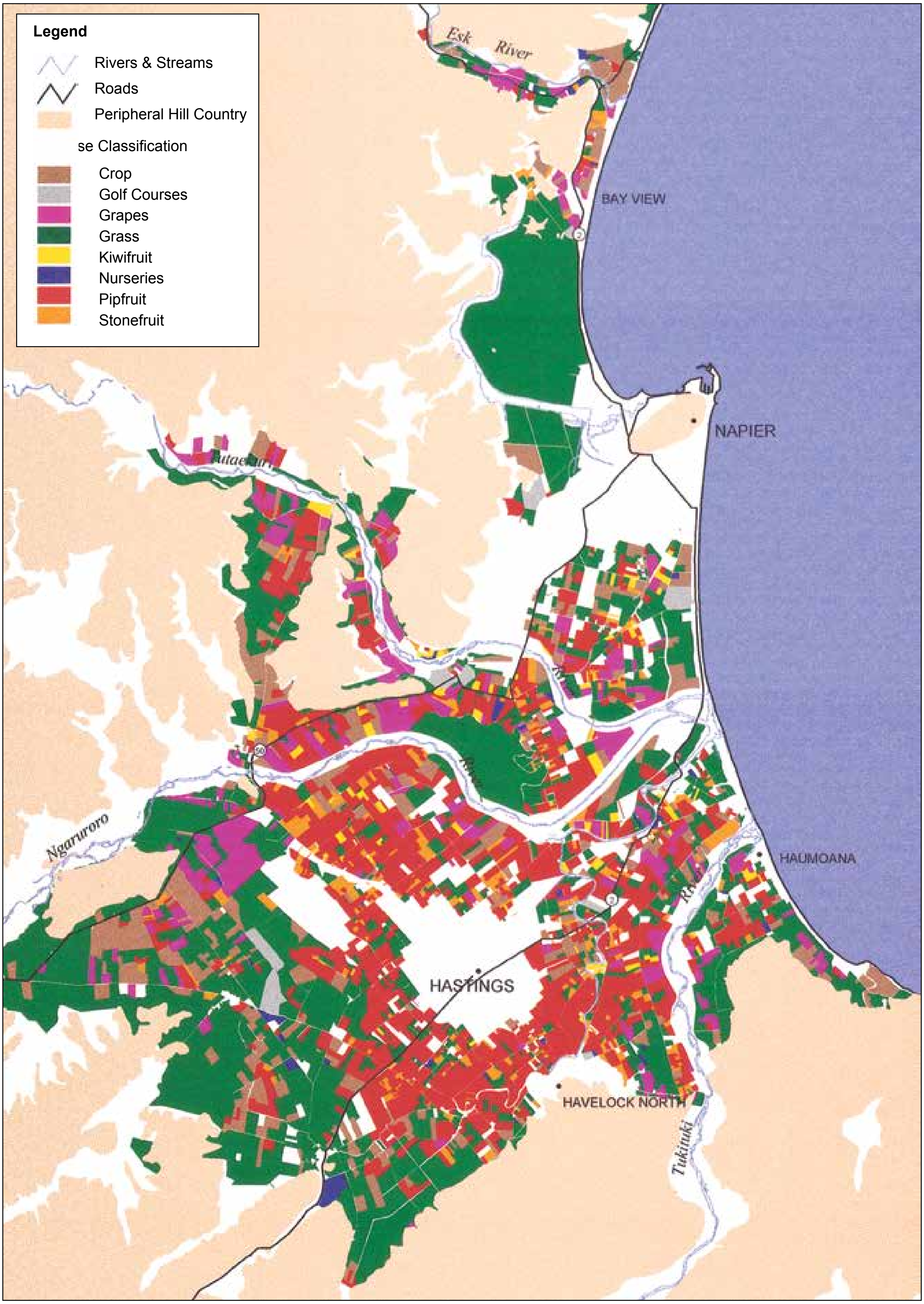


Figure 2.32: Heretaunga Plains landuse during period 1994 - 1995.

to cover 924 hectares. Sport and recreation areas including parks, reserves, golf courses, rifle ranges, a dragstrip, and an aeroclub are estimated to occupy an area of 463 hectares.

The Heretaunga Plains landuse as at 1994/95 was surveyed by Black (1994) (Fig. 2.32). The principle reason for undertaking the landuse survey was to estimate the irrigation water usage of groundwater for the water balance.

Landuse was divided into one of the following 8 landuse types:

- crops
- golf courses / sport fields
- vineyards
- pasture
- kiwifruit
- nurseries
- pipfruit
- stonefruit

The Heretaunga Plains surveyed landuse during 1994/95 is summarised in Table 6.8. The area under pasture is estimated to cover about 10 000 hectare (33.3 %) whereas area under pipfruit is about 6 783 hectare (22.6 %). Stonefruit and grapes occupy an area of 1082 hectare (3.6%) and 2161 hectare (7.2%) respectively. Kiwifruit, various crops and nursery occupy a total area of 895 hectare which is about 2.9% of the Heretaunga Plains area.

The Heretaunga Plains landuse has changed considerably in the last twenty years with an increase in intensive horticulture and market garden activities replacing pasture. About 92% of total water take consents on the Heretaunga Plains are now for irrigation. The changing landuse directly results in increased use of groundwater for irrigation.

On the Heretaunga Plains a considerable quantity of gravel is extracted from the Ngaruroro River between Ohiti and Fernhill for construction and road work purposes. This is also an unconfined aquifer recharge area. Figure 2.33 shows a plot of %cumulative monthly mean deviation from long-term mean of gravel extracted during 1977 to 1995 period. The plots have been produced by accumulating the positive and negative departures from the monthly means.

The plot suggests that the gravel extraction was above average during 1977 - 1982, 1985 - 1988 periods and extraction was below average during intervening 1982 - 1985 period. The gravel extraction declined below average about 1989 and continued to decline with minor fluctuations to the present day due to declining demand.

The graphs of cumulative monthly mean deviation from mean Ngaruroro River stages at Ohiti, Fernhill and gravel extraction bear no apparent relationship with each other. The Ngaruroro River between Roys Hill and Fernhill is braided and the river bed is unstable. More river stage, groundwater levels and gravel extraction monitoring data will be required to ascertain the effect of gravel extraction on river and groundwater levels. At this stage it appears that the gravel extraction has little or no effect on river and aquifer levels.

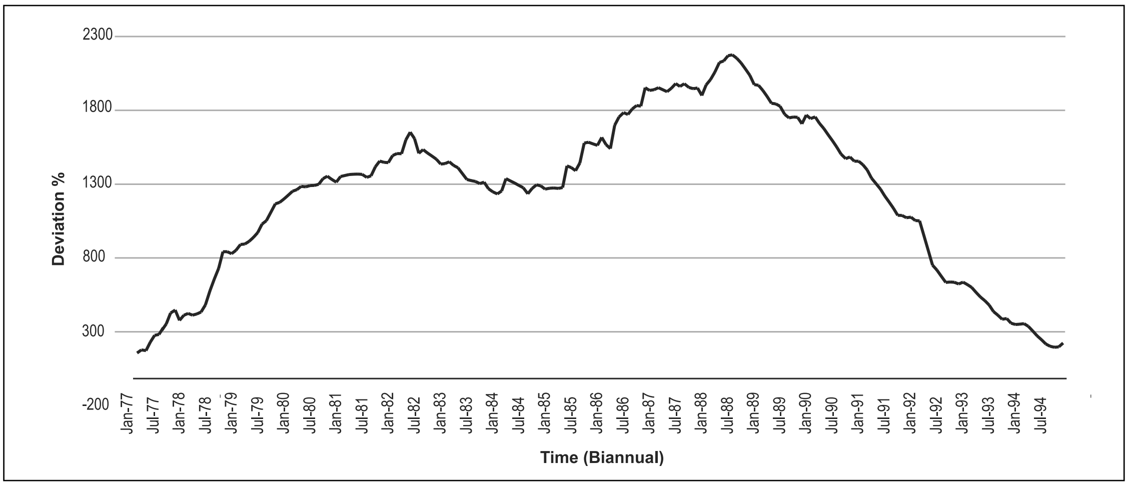


Figure 2.33: % cumulative monthly mean deviation from long-term mean of gravel extraction.

Figure 2.34: Napier and Scinde Island with Ahuriri Lagoon in middle distance. *(photo: Lloyd Homer, IGNS CN17740)*

CHAPTER 3

APPROACH

3.1 BACKGROUND

Hydrogeology is a science that deals with the geological and physical considerations of groundwater as a resource - i.e. the "plumbing" of the aquifer systems. Regional groundwater investigations collate and assess hydrogeological information - geology, hydrology, groundwater recharge sources, the groundwater flow path, the rate of flow, the aquifer storage capacity, natural and artificial outflows, and water geochemistry and quality. The resultant knowledge is applied towards formulating policies to enable sustainable management of the groundwater resources.

Acquiring hydrogeological information is a time-consuming and expensive process. An investigation generally begins with a review of available groundwater information to identify the deficiencies in knowledge. Once these deficiencies are identified, the process of planning an investigation strategy to collect the required data can begin. For the Heretaunga Plains groundwater study the accomplishment of the following three significant goals were identified as being essential for the successful outcome of the study:

- A review and collation of all information from published and unpublished sources pertinent to Heretaunga Plains groundwater resource evaluation and identifications of gaps in knowledge.
- Based on this state of knowledge assessment undertake a 5 year groundwater investigation programme to acquire the missing information.
- Apply the existing and newly acquired knowledge to formulate groundwater management policies and practices to achieve sustainable management of the groundwater.

3.2 REVIEW OF PREVIOUS WORK

3.2.1 Pre-1930

The first published account of the hydrogeology of the Heretaunga Plains was by Hutton (1871) which documented observations and data collected in July 1867, just after the first artesian well had been drilled near Meanee. This was followed by the papers of Henry Hill (1887, 1889, 1905 and 1923) using well logs and other groundwater data, which form a major contribution to groundwater knowledge for the Heretaunga Plains. Henry Hill came to New Zealand in 1873 to work for the Canterbury Provincial Government. In 1878 he graduated with a degree in geology from Canterbury College and was appointed as Inspector of Schools in Hawke's Bay. For the rest of his life he lived in Hawke's Bay. Henry Hill held various important local government positions including Mayor of Napier and was a member of the Hospital and Power boards. Hill wrote widely on education, geology, Maori folklore and traditions. Most of his papers on geology and paleontology are published in Transactions of New Zealand Institute. In his 1923 paper on groundwater conservation Hill stated: "under a properly constituted authority a vast amount of information might be collected as to flowage, corrosion of pipes, changes in the pressures, and the changing character of the materials held in solution. These facts could be used to suggest profit and loss in the sources of supply, and the corrosion of pipes, and even as to whether creeps are taking place in overlying beds." Henry Hill School, Dick Place, Pirimai, Napier is named as recognition of Henry Hill's contribution and work for community, cultural and scientific activities and knowledge in Hawke's Bay. Other early researchers on Heretaunga Plains groundwater were R.W. Holmes (1916 and 1917) and E.A. Williams (1920) with papers on the Westshore trial bore and Napier water supply.

3.2.2 1930-1980

After the 1931 Hawke's Bay earthquake, the HBCC assigned R.J. Findlay to inspect and report the extent of damaged bores on the Heretaunga Plains. The results of this survey were never published but the original data is retained by HBRC and has been summarised and used in this report (see 5.3.4.4).

In 1937, M. Ongley of NZ Geological Survey reviewed the knowledge of the Hawke's Bay groundwater resources and concluded, "Nature has provided water so generously that man has had little to do to secure a supply and has not had to give much thought to problems in connection with it. No one knows how many wells there are, or anything about them except as they affect their own special interest. In the writer's opinion the underground water of the Heretaunga Plains is provided by the Ngaruroro River percolating into the porous beds of gravel that underlie the plain, supplemented by other streams, so that waste has mattered little, for as fast as water is drawn out of the wells more flows in from the rivers. This happy state of affairs is something to be thankful for and to be conserved". Ongley also noted in his paper that "this underground water has been hurriedly and somewhat irresponsibly developed".

The Heretaunga Plains Underground Water Authority (HPUWA) was established in 1957. The HPUWA was incorporated into the Hawke's Bay Catchment and Regional Water Board formed in 1962. During its operation the HPUWA carried out groundwater surveys to establish hydraulic gradients, flow paths and the influence of the Ngaruroro River on well water levels.

Various site specific hydrogeological and groundwater studies provided the background information for regional assessments of the Heretaunga Plains aquifers by the HBCB and the Ministry of Works. The results of this work is summarised in Grant (1972). The potential for groundwater pollution in the unconfined area of the Heretaunga Plains aquifer adjacent to the Ngaruroro River recharge source was recognised. In 1972, concern over the siting of the Flaxmere "outer" suburb of Hastings, and industrial and urban development over the unconfined aquifer area (Fig. 3.1) resulted in the Ministry of Works and Development commencing a study of the possibility of pollution of groundwater in the unconfined aquifer. The main objectives of the study were to determine the boundaries of the unconfined aquifer and to advise on landuse planning in the unconfined aquifer area. Eighty two investigation wells were drilled to an average depth of 30 m to delineate the unconfined aquifer boundary. Wells and rivers were sampled to determine water quality. Although the study identified point sources of contamination and concluded that unwise landuse could lead to widespread contamination of the unconfined aquifer, predictions of the effects of urban developments on groundwater quality could not be made without more investigations. A further study co-ordinated by Ministry of Works and Development was begun in 1976 designed to quantify potential contaminant movement processes into and through the Heretaunga Plains aquifer system. During

COLOUR SCAN

Figure 3.1: Flaxmere urban area and industrial sites located on the former (pre-1867) Ngaruroro River channel and straddling the boundary between the unconfined and confined zone of the Heretaunga Plains aquifer system. *(photo: Lloyd Homer, IGNS CN 17711/5).*

this study, tracers were used to test infiltration to and within the water table. This work (Thorpe 1977) showed that the gravels above the unconfined aquifer had little or no capacity to prevent pollution from reaching the water table. It was determined that bacteria and other micro-organisms could travel freely through these gravels.

The significant findings were (Thorpe et al. 1982):

- The river gravel deposits overlying the Roys Hill - Fernhill - Flaxmere unconfined aquifer area provided no protection from contamination by leachate seepage from landuse activities.
- Residential and urban development over the unconfined aquifer area will have little impact on the quality of groundwater in the confined aquifer.
- Ngatarawa - Bridge Pa unconfined aquifer is degraded due to nitrate leached from pastureland.

Following on from trials in the summer of 1982 - 83 by the HBCB, an artificial groundwater recharge scheme was constructed utilising Ngaruroro River water that had been diverted into a water race. From the water race the water flowed into a series of ponds excavated in the river gravel deposits of the Heretaunga Plains immediately adjacent to the Ngaruroro River where natural recharge of the aquifer was occurring (Fig. 1.2). The scheme was designed to "top up" groundwater during dry summers when groundwater use was at a maximum. Approximately 1 cumec of water is extracted from the Ngaruroro River through a culvert intake, conveyed through a water race to an area of gravelly pre-1867 Ngaruroro River channel and spread onto four rectangular ponds of 1 hectare area. The effectiveness of the artificial recharge scheme has not been fully quantified (Koutsos & McBryde 1989).

3.2.3 1980-1991

Over the next ten years the main Hawke's Bay groundwater activities were reviews of HBCB groundwater data, groundwater investigations and monitoring programmes. In 1983, N.H. Smith of NZ Geological Survey concluded:

- There was difficulty in cross referencing well data, water chemistry and water right data for integrated research investigations.
- The validity of well data (particularly well location) was often suspect and important historical groundwater data had not been incorporated into the filing system.
- The geological component of investigation had been directed at site specific studies and specific problems. In general, there was a lack of knowledge of the geological depositional history and the processes that had formed the Heretaunga Plains.

In 1991, D.H. Scott of DSIR Geology and Geophysics reviewed the data required to establish a groundwater model of the Heretaunga Plains aquifers. He identified the following deficiencies:

- Inadequate water use data.
- Limited records of the transient behaviour of piezometric level in the confined aquifer region.
- Limited knowledge of structural control on the nature and extent of aquifers.

This was the background and some of the problems acquired by the HBRC when it was established on 1 November 1989 and which would have to be addressed in terms of the sustainable management of the groundwater resource as required under the Resource Management Act 1991.

In 1991, HBRC reviewed the current Heretaunga Plains groundwater knowledge (Dravid 1991c and 1992a) and identified deficiencies that could be addressed in the HBRC 5 year strategic plan. These reviews noted the need for multidisciplinary research and systematic hydrogeological exploration to understand the aquifer configuration, groundwater, chemical and isotope quality variables and the depth of groundwater basement.

3.3 CURRENT JOINT HBRC/CRI INVESTIGATIONS

3.3.1 HBRC/IGNS Investigation

In November 1991, HBRC and IGNS agreed to co-operate in a 5 year research project of the hydrogeology of the Heretaunga Plains aquifers. In broad terms the objective of the project was " to utilise the expertise, techniques and facilities of IGNS to compile a geological history of the Heretaunga Plains and the hydrogeology of the underlying aquifers and apply this to the HBRC management plan for the groundwater resource".

This was translated into the following objective in the HBRC 1992/93 Annual Plan.

Objective 7.18

Heretaunga Plains Groundwater - HBRC / IGNS Joint Project

> *"To undertake multidisciplinary investigations in the area of regional groundwater assessment jointly with one or more specialist staff from the Institute of Geological and Nuclear Sciences throughout the fiscal year."*

Other objectives in the HBRC 1992/93 Annual Plan were designed to correct the knowledge and data base deficiencies identified by Smith (1983), Scott (1991) and Dravid (1991c and 1992a). These included -

Objective 7.16

Heretaunga Plains Seismic Survey - HBRC / IGNS Joint Project

> *"To carry out a seismic survey in the St. George's Road area to assist in defining groundwater anomalies."*

Objective 7.17

Heretaunga Plains Deep Well - HBRC / IGNS Joint Project

> *"To drill a deep exploratory water well in the middle of the Heretaunga Plains aquifer system, in order to ascertain the potential, extent, and water quality of individual water bearing layers."*

Objective 7.22

GIS Groundwater Data Entry.

> *"To enter a variety of hydrogeological and water quality data in preferred format on GIS."*

Objective 7.17 was designed to provide information on the strata and aquifer sequence underlying the Heretaunga Plains. In 1991/92 as a part of this objective an exploratory water well was drilled to a depth of 137 m at Flaxmere. In 1992/93 another exploratory water well was drilled to a depth of 257 m at Tollemache Orchard on the south side of Hastings. During 1993/95 a third exploratory well was drilled near the Hawke's Bay coast at Awatoto to a depth of 254 m. The Flaxmere well was located on seismic line (DSIR-1 Line, 1992) (Fig. 4.3) surveyed as a part of HBRC objective 7.16, to test the capability of geophysical seismic surveys to provide information on Quaternary sediments and the aquifers to a depth of 300 m. As a part of HBRC objective 7.17, IGNS personnel logged strata penetrated and collected sediments and water samples for various tests and analysis. The drilling schedule and contractual details were designed and supervised by David Dravid, HBRC. Information gained from these test bores is presented in Brown (1993) and Brown & Gibbs (1996).

Groundwater investigations of the Heretaunga Plains had been concerned with the Ngaruroro River recharged, high yielding central portion of the aquifer system. Problems and anomalies had been identified particularly on the edge or fringe of the Plains but little had been done to find out their significance. A comprehensive piezometric survey of the Heretaunga Plains and the peripheral areas had never been undertaken. On the weekend 18-19 February 1995 after a prolonged period of drought, water levels were measured in a network of 440 wells on the Heretaunga Plains so that the regional pattern of groundwater flow under low water level conditions might be established. To ensure that true water levels were measured without drawdown or reduced pressure associated with pumping, local authorities, industrial and irrigation water users were asked to minimise pumping for a 12 hour period while the survey was carried out. Figure 5.6 shows the piezometric contours plotted from this survey. Groundwater chemistry samples were collected from 85 wells including public water supply wells. Isotope samples were collected from 38 wells.

3.3.2 HBRC / Landcare Research Investigations

In 1992, Landcare Research New Zealand and the HBRC began a joint project to develop soil-crop specific irrigation water allocation procedures (Watt et al. 1993). The project is based on the concept that a sound scientific basis is needed for irrigation water allocation consents under the Resource Management Act 1991, to avoid inefficient use of water and energy (for applying the water), and to decrease risk of groundwater contamination through the leaching of pesticides and fertilisers.

The main thrust of this joint study is directed towards developing procedures to numerically simulate water storage and movement to at least 1.2 m depth root zone, and the preparation of optimum irrigation management plans for efficient and sustainable use of water and soil and aquifer protection. This is based on the uniqueness of a particular site with reference to soil water

Figure 3.2: Installation of suction lysimeters. *(photo: Jim Watt, Landcare Research NZ).*

transmission and storage. The concept of soil, crop and management is applied through the specific *"Designer"* Consent approach (Watt et al. 1993 and 1995). During 1995/96 financial year, the advantages of implementing designer consent for a water short area on the southern fringes of the main aquifer system were investigated. The interim findings of this investigations were presented at a HBRC/Landcare sponsored specialist workshop on "Issues in Water Allocation" held at Napier and Havelock North in May 1995. Ten papers presented at the workshop are collated in Volume 2 of this report.

As a part of a Landcare Research NZ/Institute of Environmental Science and Research (ESR) study, two sites in the Heretaunga Plains were chosen for agrichemical, pesticide mobility and dispersion study. The main emphasis of this study was to determine the processes involved in the leaching of pesticides to groundwater by monitoring vertical and horizontal transport and attenuation of two pesticides and three tracer compounds through the soil profile and unsaturated zone at the two sites using suction lysimeters (Fig. 3.2), and to evaluate existing models of chemical movement through soils for their accuracy in predicting the field monitored experience.

3.4 LONG-TERM INVESTIGATION PRIORITIES

A systematic modern hydrogeological study with the objective of achieving sustainable management of the Heretaunga Plains groundwater resource is a sequential process with three main phases. First, there is an exploration stage, in which various geological investigations are applied to establish a geological history of the region to identify where significant aquifers could be present. This is carried out in conjunction with a review of all other relevant information related to groundwater occurrence and utilisation. Second, there is an evaluation stage which includes drilling exploratory wells to confirm the hydrogeology and to provide information and samples for establishing various hydrogeological and hydrochemical parameters for quantity and quality determinations. Third there is a management phase, which includes considerations for planned and sustainable development of groundwater resources. The next three chapters of this report will look at these three stages in terms of the Heretaunga Plains aquifers.

Figure 3.3: Irrigation near Bridge Pa, Heretaunga Plains, January 1995. *(photo: Lloyd Homer, IGNS CN34214)*.

CHAPTER 4

HYDROGEOLOGICAL EXPLORATION

4.1 BACKGROUND

Initially groundwater exploration on the Heretaunga Plains began with wildcat wells, and prediction of groundwater availability only improved as the knowledge data base of the resource increased. The well driller was the prospector as well as the miner of the groundwater resource. With the establishment of a data base of well logs and accompanying hydraulic data, the study of hydrogeology began.

To achieve the objectives (see 1.9 and 3.3) of the joint HBRC/IGNS Heretaunga Plains aquifers investigation programme, the following hydrogeological exploration tasks were carried out:

- A review of groundwater data and data base organisation.
- Shallow seismic surveys designed to provide knowledge of the regional geology and structure.
- Drilling of strategically located deep exploratory bores and logging strata to determine aquifer-aquiclude sequence and extent of aquifer system.
- Investigation of subsurface stratigraphy from well logs by construction of lithological cross sections across the Plains.

In addition to the joint project activities, the HBRC carried out a water level survey from a network of 450 wells on and adjacent to the Heretaunga Plains in February 1995. Well sites were subsequently levelled and piezometric contours drawn to provide information on direction of groundwater flow. The results of this survey together with the collated results of average winter piezometric surveys are presented in Chapter 5 (see 5.3.3.2). In conjunction with the piezometric survey, water samples from 85 wells were collected for chemical analyses and 38 samples were collected for isotope analyses. The current and historical chemical and isotope data are discussed in Chapter 7 of this report.

4.2 GROUNDWATER DATA

By 1991, 125 years after the discovery of the Heretaunga Plains aquifer system, a considerable quantity of information on the groundwater resource was held by the HBRC and the three principle well drilling companies operating in Hawke's Bay. Other organisations including Napier City Council, Hastings District Council and Works Consultancy (previously Ministry of Works and Development), also held data relevant to groundwater studies. Most of this data was unprocessed and unsuitable for immediate use, being in the form of driller's records, files, cards, reports, and water level recorder charts and tapes. At the HBRC about 2500 well logs had been entered into a Wellarc data base but no checks had been carried out to identify errors and omissions. Different numbering and reference systems were used for well logs, water analyses, water level monitoring and consents, and this prevented cross referencing of data between files operated by different sections of the HBRC. In 1993 the HBRC installed an Arc Info Geographic Information Systems (GIS). In 1994 the HBRC provided financial assistance to the three local well drilling companies to procure a 486 computer in return for entering historical well data into a data base. An Access well data base was installed and drilling company staff were trained in data entry techniques. In the future it is proposed to review and check the accuracy of well data entered by the drillers and incorporate the checked data into a central Access well data base along with the well log data in the Wellarc data base. In 1994 the HBRC acquired the well log presentation software - Geo Technical Graphics Systems (GTGS) for graphic presentation of well logs in geological cross section form. Figure 4.1 illustrates current and proposed future organisation of groundwater data bases.

The entry of current and historical water quality data on a new Access water quality data base was completed in October 1995. Currently HBRC water consent data is entered on a separate data base called CONMAN. It is proposed to create a new Access consents database. It is intended that various Microsoft Access data bases will be linked with reference to the HBRC well numbers for integrated groundwater investigations using the GIS programme.

4.3 GEOPHYSICAL EXPLORATION METHODS

Geophysical surveys utilising the seismic reflection and resistivity exploration methods have been carried out on the Heretaunga Plains to obtain information on the structure of the Heretaunga depression, the

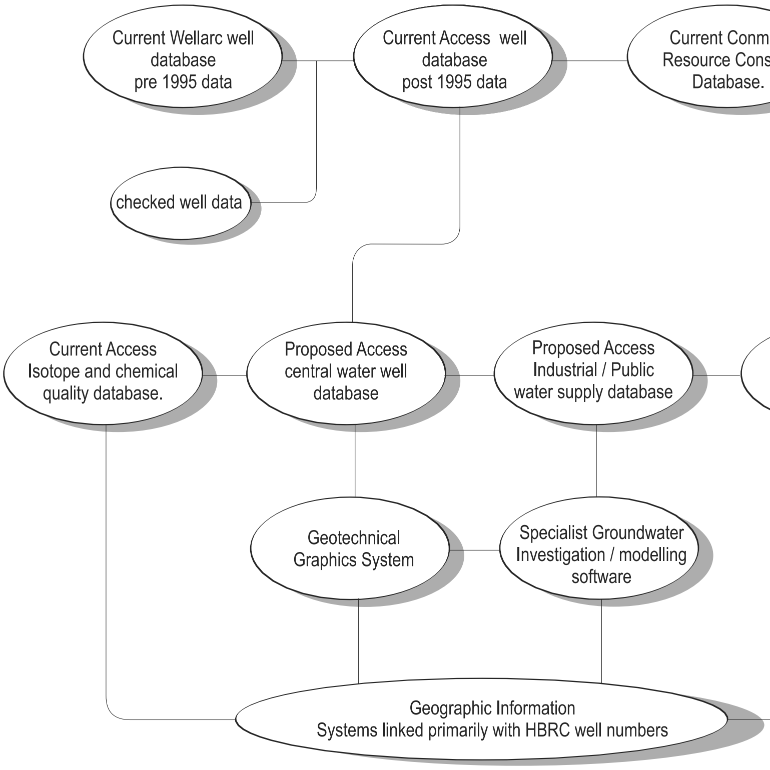


Figure 4.1: Proposed organisation and integration of groundwater databases.

depth to groundwater basement, the presence of high permeability gravel channels within the subsurface sequence of sediments and the aerial extent of potential aquifers. Oil exploration geophysical surveys using seismic reflection have been carried out both on land and offshore of the Heretaunga Plains. These provide information regarding the broad structural features of the on-shore and off-shore subsurface sediments.

4.3.1 Resistivity Surveys

In 1967 G.F. Risk of Geophysics Division, DSIR carried out a resistivity survey on the Heretaunga Plains to the northwest of Hastings in the Twyford area in a block bounded by the Ngaruroro River, Hastings - Fernhill Highway and Oak Avenue - Ormond Road. The survey was designed to test the resistivity method to see if a useful correlation could be found between the resistivity and the subsurface geological strata, and to delineate the possible extent of an area of confining strata where the strata sediments might be thixotropic and act like liquid during well drilling. The survey established that finer materials such as clay and silt have low resistivity values, whereas the coarser materials such as pumice, sand and gravel have high values. There was poor correlation between well logs and resistivity sections possibly as a result of the variations of sediments over short distances. Another problem was that the resistivity method could only identify a maximum of about five layers whereas there were many more strata reported in the well logs (Risk 1974). Despite the limited success, however, the survey suggested that the resistivity method was worth persevering with for the delineation of strata and aquifers.

In 1975, N.W. Z. Borgesius of Water and Soil Division, Ministry of Works and Development (MWD) undertook a comprehensive resistivity survey of the Heretaunga Plains groundwater recharge in the areas adjacent to the Ngaruroro River where loss of visible river flow had been measured. These were the major recharge area between Roys Hill and Fernhill and the minor recharge area between Maraekakaho and Roys Hill. 55 resistivity soundings covering an area of 22 km^2 were made. The resistivity survey showed a general slope and gradient of the "groundwater basement" in the major and minor recharge zones. The survey suggested that the deepest part of the valley was oriented along Omahu Road at about 125 m depth, while along Ngatarawa Road the depth of basement was interpreted to be about 40 m. The survey also indicated a thick confining silt layer down gradient of Fernhill Bridge and between Fernhill and Roys Hill with gravel to a depth of about 120 m. Additional resistivity soundings were undertaken by MWD to determine aquifer thickness and depth. These resistivity soundings were never verified by drilling. In 1978 MWD carried out resistivity surveys along and across the Ngaruroro River in the major groundwater recharge area and the results were interpreted as a depth to groundwater basement map and collated in reports by N.V. Hawkins (1978a and 1978b).

In 1988, C.H. McLellan of the HBCB collated the resistivity data from all the previous surveys - a total of 127 locations over the Heretaunga Plains groundwater recharge area, and produced a “basement” contour map of the unconfined aquifer area (Fig. 4.2).

The basement contour map suggested at least three subsurface river channels:

- ✏ A river channel to the north of Roys Hill and Fernhill - roughly in the same location as the present day channel.
- ✏ A river channel to the north of Roys Hill and south of Fernhill.
- ✏ A river channel south of Roys Hill.

The contour map also suggested a steep scarp of unknown depth at the eastern edge of the survey area (McLellan 1988). It was not until 1992 when the Flaxmere testbore was drilled that the possible significance of the low resistivity sediments at depth on which the “basement” contours were based could be explained. The occurrence of low resistivity and hence low permeability sediments corresponds with the boundary between the last glaciation fluvial gravels and the sand, silt and clay of the last interglacial deposits penetrated at a depth of 96.3 m by the Flaxmere testbore (Brown 1993). If this correlation is valid then Figure 4.2 provides information on the depth of early last glaciation river channels underlying the Heretaunga Plains. These channels may possibly define a groundwater flow path for deep aquifer groundwater flow.

4.3.2 Seismic Surveys

Onshore seismic surveys have been carried out on the Heretaunga Plains in an attempt to obtain information on near-surface strata and to detect aquifers and groundwater “basement”. Four of these seismic surveys were carried out by IGNS or its predecessors (DSIR Geophysics Division and DSIR Geology and Geophysics) - Ravens (1990, 1991 and 1992) and Melhuish (1993). The other survey was undertaken by Croft Petroleum of Edinburgh (B.C.M. Geophysics 1989). Offshore seismic surveys in Hawke Bay were conducted by American Exploration in 1990-91 and provide information on broad structural features (AMEX 1991) and New Zealand Oceanographic Institute, DSIR (Lewis 1973b). Figure 4.3 shows the location of various onshore seismic survey lines.

As previously outlined in sections 2.1 and 2.2, the onshore and offshore seismic surveys have provided information on the regional structure of the basin underlying the Heretaunga Plains and on the offshore Hawke Bay stratigraphy.

Ravens (1990) and Croft (1989) present interpretations of seismic profiles obtained in the Ngatarawa Road and Bridge Pa Road vicinity southeast to Louisa Stream and Middle Road on the margin of the Heretaunga Plains (Fig. 4.4) (J.M. Ravens, IGNS, pers. comm.). The interpretations suggested the following:

- ✏ Gravels of the Holocene period could range in depth from 50 to 160 m.
- ✏ Evidence of a 900 m deep basin structure bounded by steep unconfirmities and infilled with Pleistocene sediments.
- ✏ On the east of the basin a zone of thrust faulting with approximately 160 m of vertical offset, and down throw to the east.

Two seismic surveys were undertaken to determine the structure of the boundary of the confined aquifer and to identify geological features possibly related to buried river channels for aquifer recharge from the Roys Hill sector of the Ngaruroro River. These provided additional information on the overall structure of the basin but were of little direct relevance to aquifer detection and groundwater recharge (Ravens 1991 and 1992). This was probably due to the limitations of the relatively coarse geophysical exploration methods to detect subtle changes in fluvial gravel deposits where slight changes in the sand, silt and clay proportions in the matrix can produce significant contrast in permeability, and in the tightness of packing of the strata in terms of penetration during drilling operations. A seismic survey in the Tollemache Road vicinity was designed to provide seismic data for comparison with the strata penetrated by the Tollemache

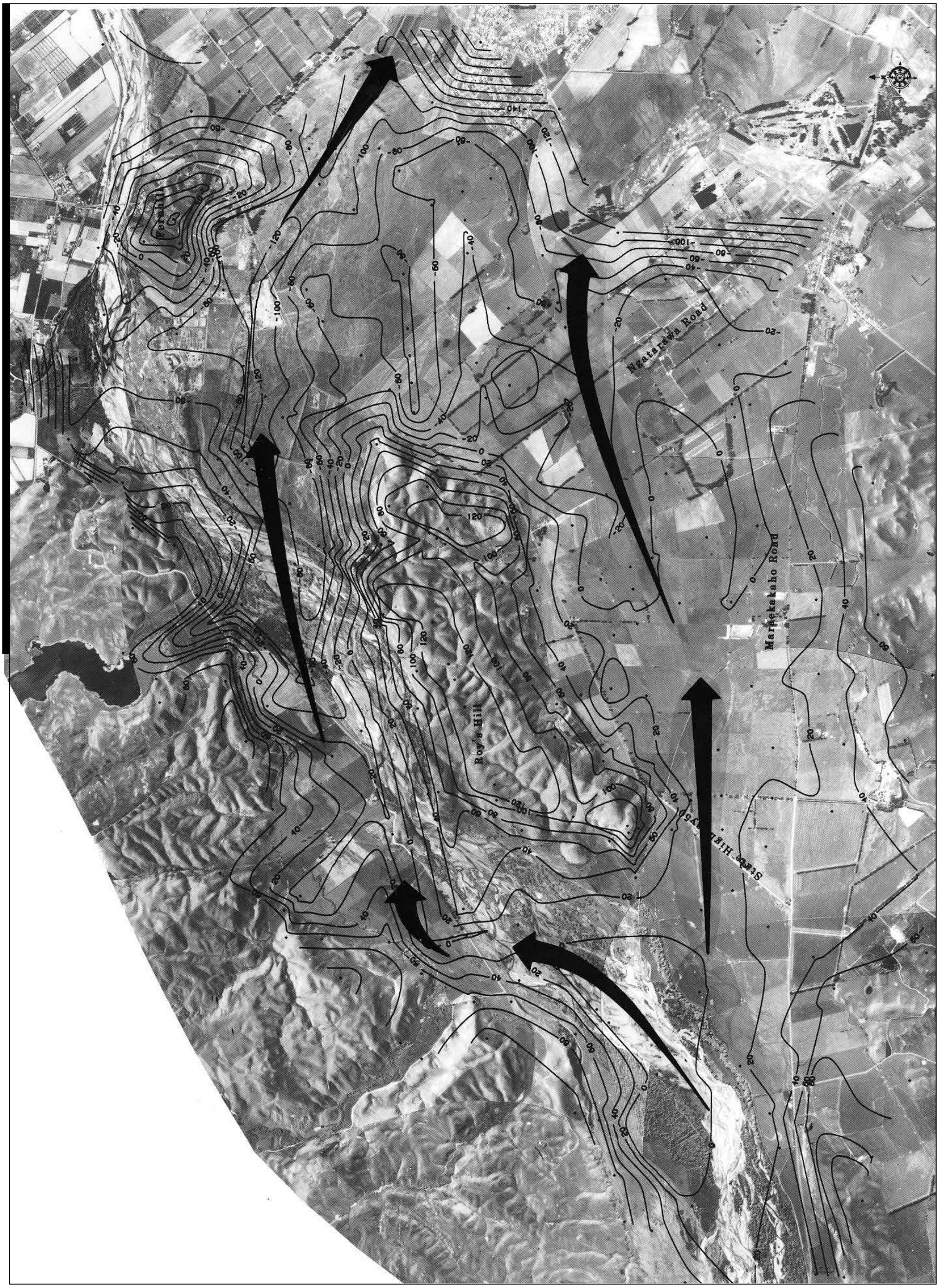


Figure 4.2: “Basement” contour map of the Heretaunga Plains unconfined aquifer area.

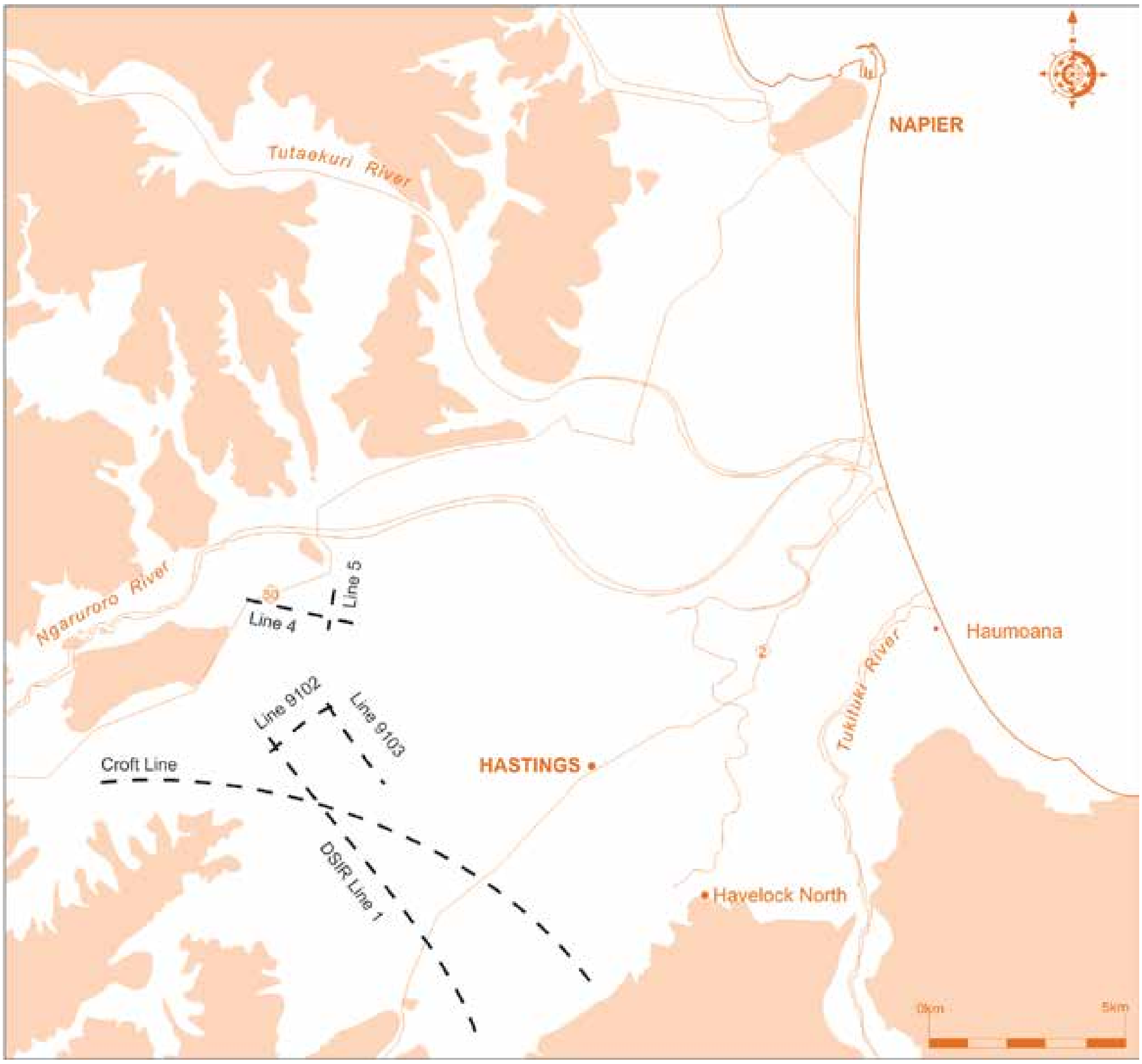


Figure 4.3: Location of onshore seismic survey lines. David Dravid, HBRC and Jonathon Ravens, DSIR marking the Seismic Survey line 9102 near Ngatarawa Road, February 1991. *(photo courtesy Hawke's Bay Herald Tribune).*

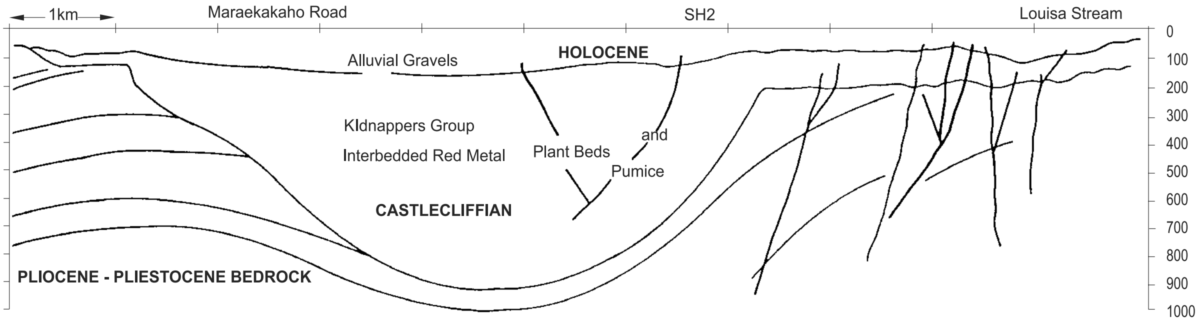


Figure 4.4: Seismically interpreted stratigraphy along the Ngatarawa Road (J.M.Ravens, IGNS).

Orchard testbore. The Tollemache Orchard testbore penetrated 256 m of sediments consisting of gravel, sand, silt, clay, peat and shell beds. The target depth of 300 m was not achieved because of the unconsolidated nature of the strata penetrated and the high sand content of the aquifers below 220 m depth (Brown 1993). Once again it was not possible to relate specific layers in the testbore to the seismic data suggesting that the frequency range of the seismic data, was not appropriate for achieving delineation in the shallow sequence (Melhuish 1993).

The American Exploration offshore seismic data (American Exploration 1991) provided information on the regional structure. The land - offshore seismic structural correlation suggest that:

- The synclinal structure extends at least 30 km offshore to the northeast.
- The width of the syncline is at a maximum offshore.
- The axis of the syncline is along a line from Pakipaki to Awatoto and northeast out into Hawke Bay.
- The syncline plunges to the northeast.

To summarise the results of the geophysical exploration methods of the Heretaunga Plains, the resistivity method provided some information on the shallow (<200 m) sediments and the confined aquifer - aquiclude sequence. The seismic reflection method provided only broad information on the regional structural trends of the Heretaunga depression.

4.4 DEEP EXPLORATORY BORES

Exploratory drilling is the only conclusive means to determine the sequence and lithology of subsurface strata and the occurrence and configuration of aquifers, aquicludes and aquitards. Samples of the subsurface strata are obtained for visual inspection, for dating and for paleoenvironment determinations. This information is essential for correlating strata between wells and determining the age and type of events that affected deposition of the strata and the presence, distribution and extent of aquifers within the regional geologic framework (Brown 1990).

Many thousands of wells have been drilled to tap the aquifers underlying the Heretaunga Plains, Hawke's Bay. Most of these are relatively shallow (<50 m deep). Only 30 wells deeper than 100 m are recorded (Brown 1993). In the period 1991-95 three deep exploratory bores have been drilled for the HBRC to provide information on the hydrogeology. The location of the testbores was chosen on the basis of the regional geologic history and structure with emphasis on sites which would yield strata material for dating and correlation. The testbores were sited at Flaxmere on the unconfined - confined aquifer transition zone, south Hastings (Tollemache Orchard) near the middle of the onshore aquifer system, and at Awatoto on the Hawke Bay coast (Fig. a). The Flaxmere and Tollemache Orchard testbore sites were also close to seismic survey lines for the geophysical exploration programme outlined above (section 4.3). In the case of the Flaxmere testbore the area had also been covered by resistivity surveys.

The drilling schedule and contractual details were designed and supervised by HBRC. IGNS personnel logged strata and collected samples for various tests and analyses. Water samples were obtained from aquifers intersected by the wells for chemical and isotopic analyses. The descriptive log of these wells together with the procedures, analyses, results and interpretations are given in Brown (1993) and Brown & Gibbs (1996).

4.4.1 Flaxmere Testbore (Well No. 3698)

The testbore was drilled by Baylis Brothers Ltd., Greenmeadows who contributed towards the drilling cost. The site off Portsmouth Road adjacent to Flaxmere was owned by Hastings District Council and at the time of drilling leased to the Hawke's Bay Equestrian Trust. The groundwater "basement" depth in the Flaxmere area was inferred from the resistivity surveys to be about 150 m while seismic surveys suggested a depth of 250 - 300 m.

Drilling began on 29 August 1991 with a Bucyrus Erie 22W cable tool rig. Because of the "tight" sandy silty gravel encountered at 59.4 m two attempts were made to achieve the target depth of 300 m. The first attempt reached 66m and was abandoned and the casing withdrawn due to lack of penetration. The second attempt also was unable to achieve a reasonable rate of penetration and at 64.3 m the cable tool rig was replaced by a rotary drilling rig - Baylis 35 top head drive. The rotary rig drilled to a depth of 137 m where slow drilling progress resulted in drilling stopping on 12 October 1992.

The detailed well log is presented in Brown (1993). Figure 4.5 summarises the well log, paleoenvironment and aquifer details. Because of the predominance of fluvial gravels to 96.3 m depth and absence of organic material no substantiated age or paleoenvironment determinations were possible to a depth of 100.5 m. From 100.5 m to the bottom of the testbore four

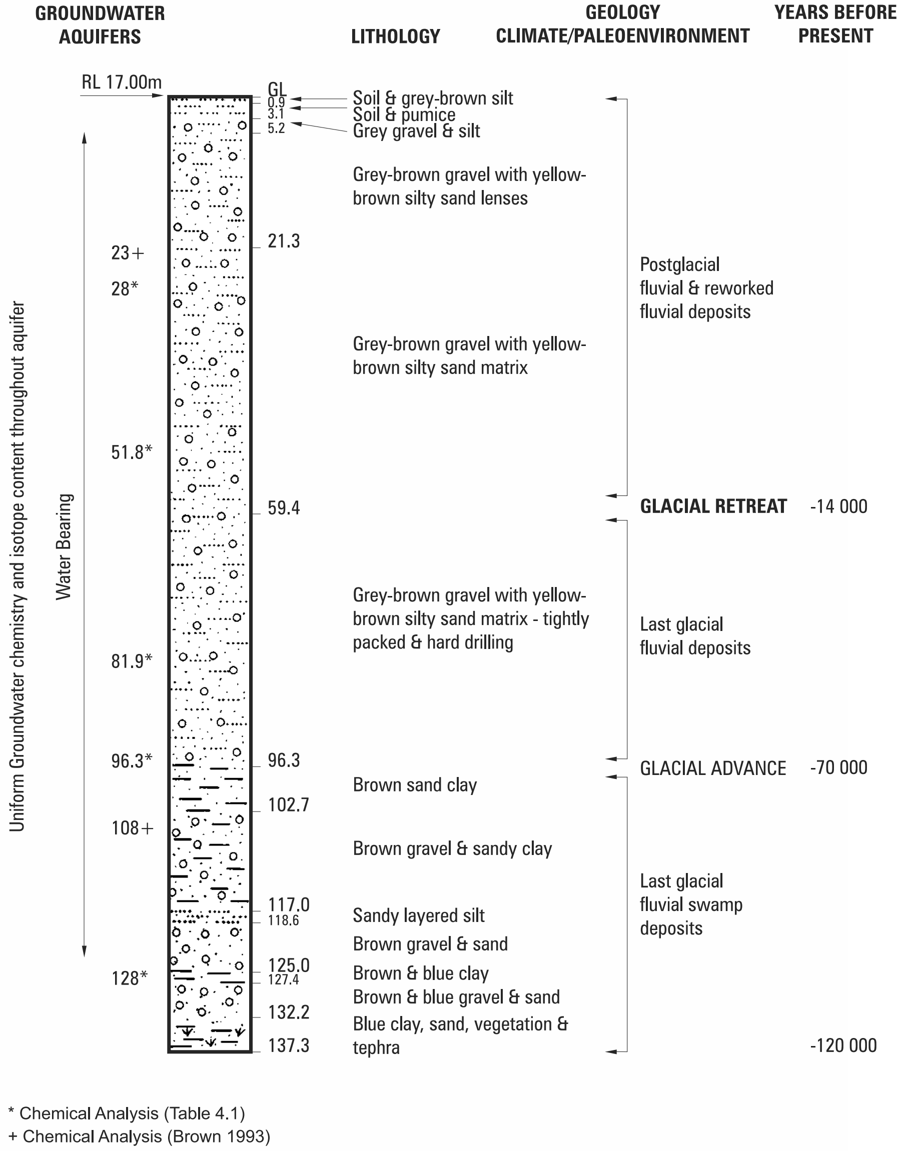


Figure 4.5: Summarised stratigraphy of Flaxmere testbore (well no. 3698).

microflora samples were collected. These contained recycled pollen and spores but enough *in situ* pollen and spores were present to confirm a temperate climate marginal marine paleoenvironment (Dr D.C. Mildenhall, IGNS, pers. comm.).

On the basis of strata lithologies, drilling conditions and palynology, tentative correlations can be made with the established New Zealand stratigraphic time scale (front and back inside cover). The gravel strata from the ground surface to a depth of 59.4 m are assigned to the Holocene. The "tight" gravel from 59.4 to 96.3 m has been correlated with river deposition during the last glacial period and the temperate climate marginal marine environment deposits as indicated by the palynology for the strata from 96.3 to 136.6 m, are assigned to the last interglacial period.

The Flaxmere testbore penetrated an almost continuous sequence of water-bearing gravel to 125 m. Gravel deposits with varying sand, silt and clay matrix content formed an interconnected subartesian confined aquifer - aquitard system. Silt and clay strata penetrated may form local aquicludes with the most obvious aquiclude occurring from 125 m to 136.6 m. Static water levels recorded during drilling did not show any significant variation with depth. This supports the concept of an aquifer system with hydraulic connection to all depths to 125 m and no significant impediments to lateral and vertical flow.

The testbore was pumped at several depths and water samples collected for chemical and isotope (oxygen 18 and tritium) analyses (see Brown 1993). The results of chemical analyses are summarised in Table 4.1. The chemical analyses show only minor variation in groundwater chemistry at 28, 52, 82, 96 and 128 m (Fig. 4.5, Table 4.1). Samples from 82, 96 and 125m were analysed for oxygen 18. The oxygen 18 analyses indicate that groundwater was derived from the Ngaruroro River. Samples from 52, 82, 96, 108 and 125 m were analysed for tritium. Tritium ratios[7] (TRs) indicate that a considerable component of the groundwater is of the post-thermonuclear era (post-1955). The absence of variation of groundwater chemistry and isotopic content with depth provides further evidence of a hydraulically interconnected single aquifer system.

	Units	Lab. No.	Lab. No.	Lab. No.	Lab. No.	Lab. No.
Determinands	g/m^3	8806	8845	8879	8898	9329
Date		02/09/91	20/09/91	27/09/91	21/01/92	22/09/92
Depth	m	28	52	82	96	128
Temperature	oC	15	14	13	14	16
pH		7.20	8.05	8.05	7.5	7,72
Conductivity	mmho/cm	270	200	205	280	210
Alkalinity	g/m3	76	69	68	67	68
Chloride	g/m3	16	15	12	14	20
Sulphate	g/m3	14	14	9	25	8
Hardness	g/m3	88	72	72	76	76
Sodium	g/m3	16	13	13	14	12
Potassium	g/m3	2.0	1.7	1.4	2.5	1.3
Magnesium	g/m3	4.2	4.1	3.8	4.3	3.5
Calcium	g/m3	28	22	22	23	25
Iron	g/m3	1.0	0.6	0.4	4.8	0.2
Manganese	g/m3	<0.1	<0.1	<0.1	0.1	<0.1
Nitrate (N)	g/m3	3.2	0.8	0.8	1	<0.5

Table 4.1: Flaxmere testbore (well no. 3698) groundwater quality variation with depth.

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[7] Tritium ratio (TR) = 1 corresponds to Tritium / Hydrogen = 10^{-18}.

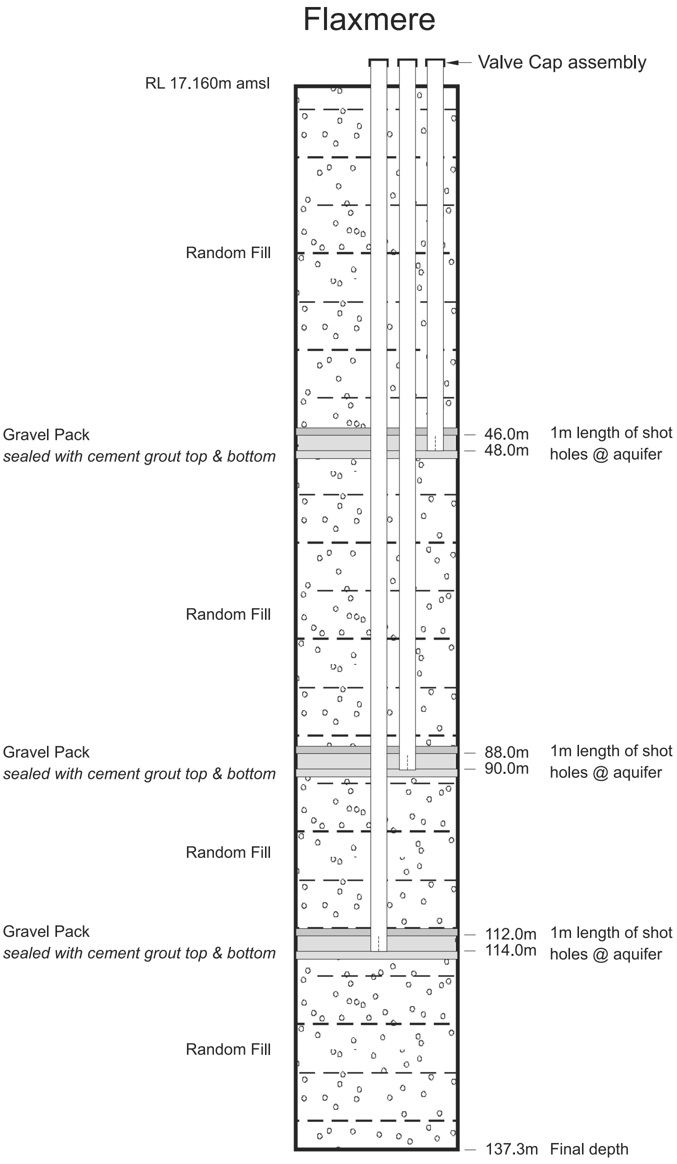

Figure 4.6: Flaxmere testbore (well no. 3698) piezometer construction details.

Piezometers were installed when the casing was withdrawn (Fig. 4.6) and water levels monitored at 46-48 m, 88-90 m, and 112-114 m show similar fluctuations supporting hydraulic interconnection.

4.4.2 Tollemache Orchard Testbore (Well No. 3697)

This testbore was drilled by Hill Welldrillers Ltd., Hastings. The site was in Tollemache Orchard, Tollemache Road immediately adjacent to the Southland Drain.

Drilling began on 2 November 1992 using a RB 27 cable tool rig and continued to a depth of 222.1 m, where the cable tool rig was replaced by a Mayhew 500 rotary drilling rig. The rotary drilling method was used to 256.5 m where drilling stopped on 6 May 1993 due to the unconsolidated nature of strata penetrated and the high sand content of the aquifers. Further attempts to drive the casing resulted in sand heaving and strata collapse even with drilling mud. The detailed geological log of Tollemache Orchard testbore is presented in Brown (1993). Figure 4.7 summarises the well log, paleoenvironments and aquifer details.

The Tollemache Orchard testbore was sited coastwards of the 6500 year BP maximum inland marine transgression coastline. Abundant fossiliferous material was present in the postglacial swamp, beach, estuarine and lagoonal sediments that form the confining strata capping the fluvial gravel aquifer. As a result more definitive age and paleoenvironment determinations were possible compared with the Flaxmere testbore.

Six shell samples from 18 to 31 m depth and a wood sample from 37 m have been radiocarbon dated. These ages along with other Heretaunga Plains radiocarbon dated material from water wells, testbores and other sites (Table 4.2) are plotted on Figure 4.8 and compared with the New Zealand eustatic sea level curve of Gibb (1986).

All Heretaunga Plains dates plot below the Gibb curve indicating subsidence of the strata since deposition. The Tollemache Orchard sample dates range from 8000-5340 years BP and cover the final stages of the postglacial sea level rise at about 6500 years BP.

Thirteen Holocene shell samples to a depth of 36 m were examined by Dr.A.G. Beu, IGNS. The macrofauna determinations indicated a paleoenvironment associated with a gradually deepening depositional environment as the sea transgressed over the land inland of the testbore site then a slight shallowing of water depth

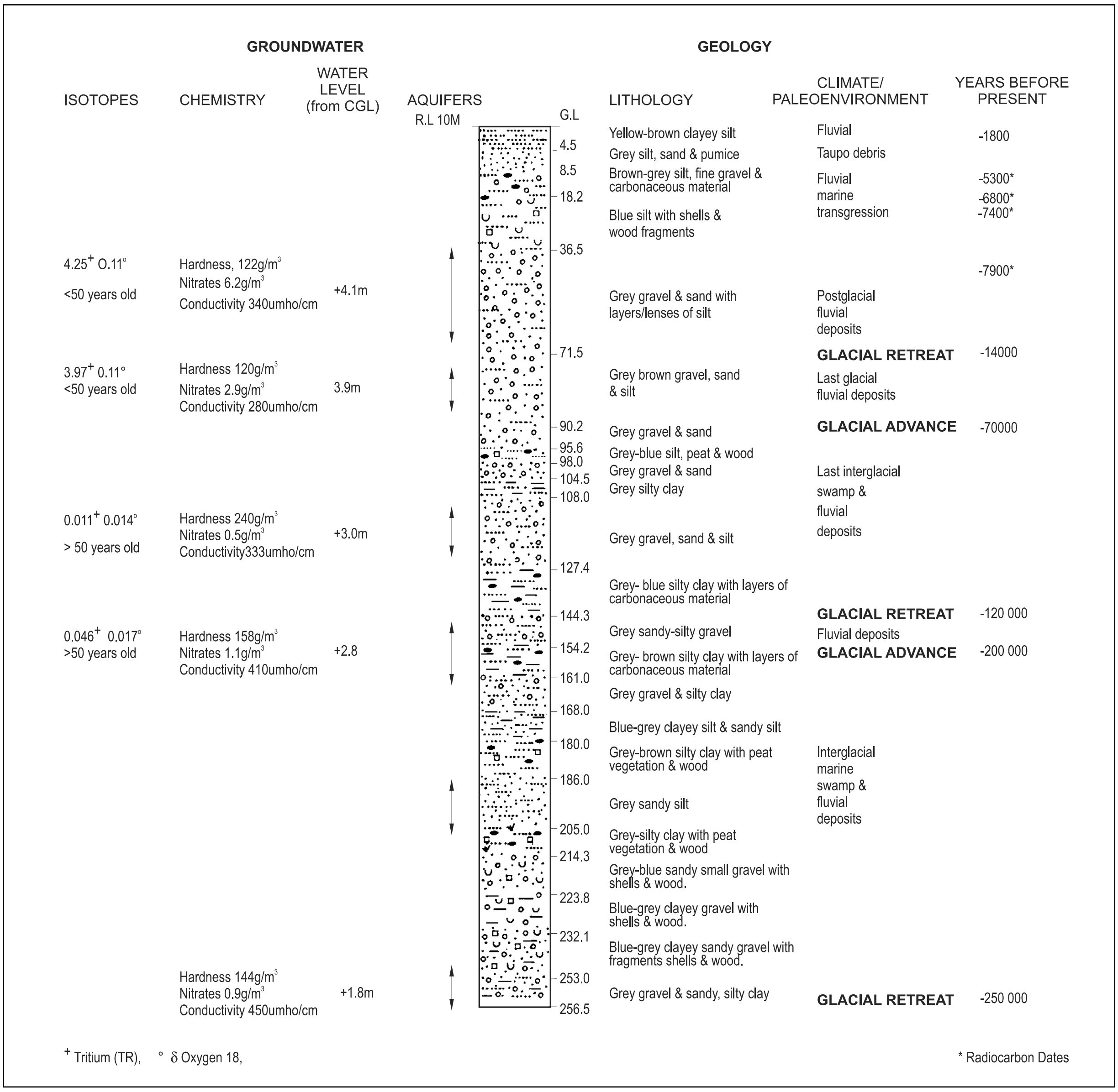

Figure 4.7 Summarised stratigraphy of Tollemache Orchard testbore.

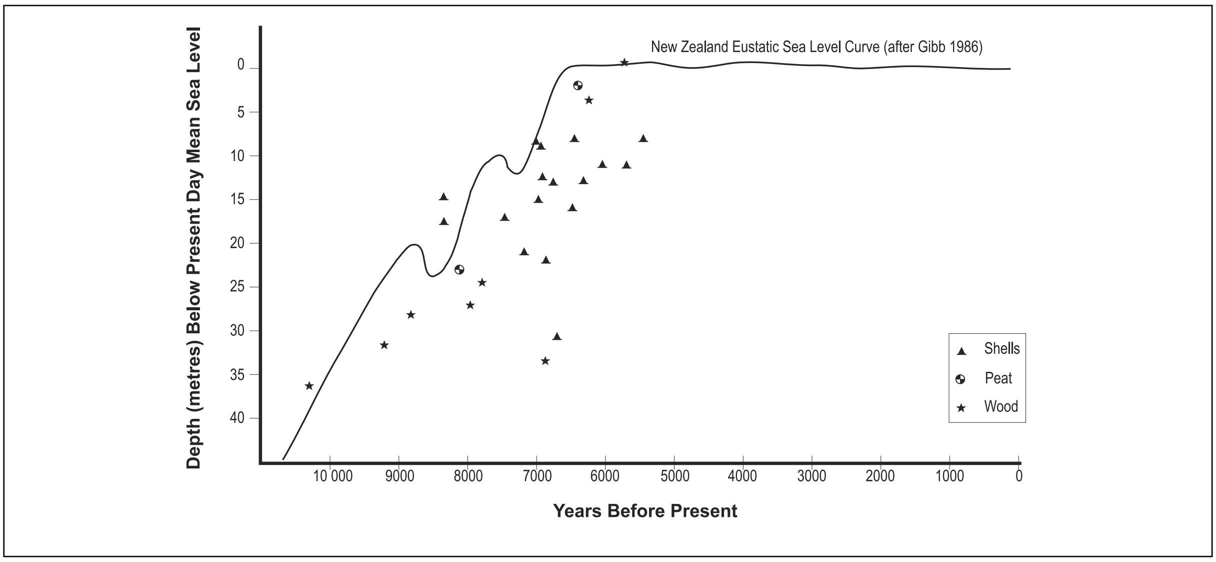

Figure 4.8: Eustatic sea level curve of Gibb.

Age (Years B.P)[8]	Lab No.	Fossil Record No.[10]	Sample	Locality	Grid Ref.	Depth (m)	Altitude with ref to MSL (m)
20550 ±300	NZ12	N134/f598	Wood	Hospital Hill	V21/454834	1.5	+77
15484 ±202	NZ2572	B23/x[9]	Carbonate	Hawke Bay	Offshore		-108
10700 ±102	NZ2644	B21/x3[9]	Shells	Hawke Bay	Offshore		-88
10397 ±535	NZ2643	B21/x7[9]	Shells	Hawke Bay	Offshore		-87
10247 ±99	NZ8146	V21/f273	Wood	Awatoto	V21/452744	53	-37
9195 ±85	NZ8145	V21:f267	Wood	Awatoto	V21/452744	48	-32
9063 ±301	NZ2571	B23/x[9]	Organic	Hawke bay	Offshore		-108
8740 ±80	Wk3932	V21/f260	Wood	Awatoto	V21/452744	45	-29
8350 ±80	Wk3931	V21/f253	Shells	Awatoto	V21/452744	34	-18
8320 ±80	Wk3928	V21/f246	Shells	Awatoto	V21/452744	31	-15
8067 ±98	NZA5692	V21/f257	Wood	Awatoto	V21/452744	36	-20
8063 ±77	NZ3135	N134/f647	Peat	Hastings	V21/404673	30.5	-23
7889 ±114	NZ7996	V21/f132	Wood	Hastings	V21/383655	37	-27
7739 ±84	NZ8144	V21/f259	Wood	Awatoto	V21/452744	41	-25
7436 ±74	NZ8026	V21/f125	Shells	Hastings	V21/383655	27	-17
7167 ±72	NZA3210	V21/f128	Shells	Hastings	V21/383655	31	-21
6930 ±73	NZ8025	V21/f123	Shells	Hastings	V21/383655	25	-15
6922 ±115	NZA5518	V21/f235	Shells	Awatoto	V21/452744	25	-9
6902 ±58	NZ127	N134/f600	Shells	Hastings	V21/400669	18	-9
6851 ±69	NZ8024	V21/f121	Shells	Hastings	V21/383655	22-23	-12
6815 ±64	NZ8121	V21/f90	Wood	Taradale	V21/420788	36	-34
6808 ±106	NZ7931	V21/f82	Shells	Hastings	V21/405674	30	-22
6711 ±85	NZ3134	N134/f646	Shells	Hastings	V21/404673	21	-13
6672 ±63	NZ7932	V21/f88	Shells	Hastings	V21/405674	38.5	-30.5
6454 ±95	NZ3137	N134/f649	Shells	Hastings	V21/402671	24	-16
6405 ±124	NZ6148	V21/f46	Shells	Havelock Nth	V21/413629	17	-8
6308 ±66	NZ8122	V20/f382	Peat	Bay View	V20/438938	9.5	-2
6278 ±85	NZ3136	N134/f648	Shells	Hastings	V21/402671	21	-13
6200 ±70	Wk3930	V21/f225	Wood	Awatoto	V21/452744	20	-4
5998 ±48	NZ8023	V21/f119	Shells	Hastings	V21/383655	21	-11
5666 ±76	NZ7930	V21/f68	Shells	Hastings	V21/405674	19	-11
5660 ±70	Wk3929	V21/f215	Wood	Awatoto	V21/452744	16	+.6
5346 ±82	NZ8022	V21/f117	Shells	Hastings	V21/383655	18-19	-8-9
5040 ±89	NZ3132	N134/f643	Paleosol	Bridge Pa	V21/332676	9.5	-8
4677 ±67	NZ8120	V21/f197	Wood	Fernhill	V21/331707	16	+19
3223 ±37	NZ3133	N134/f644	Wood	Twyford	V21/350715	15	+4.5
2057 ±52	NZ113	B4[9]	Carb. Wood	Hawke Bay	Offshore		-60
1846 ±63	NZ3130	N134/f642	Peat	Twyford	V21/378713	0.8	+8.7
1806 ±35	NZ3129	N134/f641	Peat	Twyford	V21/378713	0.75	+8.7
1791 ±60	NZ5610	V21/f42	Peat & Twigs	Poraiti	V21/407831	0.8	+2.2
1773 ±43	NZ158	N134/f594	Charcoal	Bridge Pa	V21/352642	3	+10.5
1763 ±43	NZ159	N134/f593	Wood	Bridge Pa	V21/348654	1	+11
1735 ±60	NZ5611	V21/f43	Wood	Poraiti	V21/407831	0.8	+2.2
1469 ±60	NZ8223		Leaves	Lake Rotokare	V21/359743		+13
1180 ±110	NZA5691	V21/f204	Wood	Awatoto	V21/452744	10	+6
859 ±82	NZ5613	V21/f45	Shells	Poraiti	V21/407831	0.6	+2.4
774 ±45	NZ5612	V21/f44	Shells	Poraiti	V21/407831	0.3	+2.7
679 ±59	NZ3131	N134/f645	Charcoal	Havelock Nth	V21/430642		+9
497 ±55	NZ5609	V21/f41	Human Bones	Poraiti	V21/406830	1.2-1.5	+1.5-+1.8
428 ±55	NZ5608	V21/f40	Human Bones	Poraiti	V21/407831	1-1.5	+1.5-+2

[8] All radiocarbon dates are Conventional Radiocarbon Age as defined by Stuvier and Polach (1977) in years before present (1950 AD).

[9] New Zealand Oceanographic Institute, Department of Scientific and Industrial Research, Hawke Bay piston core station number and sample number.

[10] New Zealand Fossil Record File Number

Table 4.2: The Heretaunga Plains radiocarbon data.

as the coast prograded once sea level stabilised 6500 years BP. The gradual development and disappearance of a "pipi" bed could represent a tidal channel moving laterally across the deposition site. A shell sample from a depth of 126 m was identified as reworked older (Nukumaruan) fossils. Shell sample species from 214 to 221.5 m indicated an estuarine paleoenvironment. Shell fragments at 245 and 248 m were unidentifiable, severely abraded bivalves, possibly reworked from older rocks (Dr A.G.Beu, pers. comm.).

Thirty one samples from throughout the sequence were submitted for palynology determination to Dr D.C. Mildenhall, IGNS. These did not indicate any major changes in regional vegetation over the period of time covered. Pollen and spores species representative of temperate climate were common. In some samples the presence of dinoflagellate cysts indicated a near coastal paleoenvironment. Recycling of spores and pollen also appeared common and there was also a relatively high frequency of fine charcoal in most of the samples suggesting recycled coal measures and/or recycled organic material. There was no evidence of recycled material older than Cenozoic (Dr D.C. Mildenhall, pers. comm.).

Wood samples from 135 and 152 m were from a coalified and severely charred conifer of indeterminate species, totara and rata (*Metrosideros sp.*) and kohekohe (*Dysoxylum spectabile*) were identified from 219 and 222 m (Dr Lloyd Donaldson, NZ Forest Research Institute and Dr Rajh Patel, Landcare, pers. comms.).

Microfauna samples from 183 to 220 m were examined for nannofossils by A.R. Edwards, Stratigraphic Solutions. The taxon present suggested temperate climate and a depositional environment typical of a marginal marine site, and an age of Upper Castlecliffian to middle Haweran (A.R. Edwards, pers. comm.).

On the basis of the strata lithologies, radiocarbon ages, fossil determinations, and paleoenvironments, correlations can be made between the strata penetrated by the testbore and the late Quaternary climatic stages (Table 4.3)

The Tollemache Orchard testbore encountered six flowing artesian aquifers. The aquifers were postglacial fluvial gravel at 37 to 66 m, glacial gravel 70 to 84 m, interglacial fluvial gravel 112 to 126 m, glacial and interglacial gravel 145 to 164 m, interglacial gravel 193 to 210 m, and interglacial beach gravel at 244 to 256.5 m. Silt and clay strata form aquicludes and Holocene marine transgression and progradation deposits form the confining strata. Static water levels did not show any significant change with depth, suggesting hydraulic connection despite apparent separation of aquifers by impermeable aquicludes.

Depth Range (m)	Climate	Age in Years (B.P.)
0.00 - 71.50	Postglacial marine and fluvial	Present day to 14000
71.50 - 90.20	Last glaciation fluvial	14000 to 70000
90.20 -144.00	Last interglacial	70000 to 125000
144.00 -154.00	Penultimate glacial fluvial	125000 to 200000
154.00 -256.00	Penultimate interglacial	200000 to 250000

Table 4.3: Climatic stages penetrated by the Tollemache Orchard testbore (well no. 3697).

The testbore was allowed to flow, usually overnight, and water samples were collected from the six aquifers for chemical and isotope (oxygen 18 and tritium) analyses (see Brown 1993). The beach gravel aquifer at 244 to 256.6 m was pumped for 10 hours to clear very fine sand suspended in the water and the residue of "mud" used in the rotary drilling process, prior to sampling. The results of chemical analyses are summarised in Table 4.4.

The proportion of several cations and anions (including iron) present in the water increased at 122.5 m. This suggests a longer residence time allowing for interchange of chemical components between the groundwater and the sediments of the aquifers and aquicludes. An increase in free carbon dioxide with depth was observed, indicating increasing redox potential. This suggests increasing degree of aquifer confinement with depth. The aquifer at 162 m yielded a significant flow of methane, which was probably derived from the decomposition of carbonaceous beds interbedded with the interglacial gravel, again indicating an increase in redox potential.

The oxygen 18 analyses suggest all the groundwater is derived from the Ngaruroro River. The tritium concentrations confirm decreasing flow rates with depth. Tritium analyses of groundwater from a depth of 56 and 77 m show that the water is of post-thermonuclear origin (post-1955). At 115 m, the groundwater is a mixture of mainly pre-thermonuclear water (pre-1955) and some post-thermonuclear water; while deeper groundwater is entirely pre-thermonuclear.

Determinands	**Units**	**Lab. No. 9374**	**Lab. No. 9400**	**Lab. No. 9415**	**Lab. No. 9417**	**Lab. No. 9573**	**Lab. No. 9584**	**Lab. No. 9842**
Date		22/10/92	04/11/92	17/11/92	24/11/92	09/02/93	16/02/93	04/05/93
Depth	m	55	77	116	122.5	152	163.5	248
Temperature	oC	13	12	12				
pH		7.7	7.65	7.65	7.75	7.6	7..30	8.05
Conductivity	mmho/cm	340	290	300	550	410	700	450
Alkalinity	g/m^3	96	91	135	236	195	333	170
Chloride	g/m^3	22	32	40	10	10	19	52
Sulphate	g/m^3	13	11	<1	1	7.0	11	9
Hardness	g/m^3	122	106	240	209	158	271	144
Sodium	g/m^3	17	15	16	23	22	31	41
Potassium	g/m^3	1.9	1.7	3.4	5.3	5.4	8.3	2.6
Magnesium	g/m^3	7.5	6.2	4.2	8.5	10.2	19.6	17.2
Calcium	g/m^3	36	32	89	70	46	76	46
Iron	g/m^3	0.2	0.3	0.5	0.8	3.3	4.4	0.6
Manganese	g/m^3	<0.1	<0.1	0.3	0.6	0.7	1.5	0.1
Nitrate (N)	g/m^3	6.2	4.7	<1		1.1	0.7	0.9
Free CO2	g/m^3	4.0	5.0	7.5	9.0			

Table 4.4: Tollemache Orchard testbore (well no. 3697) groundwater quality variation with depth.

Grant-Taylor & Taylor (1967) report TR analyses of samples collected from the Heretaunga Plains aquifers in 1957 and 1964 which include an estimate of travel time for the shallow artesian aquifer at Clive of 7 years since the water seeped into the groundwater aquifers from the Ngaruroro River recharge area. The Tollemache Orchard testbore groundwater TRs show a significant ageing and longer travel time for the deeper groundwater compared with the 7 year groundwater travel time from the Clive well. This may be a result of one or both of the following:

- Increasing groundwater abstraction from the upper aquifer may induce faster flow of water from the recharge area.
- Decrease in aquifer permeability with depth.

Because of the shallow depositional gradient of the aquifers, only the upper (early postglacial - late last glaciation) gravel aquifers are likely to outcrop on the sea floor and discharge fresh water into the ocean in Hawke Bay (Fig. 2.25). Therefore through flow in deeper aquifers is likely to be maintained only by relatively slow upward leakage through aquitards and aquicludes.

Five piezometers were installed when the casing was withdrawn (Fig. 4.9) in September 1993 at 48, 88, 113, 152 and 221 m. A two channel continuous water level recorder was installed to measure piezometric pressures from the piezometers at 48 and 88 m. To date water pressures show similar fluctuations (Fig. 4.10) suggesting a hydraulically interconnected aquifer system.

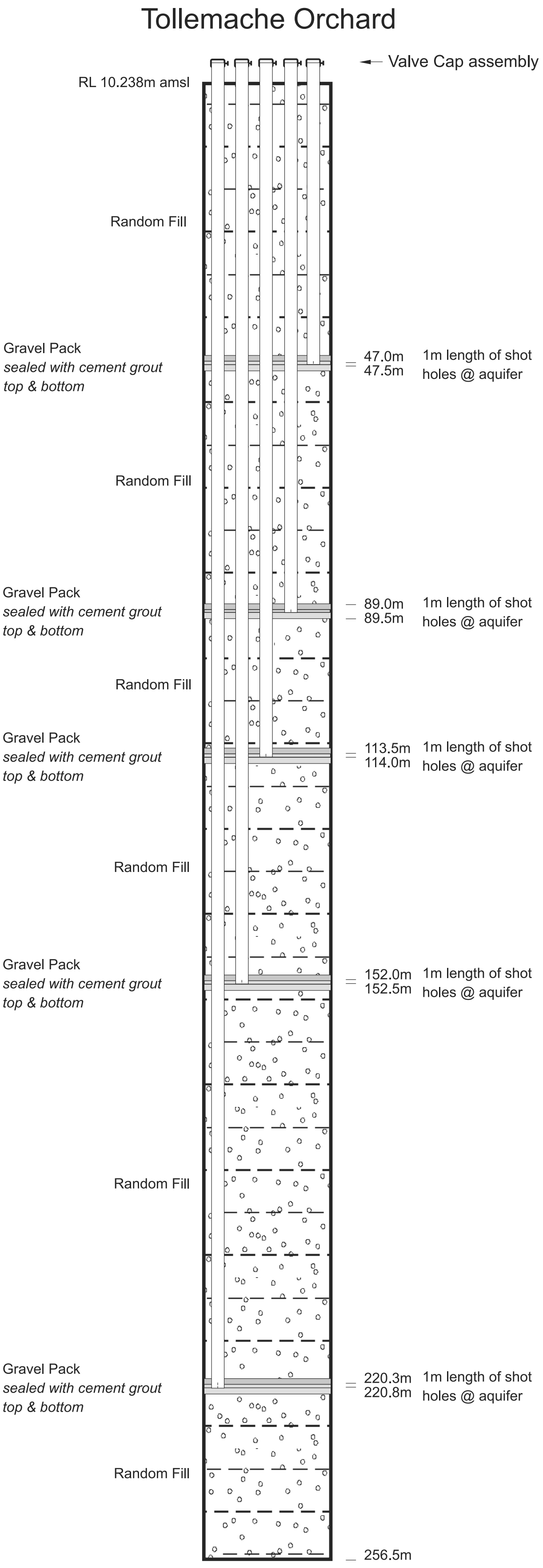

Figure 4.9: Tollemache Orchard testbore piezometer construction details.

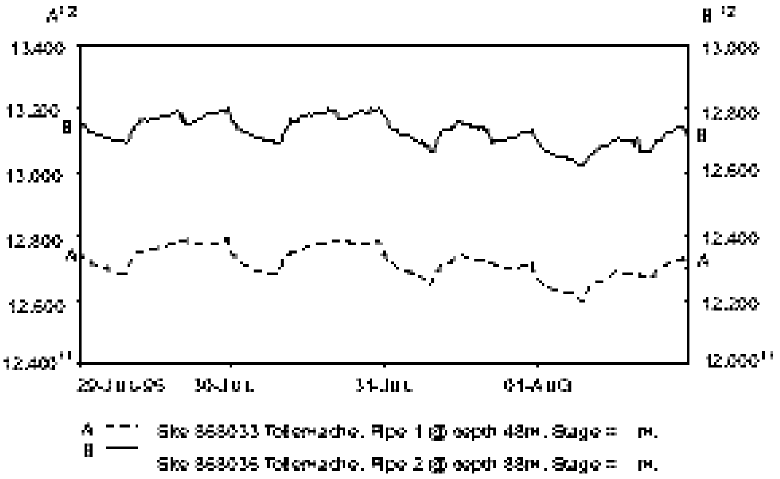

Figure 4.10: Tollemache Orchard testbore piezometric pressure variation with depth.

4.4.3 Awatoto Testbore (Well No. 3699)

Awatoto testbore was drilled by Hill Welldrillers Ltd., Hastings. The site was on the stopbank about 2 km upstream of the mouths of the Tutaekuri and Ngaruroro rivers and about 2 km downstream of the Brookfield Bridge over the Tutaekuri River. Drilling began on 10 January 1994 using a RB 27 cable tool rig and continued intermittently to a depth of 254 m before “tight” and difficult drilling conditions stopped drilling 46 m short of the target depth on 7 December 1994.

The detailed well log is presented in Brown & Gibbs (1996). Figure 4.11 summarises the well log and the paleoenvironment and aquifer details. Because the Awatoto testbore was sited near the Hawke Bay coast abundant fossiliferous material was present in the beach, estuarine and lagoonal sediments that form the postglacial confining strata capping the fluvial gravel aquifer, as well as in the interglacial marine strata forming the aquicludes. 264 samples with potential to provide an age or contribute to a paleoenvironment determination were collected. Strata were correlated with the sequence penetrated by the Tollemache Orchard testbore 11 km to the southwest and a broad hydrogeological framework was established for the late

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[11] These and all subsequent continuous water level measurements are with respect to mean sea level. datum = 0

[12] In order to accommodate the range of continuous water level measurements on the same hydrograph these and all subsequent water levels are scaled individually.

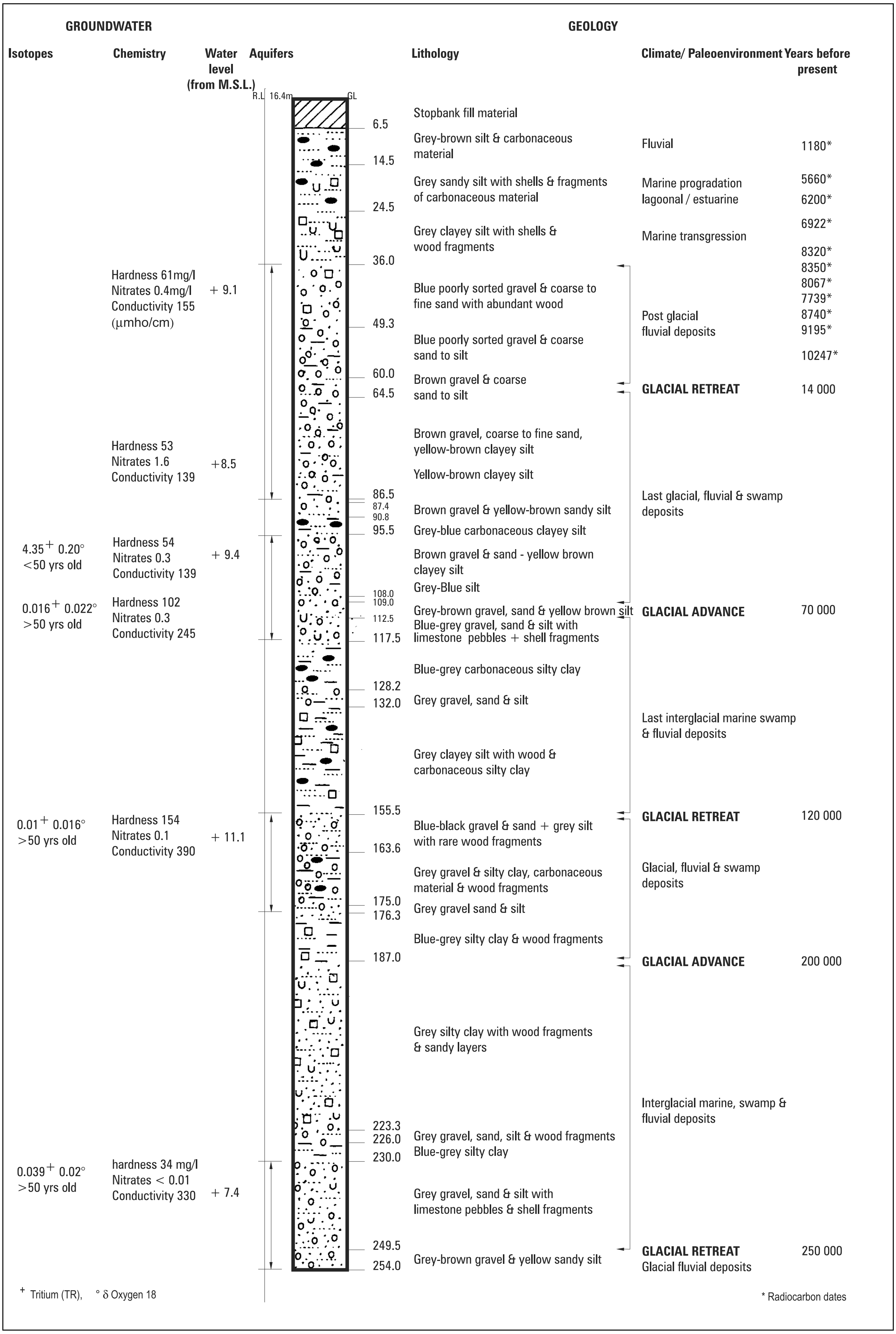


Figure 4.11 Summarised stratigraphy of Awatoto testbore.

Quaternary sediments infilling the Heretaunga depression to form the Heretaunga Plains (Fig. 4.11).

Five shell samples from 16 to 35 m depth and six wood samples from 10 m and 36 to 53m have been submitted for radiocarbon dating. These ages and other Heretaunga Plains radiocarbon dated material from water wells and testbores (Table 4.5) are plotted in Figure 4.8 and compared with the New Zealand eustatic sea level curve of Gibb (1986). These samples are observed to plot below the curve suggesting subsidence of the strata since deposition. The Awatoto testbore well log and these dates suggest that the postglacial marine transgression reached the present day Hawke Bay coast about 9000 years BP; the beach ridge (tombolo) enclosing the Ahuriri Lagoon and connecting Scinde Island to the mainland formed about 4500 years BP and infilling of the lagoon in the vicinity of the testbore site by fluvial overbank silts occurred about 2000 years BP.

A total of 125 shell samples have been examined from the Awatoto testbore by Dr A.G. Beu, IGNS. Of the shells, 47 samples from a depth of 14.5 to 35.5 m accumulated during the postglacial marine transgression and subsequent coastal progradation. The macrofauna determinations indicate changing paleoenvironments over the last 7500 years at Awatoto are typical of the paleoenvironments associated with coastal progradation. As sea level rose and transgressed over the land westward migration of the coast is indicated by the estuarine mud flat fauna from 32 to 35.5 m and the change to sandy tidal channel and then open embayment fauna at 23 to 30 m. Progradation produced a reverse of the transgression sedimentation sequence with open embayment to sand beach to bay-bar at 19 m. Tidal channel fauna were observed between 16 to 18.5 m. These were overlain with intertidal estuarine mud-flat fauna and swamp and river overbank silt deposits. From 64.5 to 117.4 m almost all fossils observed were reworked Nukumaruan fossils which are present in the Scinde Island Limestone or mudstones that occur further inland. The few *in-situ* shells are species typical of the surf zone of open beaches and could be contemporaneous with beach gravels. From 187.0 to 222 m paleoenvironments associated with changing more sheltered water depths were observed. From 234.5 to 242.5 m gravel with common pebbles of Nukumaruan shelly conglomeratic limestones and abraded shells possibly derived from a Te Aute facies limestone (Dr A.G.Beu, pers. comm.) were observed.

Seventy seven samples from throughout the sequence were collected for palynology determinations and submitted to E.M. Crouch and Dr. D.C. Mildenhall, IGNS for investigation. The samples varied considerably in spore/pollen and dinoflagellate content. The preservation was poor in most cases, indicating damage caused by the fluvial deposition processes. Abundant macerated, very fine organic debris was also present in many samples as was recycled charcoal. Many samples contained dinoflagellates, suggesting close proximity of the depositional site to the coast. It was not possible to determine the age of the samples because of the presence of recycled material which included taxa from Cretaceous, Paleogene and Neogene sediments. Most of the samples contained *in situ* taxa associated with a warm frost-free climate. There were some groups of samples where the total pollen assemblage suggested the temperate climate taxa were recycled and the paleoenvironment was that of a cold climate (Dr D.C. Mildenhall and E. M. Crouch, pers. comm.).

Eightyone wood samples were collected. These have not been identified as they are unlikely to yield age or paleoenvironment diagnostic information. An ash layer at 246 m did not contain enough volcanic glass for a tephra age determination (Dr D. Eden, Landcare, pers. comm.).

Microfauna samples from 201 and 218.5 m were examined for nannofossils by A.R. Edwards, Stratigraphic Solutions. Both samples contained many recycled nannofossils but the 201 m sample had a few *in situ* specimens suggesting an Upper Castlecliffian to middle Haweran age range (A.R.Edwards, pers. comm.).

On the basis of strata lithologies, radiocarbon ages, fossil identifications, and paleoenvironment data, the correlations can be made between the strata penetrated by the testbore and the late Quaternary climatic stages (Table 4.5).

The Awatoto testbore encountered six flowing artesian aquifers. The aquifers encountered were:

- postglacial fluvial gravel at 36 to 64.5 m;
- glacial gravel 75 to 113 m;
- interglacial gravel 113 to 118 m;
- glacial gravel 128 to 132 m;
- interglacial gravel 154 to 163.5 m;
- beach gravel 239 to 254 m.

Silt and clay strata form aquicludes while the Holocene marine transgression and progradation deposits form the confining strata.

Depth Range (m)	Climate	Age in Years (B.P.)
0.00 - 64.50	Postglacial marine and fluvial	Present day to 14000
64.50 - 113.00	Last glacial fluvial	14000 to 70000
113.00 - 117.00	Last interglacial	70000 to 125000
117.00 - 132.00	Penultimate glacial fluvial	125000 to 200000
132.00 - 254.00	Penultimate interglacial fluvial and marine	200000 to 250000

Table 4.5: Climatic stages penetrated by the Awatoto testbore (well no. 3699).

The testbore was pumped until the water had cleared sufficiently of suspended sediments for the water to rise above the top of the casing and then allowed to flow naturally (usually overnight) and water samples were collected from the aquifers for chemical and isotope (oxygen 18 and tritium) analyses. Samples were collected from 42, 79, 99.5, 117, 162, and 245 m. The results of chemical analyses are summarised in Table 4.6. The proportion of several cations and anions (including iron) present in the water increased significantly below 117 m. This suggests higher mineralisation due to longer residence times. The aquifers at 162 and 245 m show increased alkalinity, chloride, hardness, sodium, iron and manganese suggesting confinement and an increase in redox potential.

The oxygen 18 analyses of samples from 99.5, 117 and 162 m suggest the groundwater is derived from the Ngaruroro River. The low tritium concentrations below 117 m depth confirm the long term groundwater residence time. Tritium analyses of groundwater down to 99.5 m depth suggest that the water is of post-thermonuclear origin (post-1955). At 117 m, the groundwater is entirely pre-thermonuclear.

The chemical and isotope data suggest a longer groundwater residence time and a slower flow below 117 m depth and perhaps a “blind” aquifer without an offshore outflow. Increasing piezometric pressure with depth below 117 m suggests that there is potential for groundwater from the deeper aquifers to leak upward through the sequence of aquitards and aquicludes.

Determinand-sin g/m3	Units	Lab. No. 10591	Lab. No. 10592	Lab. No. 10629	Lab. No. 10630	Lab. No. 10720	Lab. No. 11655	Lab. No. 11678
Date		25/01/94	25/01/94	09/02/94	09/02/94	07/03/94	22/09/94	26/09/94
Depth	m	42	79	99.5	117	162	245	245
Temperature	oC	14	14		14	14.5	15	15
pH		7.52	7.61	7.7	7.3	7.2	8.06	8.4
Conductivity	mmho/cm	155	140	139	245	390	330	330
Alkalinity	g/m3	66	53	48	120	183	137	138
Chloride	g/m3	8	7	8	8	12	30	29
Sulphate	g/m3	13	15	18	6	6	2	2
Hardness	g/m3	61	53	54	102	154	34	24
Sodium	g/m3	13	11	10	15	24	72	68
Potassium	g/m3	1.8	1.6	1.3	2.5	4.3	1.6	1.6
Magnesium	g/m3	3.1	3	<0.1	0.1	0.4	2.2	1.8
Calcium	g/m3	19	16	17	34	48	10	7
Iron	g/m3	<0.1	0.2	0.1	0.4	2.0		0.2
Manganese	g/m3	<0.1	<0.1	<0.1	0.1	0.4		<0.1
Nitrate (N)	g/m3	0.4	1.6	0.3	0.3	0.1	<0.1	0.02

Table 4.6: Awatoto testbore groundwater quality variation with depth.

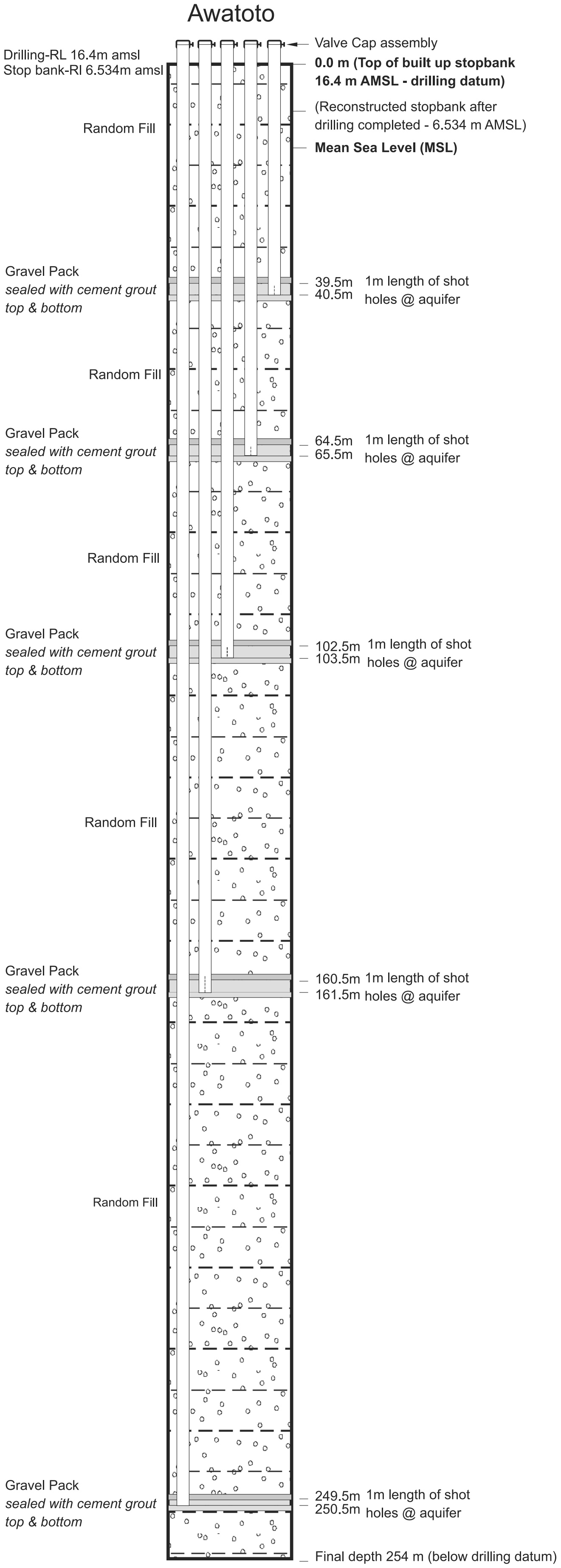


Figure 4.12: Awatoto testbore Piezometer construction details.

Piezometers were installed when the casing was withdrawn in May 1995 and water levels can be monitored at 39, 66, 102, 160 and 250 m depths (Fig. 4.12).

A five channel continuous water level recorder was installed in October 1995 to measure piezometric pressures at 39, 59, 101 and 160 m (Fig. 4.12). Figure 4.13 shows the continuous water level data from these piezometers from 29 September 1995 to 2 October 1995. Unlike the decreasing piezometric pressures with depth observed in the Flaxmere and Tollemache Orchard testbores, increasing piezometric pressures with depth in the upper three piezometers to 160 m in the Awatoto testbore support the concept of a hydraulically interconnected system with flow in deeper aquifers maintained by upward leakage through aquitards and aquiclude. The water level in all piezometers fluctuate with tides, but with fluctuation amplitude being damped with depth.

4.5 GEOLOGICAL CROSS SECTION DATA

Nine geological cross sections were constructed using well log data. The location of these geological cross section lines are shown in Figure 4.14 . The long geological cross sections show the variation in regional stratigraphy as depositional environments and processes adjusted to changes in climate, sea level and tectonism, and the extent and lateral continuity of aquifers. The short geological cross sections provide clues in understanding the localised changes in aquifer overlap areas and hydraulic interconnections and the recharge sources.

This section will discuss the geology and stratigraphy of five long geological cross sections and their implication in understanding various aspects of the aquifer system. These long cross sections include data from 134 wells in the depth range of 25 to 250 m located within a distance range of up to 300 m from the section line.

Formal stratigraphic units have not been defined for the late Quaternary deposits underlying the Heretaunga Plains because of the uncertainty of the relationship with the strata of the Kidnappers Group. The cross section correlations have been accomplished by using the radiocarbon ages (Table 4.2) and the paleoenvironmental determinations of the samples obtained from the Flaxmere, Tollemache Orchard and Awatoto testbores. The paleoenvironmental determinations allow correlation with the climate stages. These are:

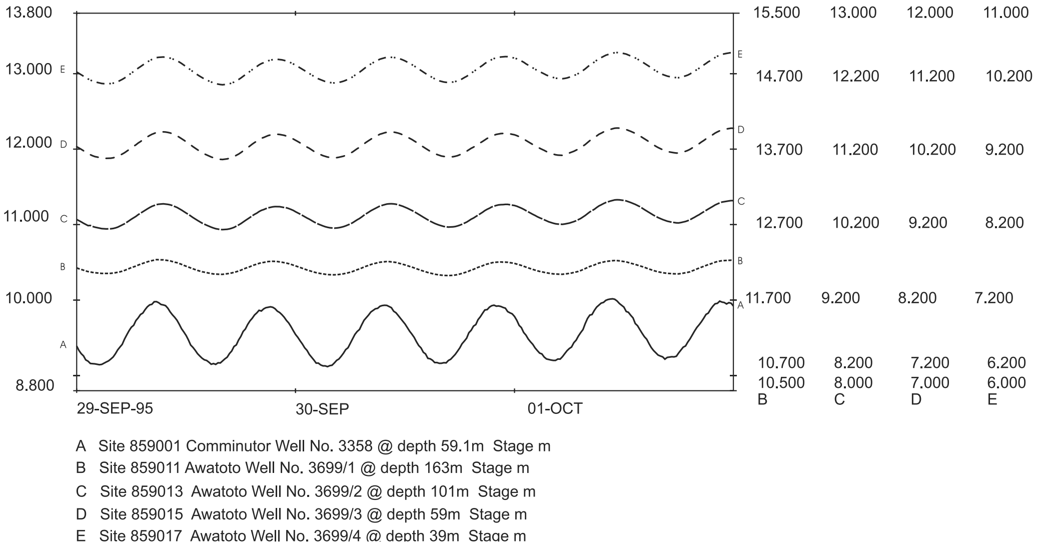


Figure 4.13: Awatoto testbore piezometric pressure variation with depth.

- Penultimate interglacial (250 000 - 200 000 years BP).
- Penultimate glacial (200 000 - 125 000 years BP).
- Last interglacial (125 000 - 70 000 years BP).
- Last glacial (70 000-14 000 years BP).

The postglacial period (14 000 years to present) deposits are subdivided into river (fluvial) and marine related depositional units. The postglacial marine deposits have a transgressional component (PGM 2) which accumulated 9000 to 6500 years BP when the rising sea level was advancing over the Heretaunga Plains land surface, and a progradational component (PGM 1) which accumulated when sea level stabilised at close to the present day level 6500 years BP and the coastline was building out to the present position. Also it is possible to recognise and correlate beach deposits (predominantly beach gravels - PGB) associated with the establishment of beach ridges and the tombolos connecting Scinde Island to the mainland.

The postglacial fluvial deposits can be subdivided into units based on river deposition response to several influences including shortening of course imposed by rising sea level, tectonism, volcanic eruptions (particularly Taupo 1400 years BP) and severe storms in their catchments. Apart from sea level rise (see Fig. 2.4) and the record of dated volcanic eruptions, only historic observation is available as an indication of the effects of earthquakes and storm flood events. Four depositional units are shown on the cross sections (PGF 1-4) and within these, three gravel channel layers (PGG 1-3) persist over relatively wide areas. The gravel channels probably are the product of reworking and redeposition of fluvial floodplain deposits by meandering rivers criss-crossing over the flood plain. It is not possible to assign definite age constraints on these depositional units, but their relationship to the more tightly age-constrained postglacial marine deposition units allows a broad age range to be defined.

PGF 1 and PGG 1	- present to 2000 years BP.
PGF 2 and PGG 2	- 2000 to 6500 years BP.
PGF 3 and PGG 3	- 6500 to 9000 years BP.
PGF 4	>9000 years BP.

Figure 4.15, cross section legend, summarises the correlation units.

In terms of hydrogeology and aquifers the beach gravels and reworked channel gravel deposits (PGG) and the glacial-postglacial and glacial-interglacial transition gravel deposits provide the greatest potential for the occurrence of high yielding aquifers. There is a general pattern (see Fig. 5.4) for the higher yielding aquifers to be in the central part of the Heretaunga Plains rather than on the margin adjacent to the hills.

4.5.1 Napier - Haumoana Section

(See Fig. 4.16)

This coastal section extends over 15 km from the Courthouse well (well no. 1776), Hastings Street, Napier to well no. 1150, Clifton Road, Haumoana. 23 wells make up the section including the 254 m deep Awatoto testbore (well no. 3699) which penetrated penultimate interglacial marine deposits from a depth of 132 m. Between Awatoto and Napier, wells penetrate last glaciation fluvial deposits at about 70 m. Several wells obtain groundwater from a gravel aquifer within the last glaciation deposits. The overlying postglacial fluvial deposits (PGF 3, PGF 4) contain gravel aquifers which are a product of deposition and redeposition in the postglacial period prior to the marine transgression. These postglacial fluvial gravel aquifers are tapped by wells at the coast from the Tutaekuri - Ngaruroro River mouth south to Haumoana. Towards Napier there is more sand and silt matrix binding the fluvial gravel. This suggests that the main river channels with gravel deposition and reworking were in the area from Awatoto to Haumoana in the immediate postglacial period. Towards Napier fluvial deposition would have been constrained by the limestone promontory that connected Napier Hill (Scinde Island) to the mainland.

The postglacial fluvial aquifer (PGG 1) at the southern (Haumoana) end of the section is probably a Tukituki River channel with groundwater derived from that river. The section intersects near surface beach gravels north of the Ngaruroro - Tutaekuri River mouth. These are formed as part of the gravel spits that built up the tombolo that connected Scinde Island to the mainland 4500 years BP. Lagoonal silts and sands accumulated in the lagoon on the land side of the beach ridge system. Since European settlement and before the 1931 earthquake the Tutaekuri River course was adjacent to the beach ridge with channels where Wellesley Road, Georges Drive and Riverbend Road are today.

There are also two short sections (Figs. 4.17 & 4.18) which extend from the Hawke Bay coast south of Napier Hill northwestwards towards the former Ahuriri Lagoon. Typically a veneer of fluvial silt and sand overlies postglacial marine progradational and transgressional deposits, pre-transgressional fluvial deposits and the last glaciation predominantly gravel deposits. A conspicuous feature of these sections is the sandstone / limestone ridge that formerly connected Napier Hill (Scinde Island) to the mainland about 6500 years BP. This ridge forms a “divide” that prevented fluvial gravel deposition by the Tutaekuri and Ngaruroro rivers extending to the north and as such marks the northern boundary of the Heretaunga Plains aquifer system. The limestone is fractured and jointed and forms a distinct peripheral aquifer.

4.5.2 Napier - Ngatarawa Section

(See Figure 4.19)

The Napier end of this southwest-northeast section is the coastal depositional environment adjacent to the limestone promontory with beach ridge gravel deposits and lagoonal silt and sand. There is high proportion of silt and sand in the postglacial fluvial deposits that accumulated prior to the marine transgression. Further inland (southwest), the cross section intersects postglacial gravel channels. From Fernhill (well no. 1493) to Ngatarawa (well no. 1191) fluvial gravels immediately underlie the ground surface and are former historical channels of the Ngaruroro River.

Wells in the southern and western suburbs of Napier intersect sandy gravel with peat and lagoonal silt extending to 80 m depth and constitute a deep confined aquifer. These predominantly estuarine and lagoonal deposits have been deposited over Tertiary limestone, sandstone and mudstone. There are interbedded fluvial deposits derived from the Tutaekuri River which discharged into the Ahuriri Lagoon during the last 6500 years. Figures 4.17 and 4.18 show two geological cross sections across South Napier to Onekawa.

4.5.3 Roys Hill - Havelock North Section

(See Figure 4.20)

This northeast - southwest section is parallel to the groundwater flow from the Ngaruroro River major recharge area across the Heretaunga Plains. The section line follows former Ngaruroro River channels and near surface gravel channels are common. In the Flaxmere area where the confining fluvial (PGF 2 - PGF 3) and predominantly silt and marine silt and clay (PGM 2 - PGM 1) impede groundwater flow in the gravel aquifers, groundwater overflow from the aquifers at the unconfined-confined boundary forms springs which are the source of the local streams and creeks (Raupare Stream, Irongate Stream, Southland Drain) that are tributaries of the Karamu Stream - Clive River system.

4.5.4 Pakipaki - Haumoana Section

(See Figure 4.21)

The Haumoana (coast) end of this southwest - northeast section has beach gravels overlying postglacial marine progradation (PGM 1) and postglacial marine transgressive (PGM 2) deposits interbedded and overlying postglacial fluvial deposits (PGF) and the interbedded fluvial gravel deposits (PGG). At the Pakipaki (southern) end of the section 6500 year BP postglacial marine transgression deposits are indicated by shellbeds. Between Pakipaki and Havelock North near surface fluvial gravel deposits are a product of deposition by the Ngaruroro River and represent a succession of river channels in the area before the 1867 flood diversion.

4.5.5 Ngatarawa - Pakipaki Section

(See Figure 4.22)
In this section at the southern margin of the Heretaunga Plains the postglacial fluvial deposits and interbedded aquifers dip gently towards Pakipaki. At the Pakipaki (eastern) end of the section shellbeds occur in some of the wells (well nos. 2721 and 2975) and are products of deposition that occurred at the shore margin at the time of the maximum inland postglacial marine transgression c. 6500 years BP. Also at the eastern end of the section there is a change in the dip of the postglacial fluvial strata so that the strata slopes gently up towards the Havelock North Hills.

Generally all cross sections show typical characteristics of a braided river channel aquifer system within postglacial fluvial and marine deposit sequence.. The degree of sorting increases toward the coast with a better defined aquifer aquiclude sequence.

Figure 4.23: Baylis Brothers Erie 22W Cable Tool rig drilling Flaxmere testbore, September 1991. *(photo: Len Brown, IGNS).*

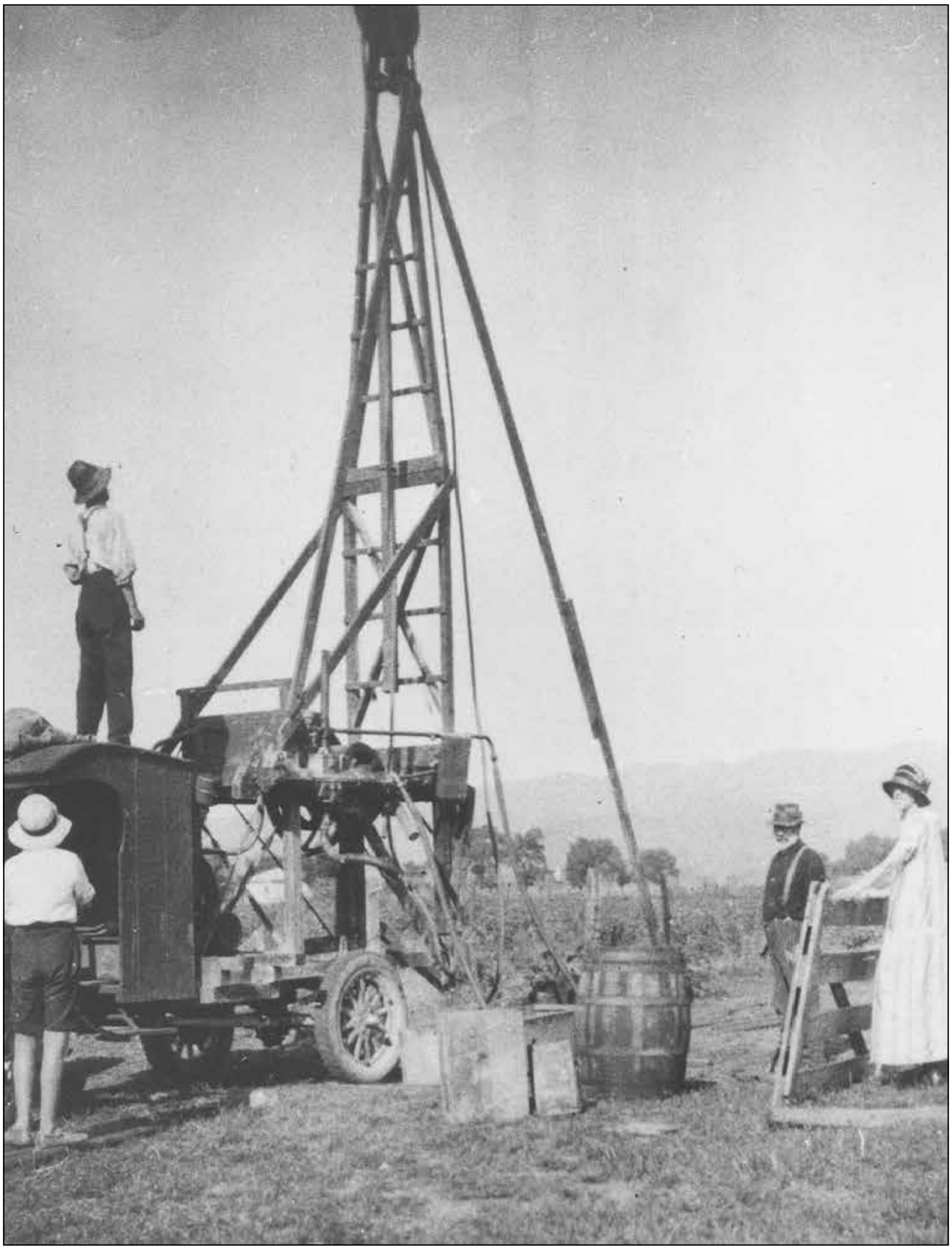


Figure 4.24: Tommy Willan setting up his rig on a drilling site on the Heretaunga Plains in the 1930's. *(photo: print donated by George Willan, Hastings).*

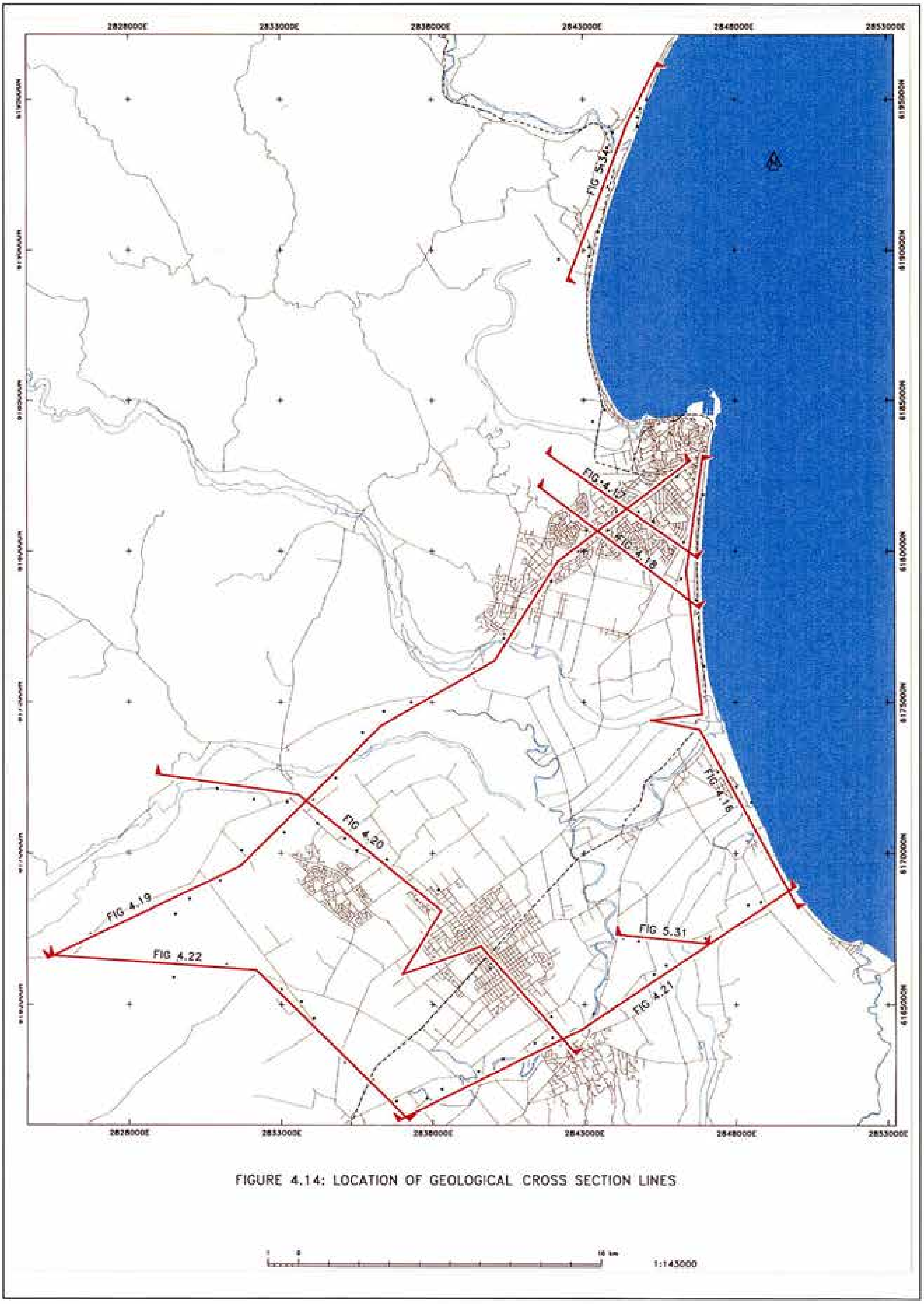
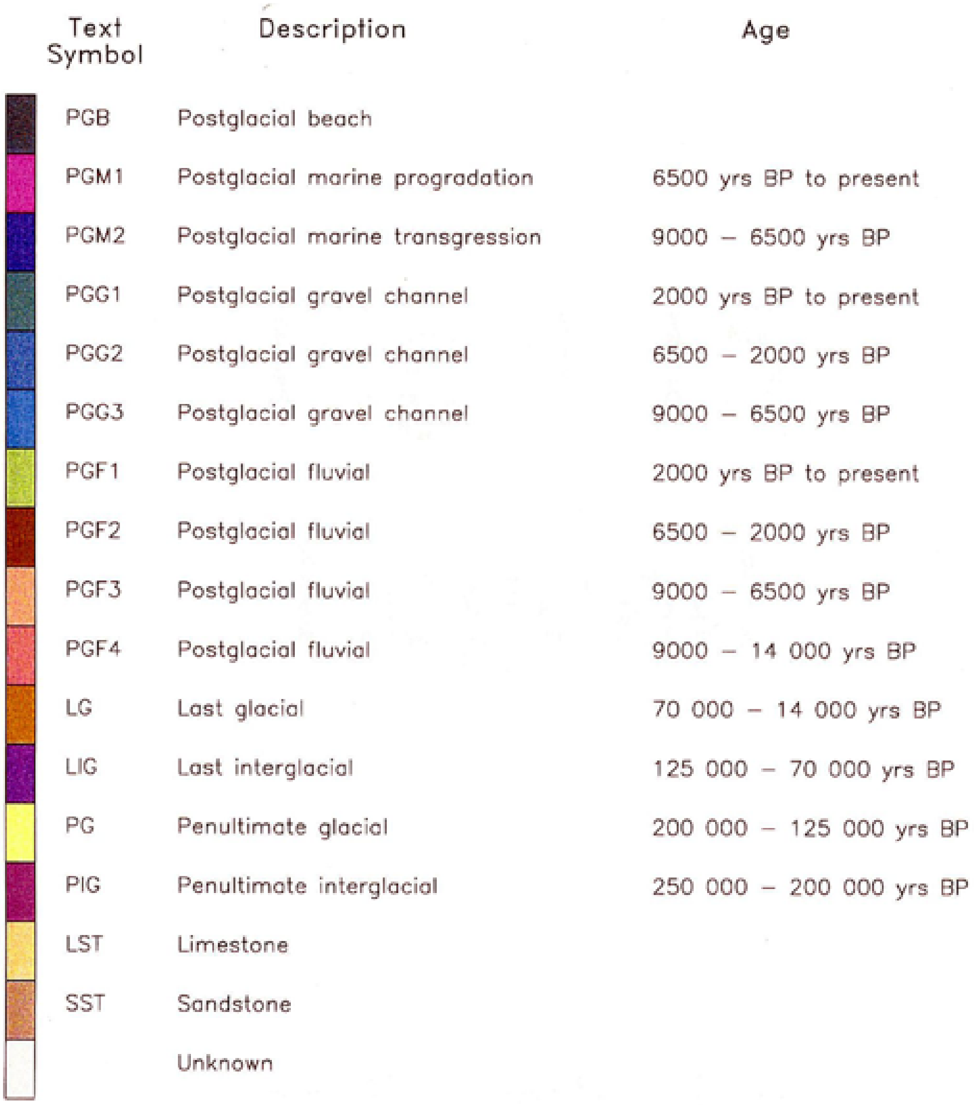


FIGURE 4.14: LOCATION OF GEOLOGICAL CROSS SECTION LINES

Figure 4.15: Location of geological cross section lines.



	Text Symbol	Description	Age
⬛	PGB	Postglacial beach	
🟪	PGM1	Postglacial marine progradation	6500 yrs BP to present
🟦	PGM2	Postglacial marine transgression	9000 – 6500 yrs BP
🟩	PGG1	Postglacial gravel channel	2000 yrs BP to present
🟦	PGG2	Postglacial gravel channel	6500 – 2000 yrs BP
🟦	PGG3	Postglacial gravel channel	9000 – 6500 yrs BP
🟩	PGF1	Postglacial fluvial	2000 yrs BP to present
🟥	PGF2	Postglacial fluvial	6500 – 2000 yrs BP
🟧	PGF3	Postglacial fluvial	9000 – 6500 yrs BP
🟥	PGF4	Postglacial fluvial	9000 – 14 000 yrs BP
🟧	LG	Last glacial	70 000 – 14 000 yrs BP
🟪	LIG	Last interglacial	125 000 – 70 000 yrs BP
🟨	PG	Penultimate glacial	200 000 – 125 000 yrs BP
🟪	PIG	Penultimate interglacial	250 000 – 200 000 yrs BP
🟨	LST	Limestone	
🟫	SST	Sandstone	
⬜		Unknown	

This legend applies to all sections (Figures 4.16 – 4.22, 5.31, 5.34).
Section lines are shown on Figure 4.14

Figure 4.16: Cross section legend

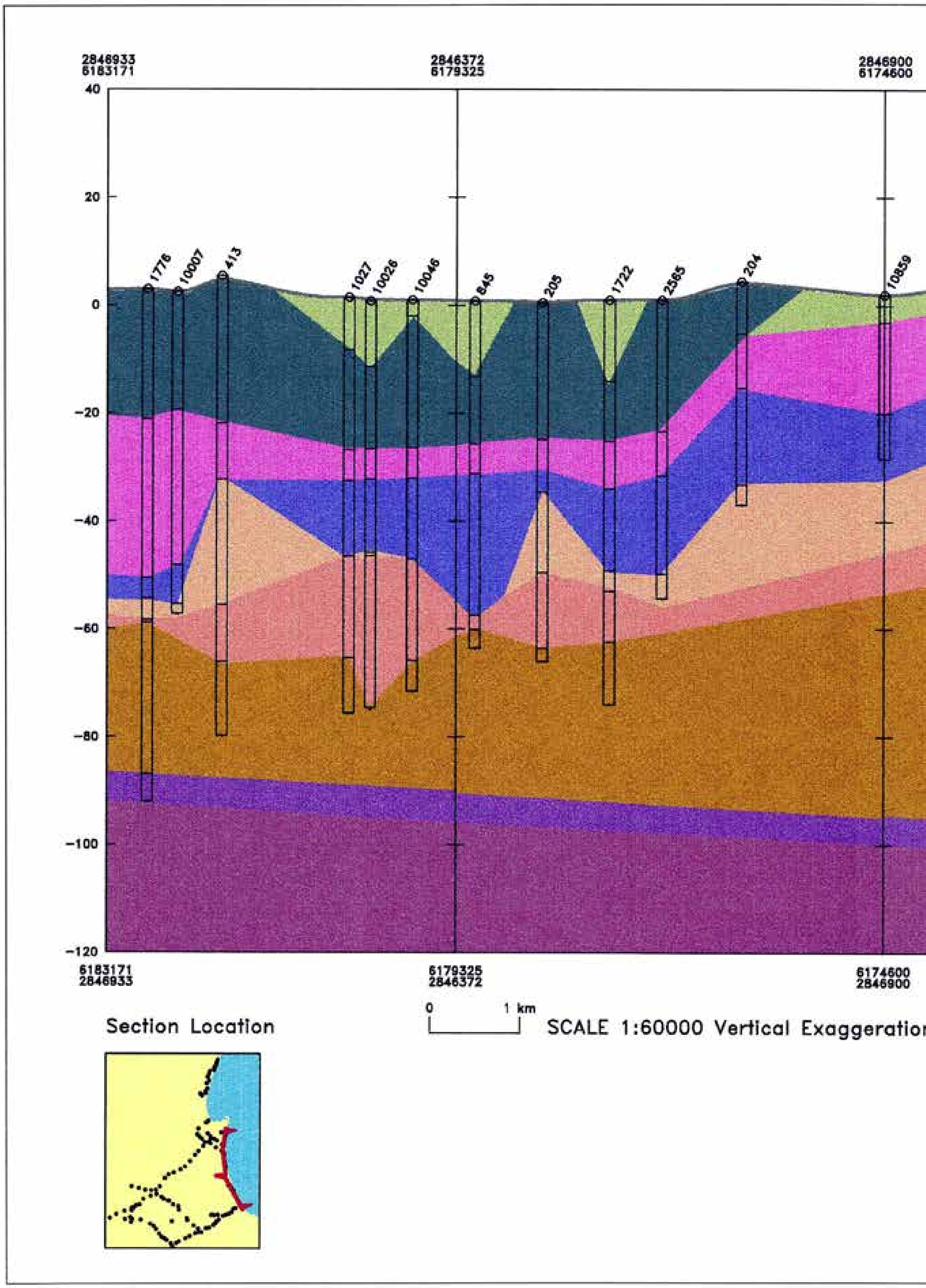
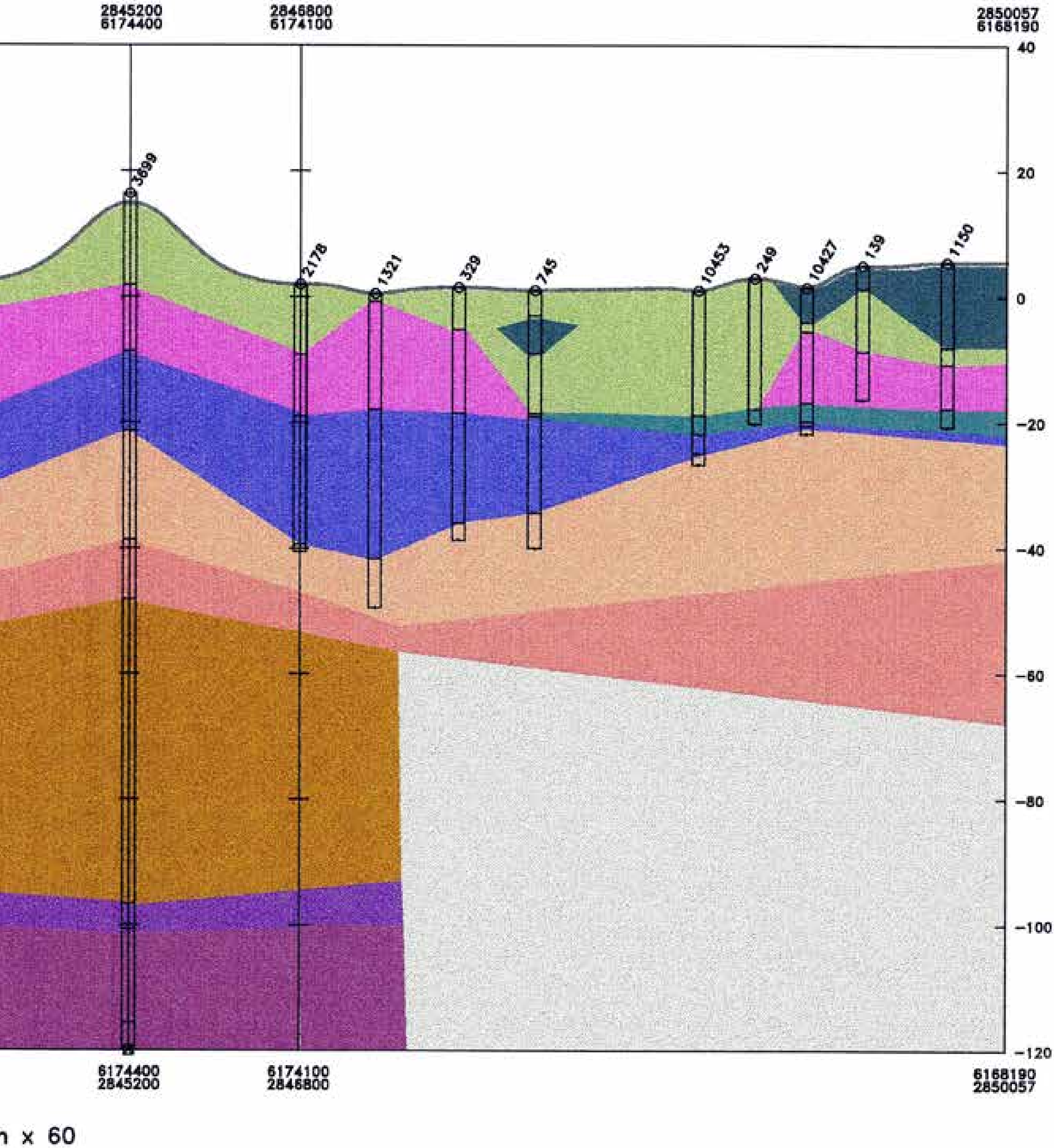


Figure 4.16: Napier - H



aumoana geological section.

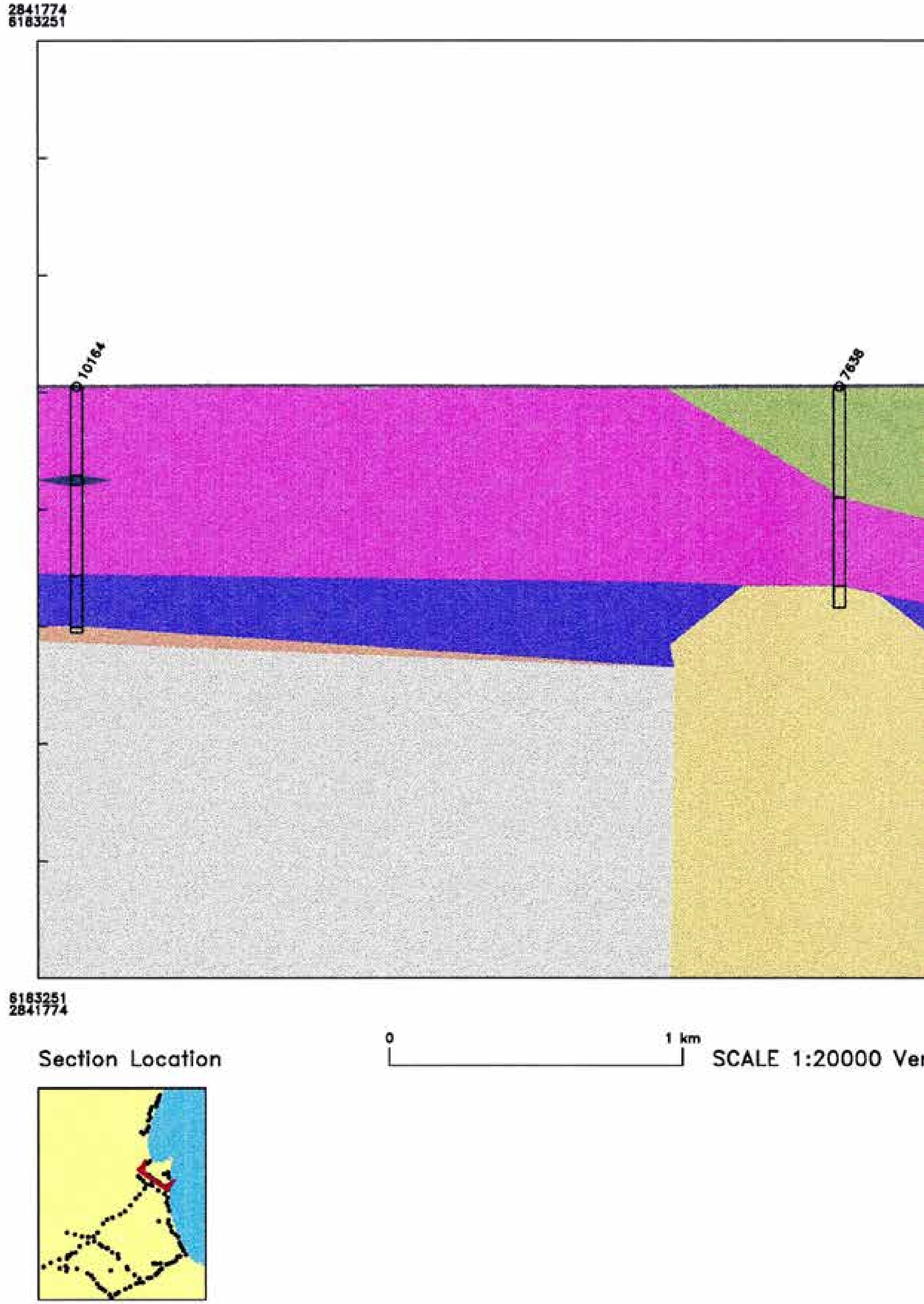
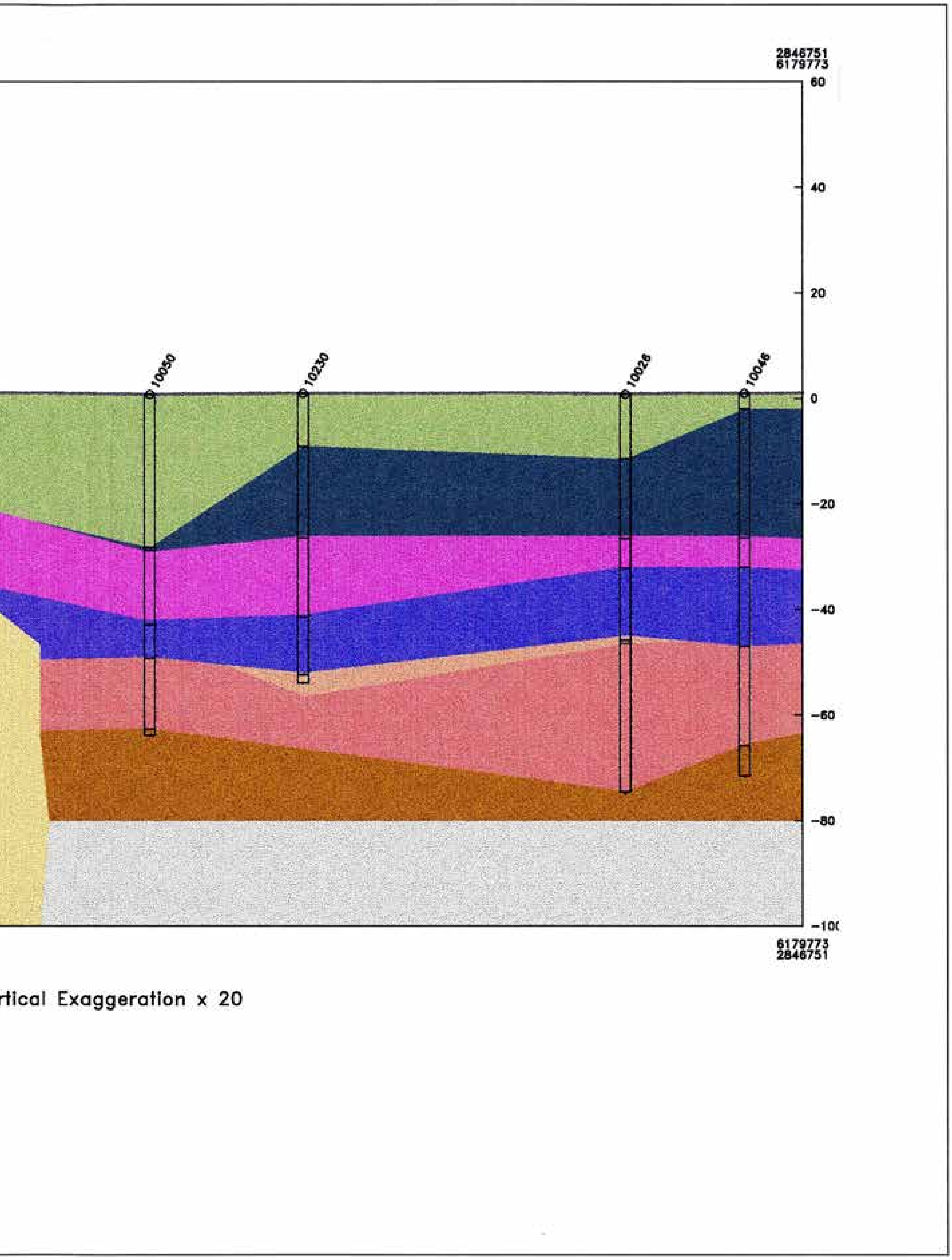


Figure 4.17: South Napier g



geological cross section 1.

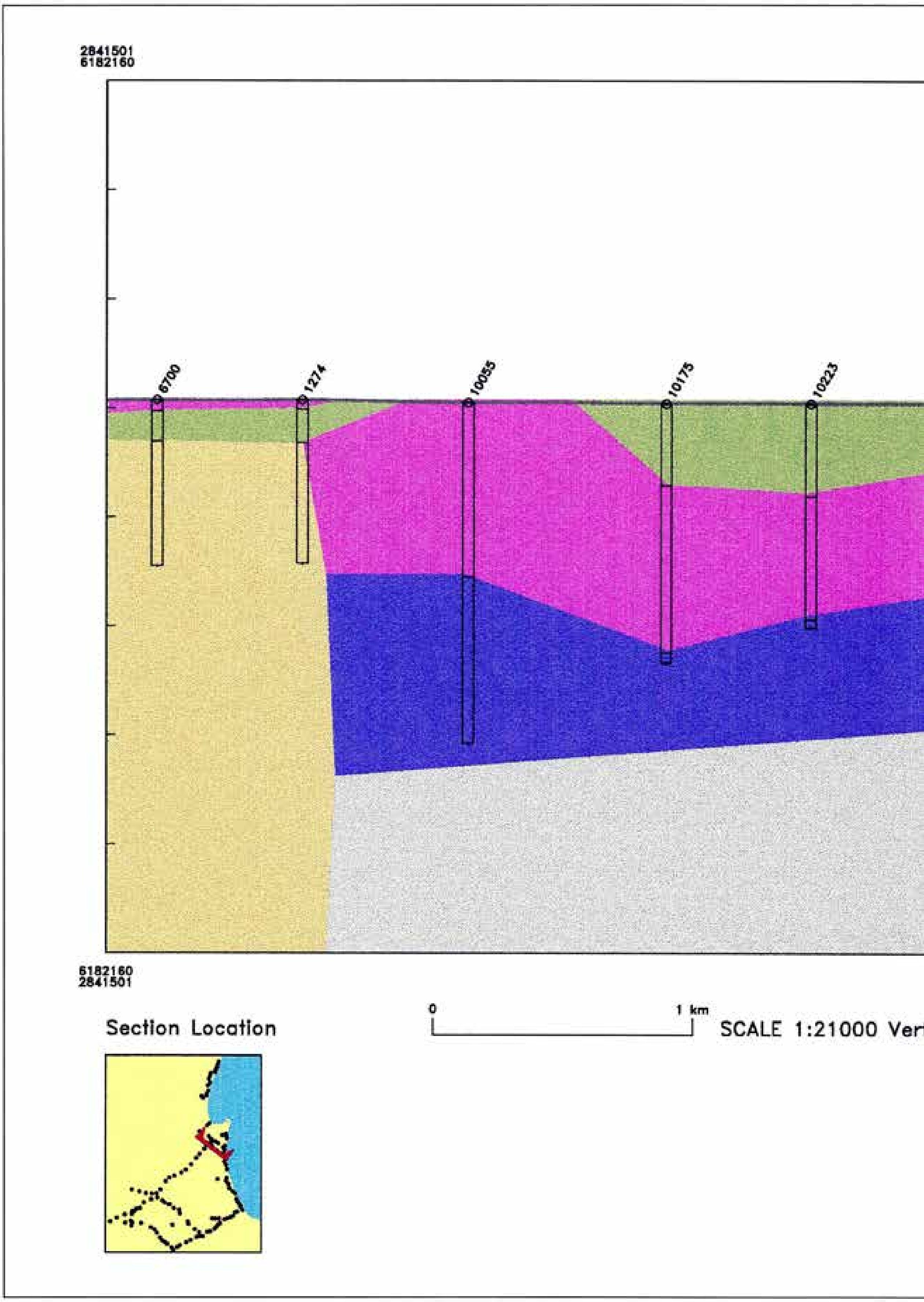
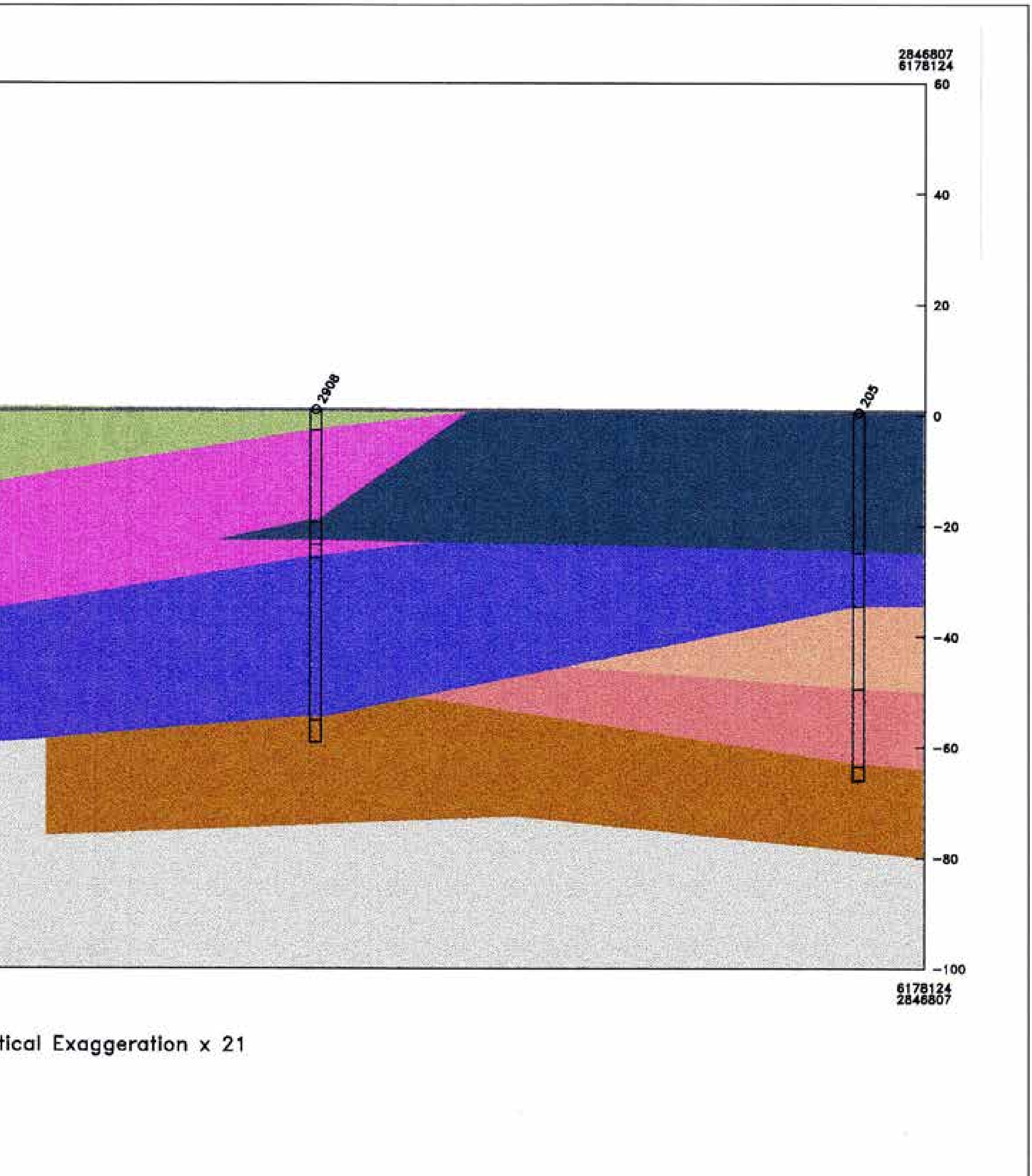
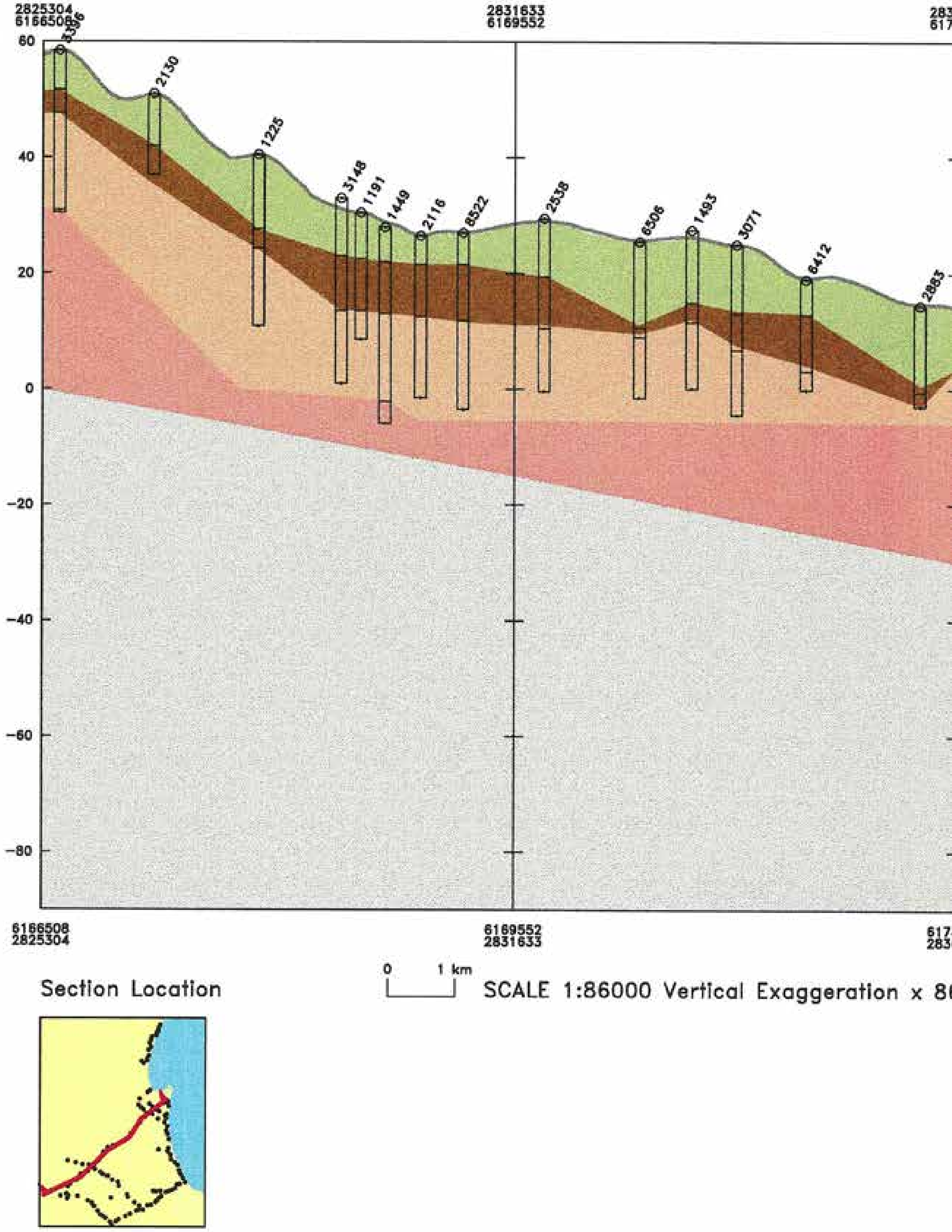


Figure 4.18: South Na

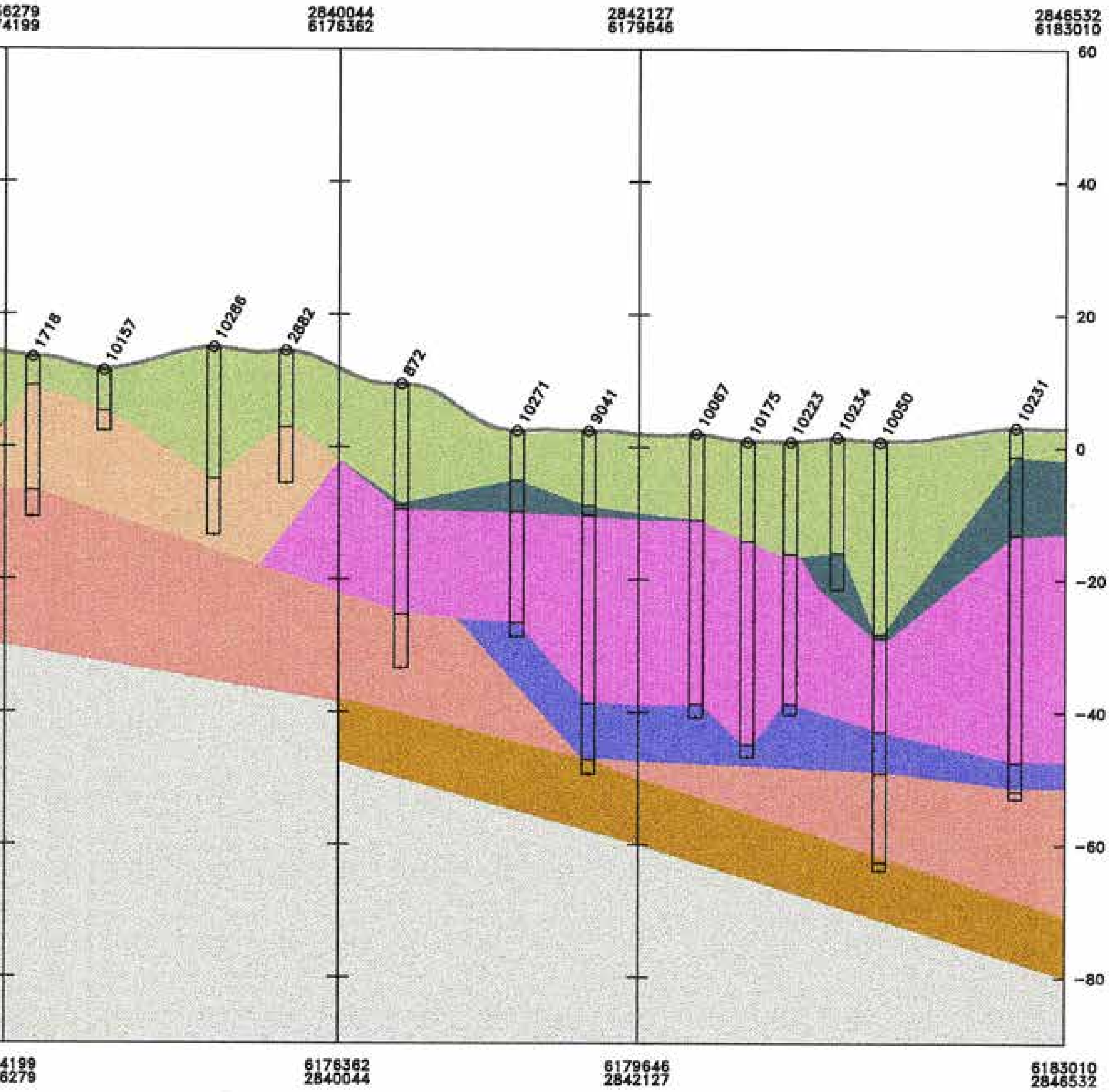


pier geological cross section



SCALE 1:86000 Vertical Exaggeration x 8

Figure 4.19: napier - Ngata



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arawa geological section

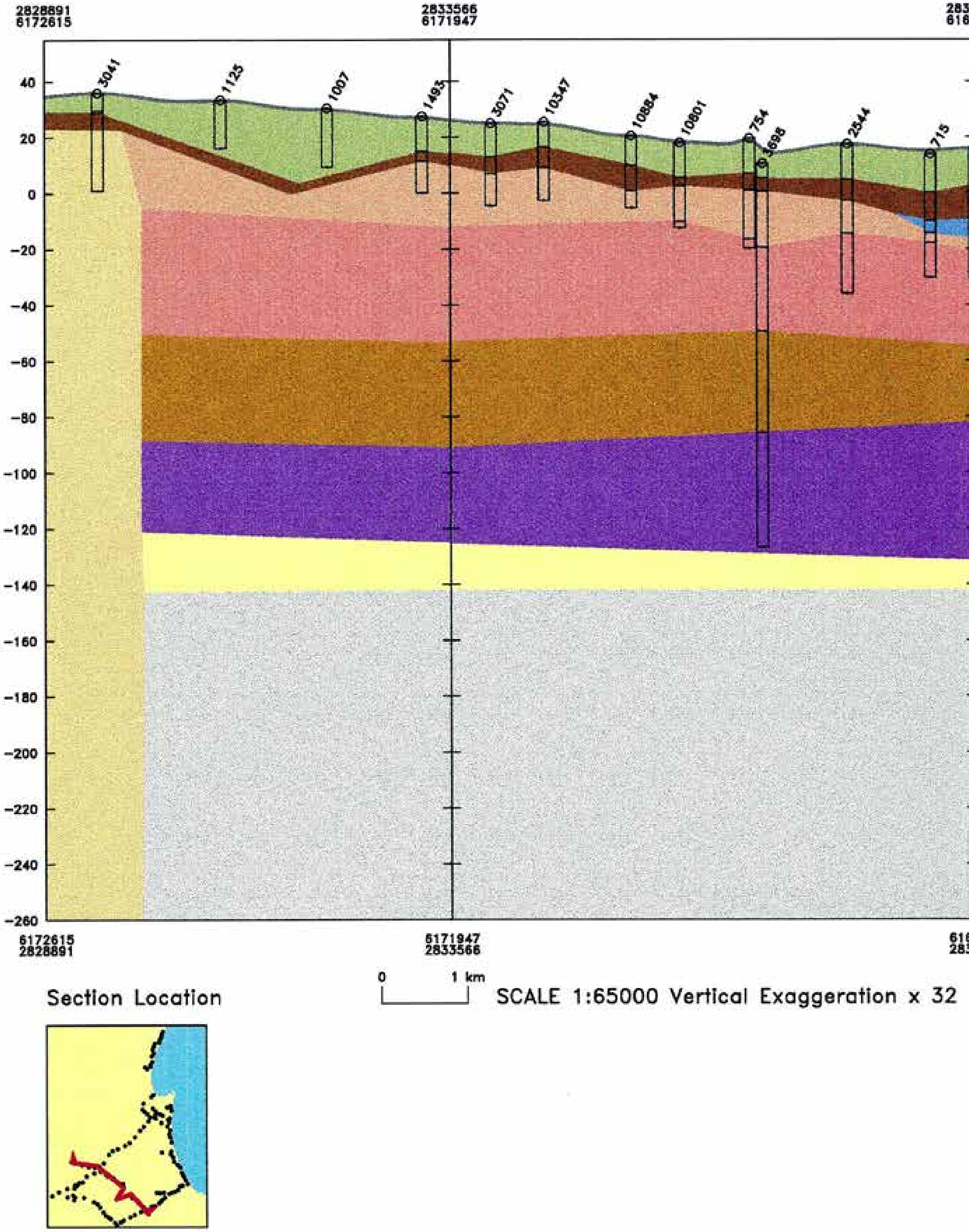
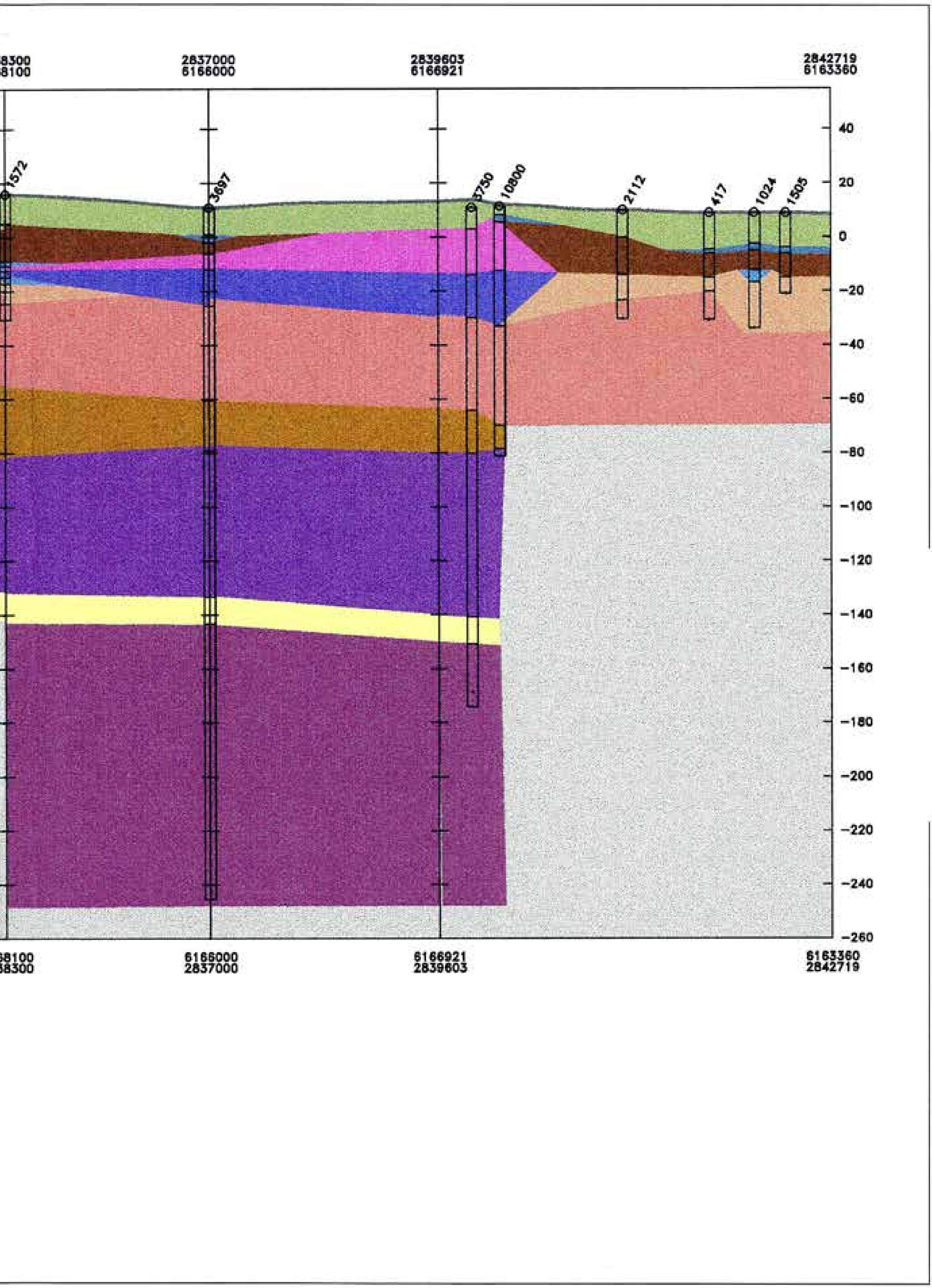


Figure 4.20: Roys Hill - Havelock



North geological section.

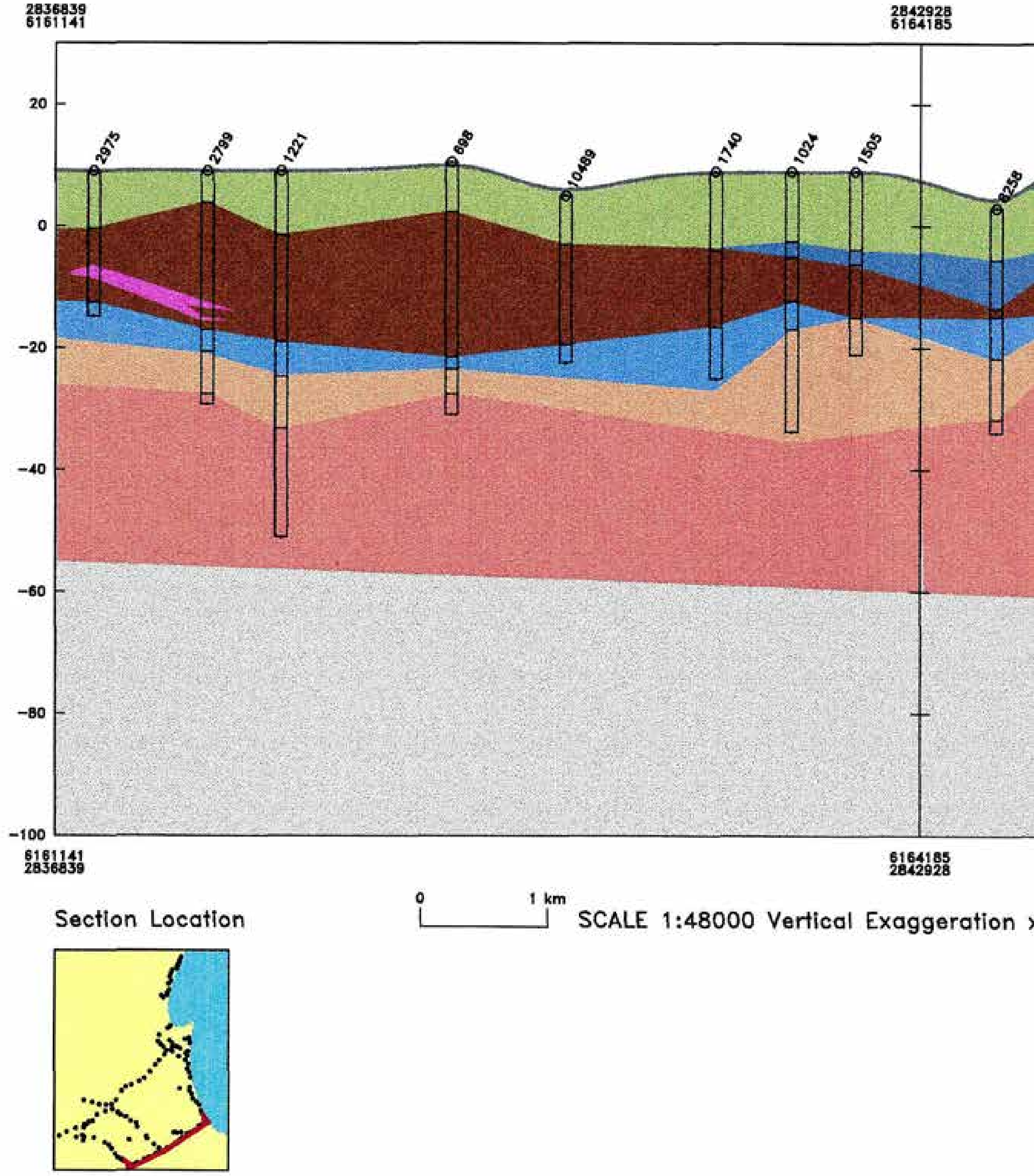
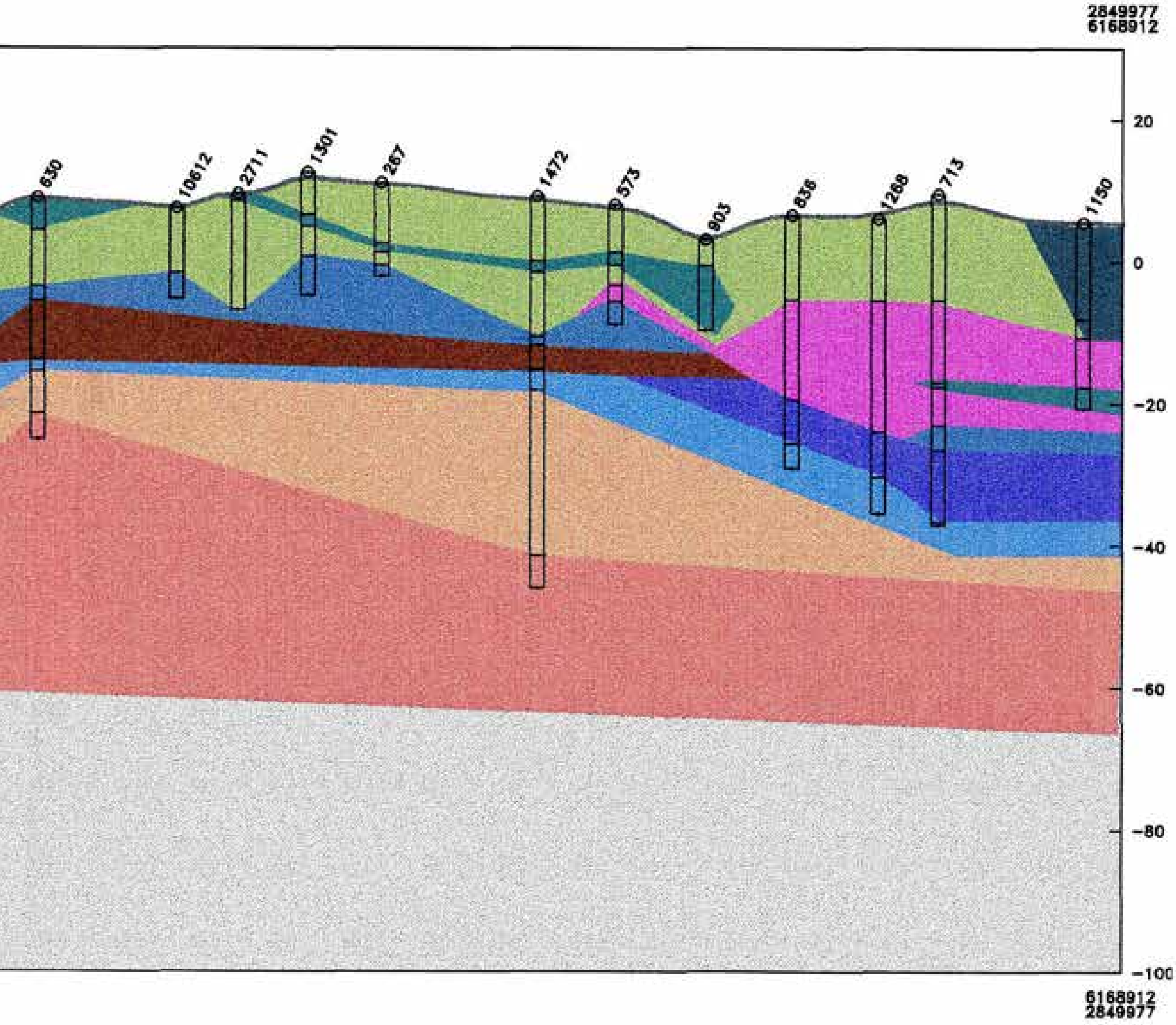


Figure 4.21: Pakipaki - Haum



x 48

hoana geological section.

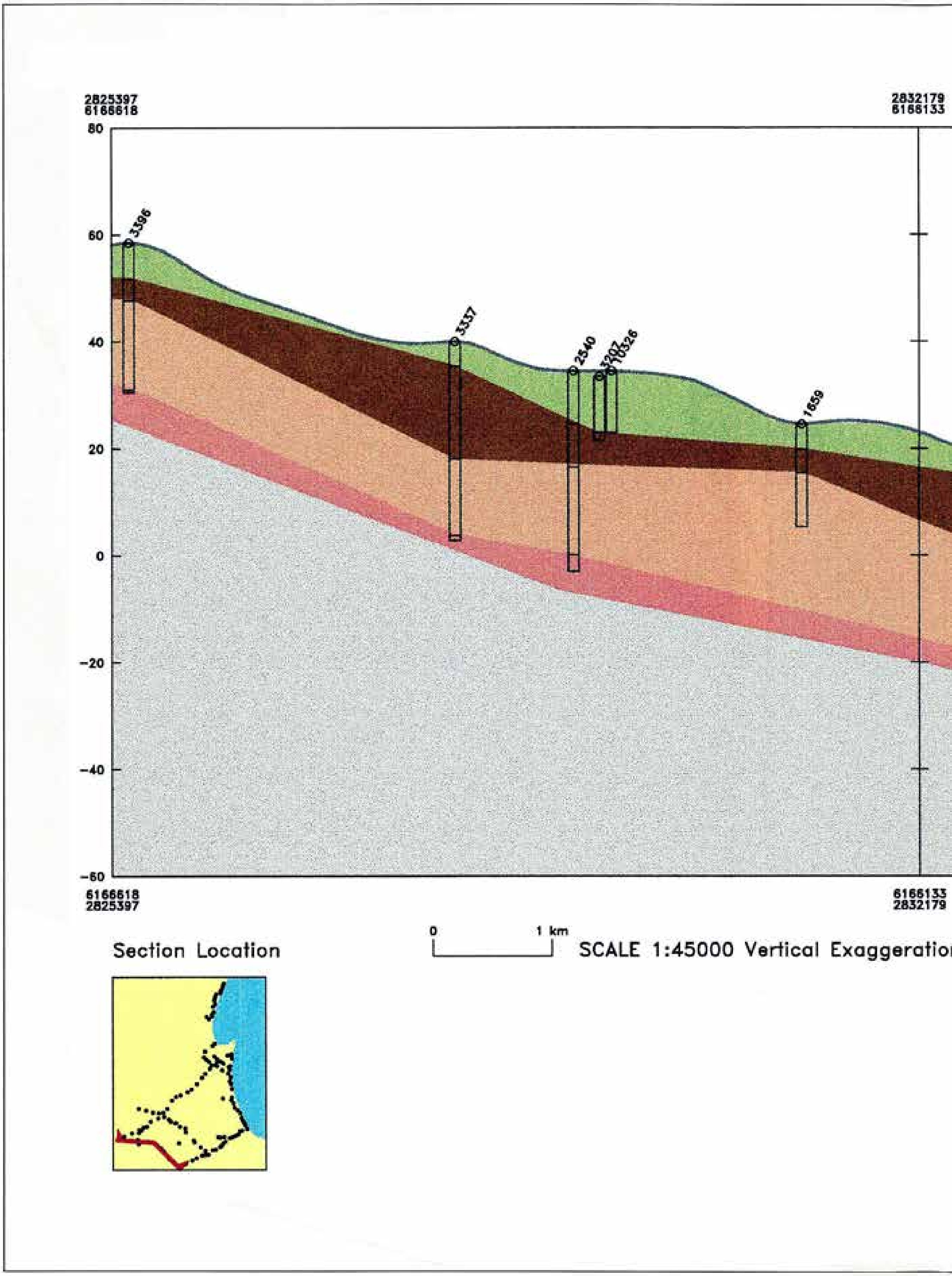
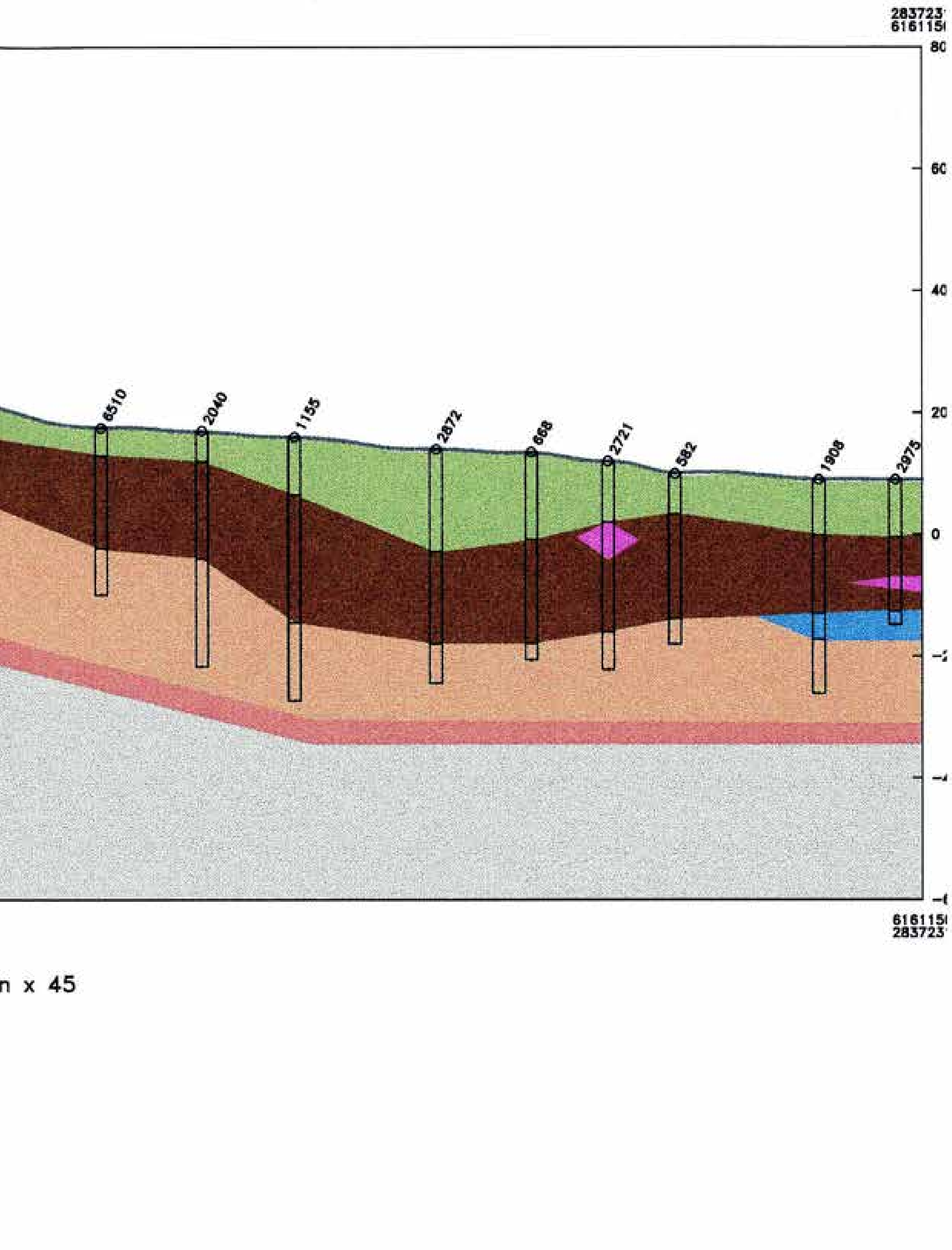


Figure 4.22: Ngatarawa - Pa



kipaki geological section.

CHAPTER 5

GROUNDWATER

5.1 BACKGROUND

The combination of tectonic deformation (subsidence of strata in the central part of the Heretaunga depression and uplift and faulting on the eastern and western flanks of the syncline), and the changing shoreline in the last 300 000 years, has influenced the hydrology and sedimentation processes of the Heretaunga Plains rivers, and consequently the deposition of a major deep (250 m) aquifer system and of at least three relatively shallow peripheral aquifers in the Heretaunga depression.

The Heretaunga Plains aquifer system is mainly river floodplain gravel deposits which have been reworked and redeposited by the rivers adjusting to fluctuating sea levels during glacial and interglacial periods of the late Quaternary. Aquicludes and aquitards are marine and marginal marine silt, clay and shell deposits that accumulated during high sea level interglacial periods and overbank flood silt deposits and poorly sorted gravel and silt. To the east of the former interglacial and postglacial sea level shorelines (Figs. 2.10, 2.12 and 2.20) sinuous gravel river channels and the intervening interglacial marine aquitards have been buried to form a complex interconnected aquifer system with multiple sources of recharge and subtle variation in piezometric pressures.

This chapter discusses and summarises the knowledge of the nature, extent, sources and flow of groundwater in the major and the peripheral aquifers, and the conditions governing the hydraulic leakages between separate aquifer systems.

5.2 DELINEATION OF RIVER CHANNEL AQUIFER SYSTEM

During the past 250 000 years, the Heretaunga Plains rivers have altered their courses many times mainly due to adjustment to tectonic processes. The Ngaruroro and Tutaekuri rivers now enter the Heretaunga Plains along the western margin while the Tukituki River enters the Plains from the southeast. The Ngaruroro River has built up the central and southern part of the Heretaunga Plains, while the Tutaekuri River has mainly infilled the area from Napier south to Meeanee. The Tukituki River has only entered the Heretaunga Plains in the last 20 000 years and during that time degraded (cut into) the Plains when sea level was rising (to 6500 years BP) and then reworked and redeposited gravel on its flood plain in the eastern part of the Plains to the present day.

Geological mapping (Fig. 2.2), the deep exploratory bores and the geological cross section data have provided a basis to broadly delineate four principally fluvial gravel aquifer systems, a postglacial fluvial gravel - marine transgression / progradation Esk aquifer system and a peripheral limestone aquifer system at the western and southern margin of the Heretaunga Plains:

- the Ngaruroro-Tutaekuri aquifer system or *main* aquifer system;
- the Tukituki aquifer system;
- the Moteo Valley aquifer system;
- valley aquifer systems;
- the Esk (Whirinaki-Bay View) aquifer system;
- the peripheral limestone aquifer system.

The main aquifer system, which extends to at least 250 m depth in the Heretaunga depression, was deposited mainly by the Ngaruroro River and underlies most of the Heretaunga Plains. Oxygen 18 analyses of groundwater to 250 m confirm a common Ngaruroro River recharge. In the middle of the Heretaunga Plains where many river channels have been buried, interconnections between channels facilitate recharge to the deeper parts (at least to explored depths of 250 m) of the aquifer system. Beneath the northern area of the Plains from Meeanee to Napier, Tutaekuri River deposits occur, and adjacent to the coast from Napier to Clifton there are beach gravel deposits which also form part of this aquifer system. On the edges of the main aquifer system, at least three localised shallow aquifer systems deposited by the Tutaekuri (Moteo Valley), Tukituki and Esk rivers can be delineated. In the valleys of the four main rivers before the Heretaunga Plains or coastal sector of their courses, and their tributaries, the areas adjacent to the river courses are underlain by shallow river valley fluvial gravel aquifers.

The aerial extent of these aquifer systems is shown in Figure 5.1 together with the unconfined - confined aquifer boundary and the inland boundary of flowing artesian wells.

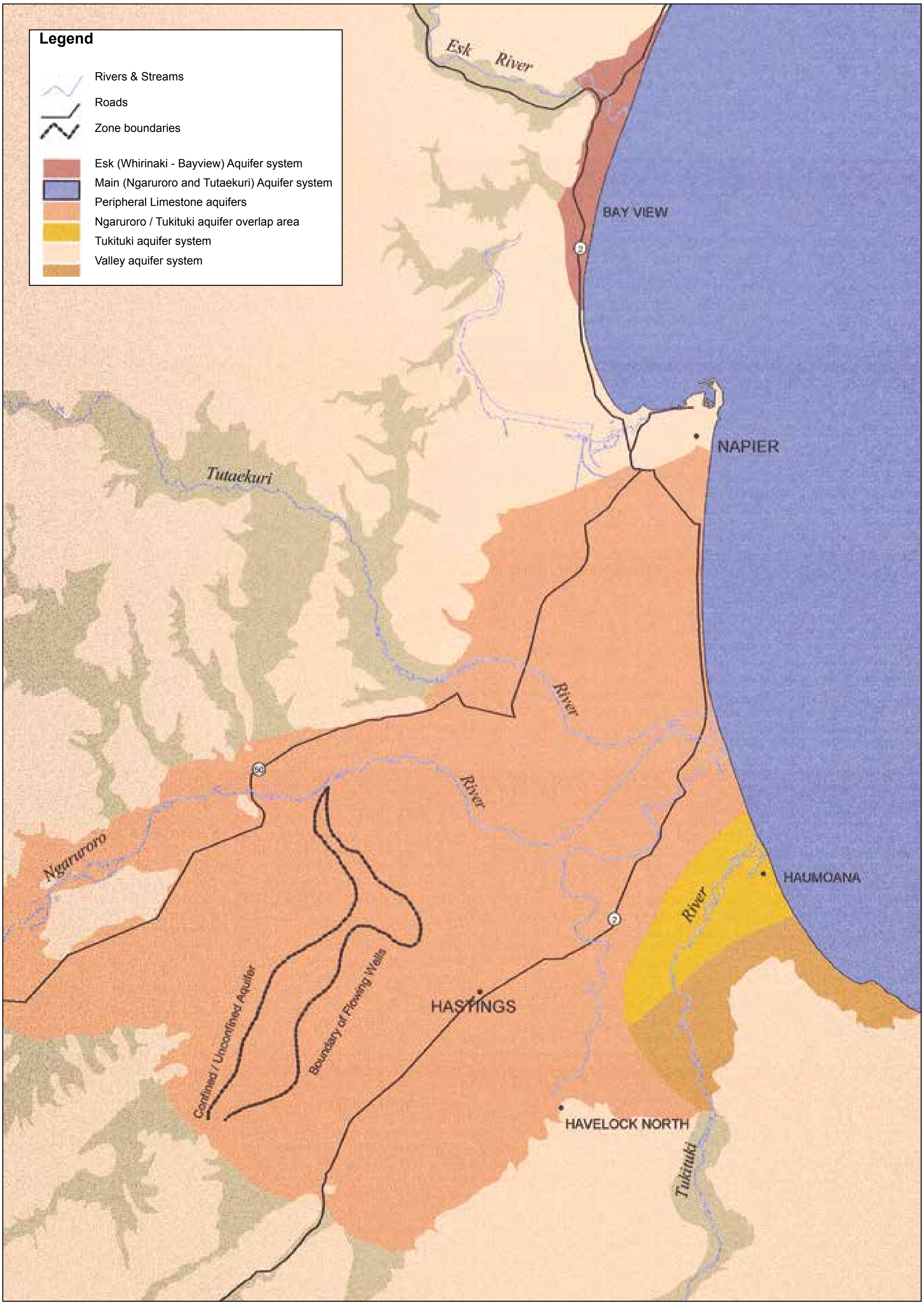


Figure 5.1: Aerial extent of individual aquifer systems, unconfined - confined aquifer boundary and the inland boundary of flowing artesian wells.

In areas where aquifer systems overlap, there is mixing of groundwater derived from the predominantly Ngaruroro River recharged main aquifer system, the Tukituki and Tutaekuri rivers, limestone aquifers and local rain. The areas of overlap can be distinguished by comparing the variations in groundwater chemistry which are related to the interaction between the groundwater and the different aquifer lithologies (Chapter 7). At the Bay View-Whirinaki coastal areas in the north, beach gravels form a shallow unconfined to semiconfined aquifer system which inland grades into a confined aquifer with multiple recharge sources including the Esk River, local rain and deep circulation of groundwater from underlying limestone aquifers.

5.3 MAIN AQUIFER SYSTEM

The main aquifer system underlies most of the Heretaunga Plains from Napier and the Hawke Bay coast in the northeast, to Maraekakaho, Roys Hill and Taradale in the west, and Bridge Pa, Pakipaki and Pukahu in the south. The total area occupied by the main aquifer system is about 250 km^2. The aquifer system is unconfined in the west and becomes gradually confined to the east. The approximate boundaries of the confining strata are shown in Figure 5.2. The unconfined aquifer area is formed of heterogeneous deposits of coarse to fine fluvial gravels and sands, with localised lenses and layers of silt and claybound gravels. The Flaxmere exploratory well proved thickness of the gravels at the unconfined-confined aquifer transition area is at least 137 m.

The thickness and extent of the postglacial transgressive and progradational marine confining layers increases towards the north and east. There are two areas on the Heretaunga Plains where postglacial deposition of overlapping river channels has resulted in the fine sediments of the confining layers being intercalated with permeable water-bearing gravel, sand and pumice. In the Twyford area (Fig. b) overlap of Tutaekuri and Ngaruroro river channels resulted in postglacial river reworking of marine and marginal marine deposits that form the confining strata, and deposition of fluvial gravel channel deposits, and channel and overbank sand and pumice deposits that form localised perched aquifers overlying the confined aquifer. Another area of river channel overlap occurs on the eastern margin of the Heretaunga Plains where Tukituki and Ngaruroro river postglacial gravel channel deposits and beach gravel and sand deposits are interbedded. Figure 5.2 shows the isopach on the confining layer overlying the main aquifer system together with the inland boundary of the flowing artesian wells for summer 1995 conditions and the areas of reworked and replaced (weak) confining seal.

On the Heretaunga Plains between the Ngaruroro and Tutaekuri river channels downstream of State Highway 50 and in the Twyford area (Fig. 5.2), the strata confining the main aquifer include a pumice sandy aquifer at a depth of about 10 m containing groundwater under pressure. In 1968, percussion cable tool drilling of an irrigation well to tap the main confined aquifer at 18 m, produced conditions which caused the pumice sand to mobilise and be carried by groundwater up the outside of the driven well casing. The removal of aquifer material by the upwelling groundwater formed a cavity into which the overlying strata collapsed and the area of leakage spread over about 5 m^2. The groundwater flow was eventually brought under control and plugged by backfilling the cavity with graded shingle and grout.

The Ngaruroro River course at the western edge of the Heretaunga Plains is partially constrained between limestone hills (Ohiti, Roys Hill and Fernhill) and stopbanks. Recent and historic Ngaruroro River bed and flood channels can be easily delineated on aerial photographs (Fig. 1.2). Between Roys Hill and Fernhill southeast toward Flaxmere and south Hastings is the 1867 channel. A Ngaruroro River paleochannel northeast of Fernhill towards Meeanee is less obvious. Another Ngaruroro River bed south of Roys Hill towards Pakipaki is marked by gravel and Taupo pumice surface and near surface deposits.

This recent (1800 years) fluvial depositional history of the Ngaruroro River on the Heretaunga Plains suggests that a similar pattern of downcutting and infilling of river bed and flood channels would have occurred for the last 6000 years as the Heretaunga Plains built out into Hawke Bay (Fig. 2.14). As a result a sinuous, braided, elongated and laterally restricted system of channel gravel aquifers hydraulically connected to a common river recharge source (the Ngaruroro River) underlies the western sector of the Heretaunga Plains. Downstream working of the fluvial river channel and floodplain deposits have resulted in the silt and sand components being washed out of the gravel deposits. This sorting of fluvial material increases toward the coast, and laterally continuous gravel aquifer networks are formed downstream of the elongated stream tubes adjacent to the riverbed.

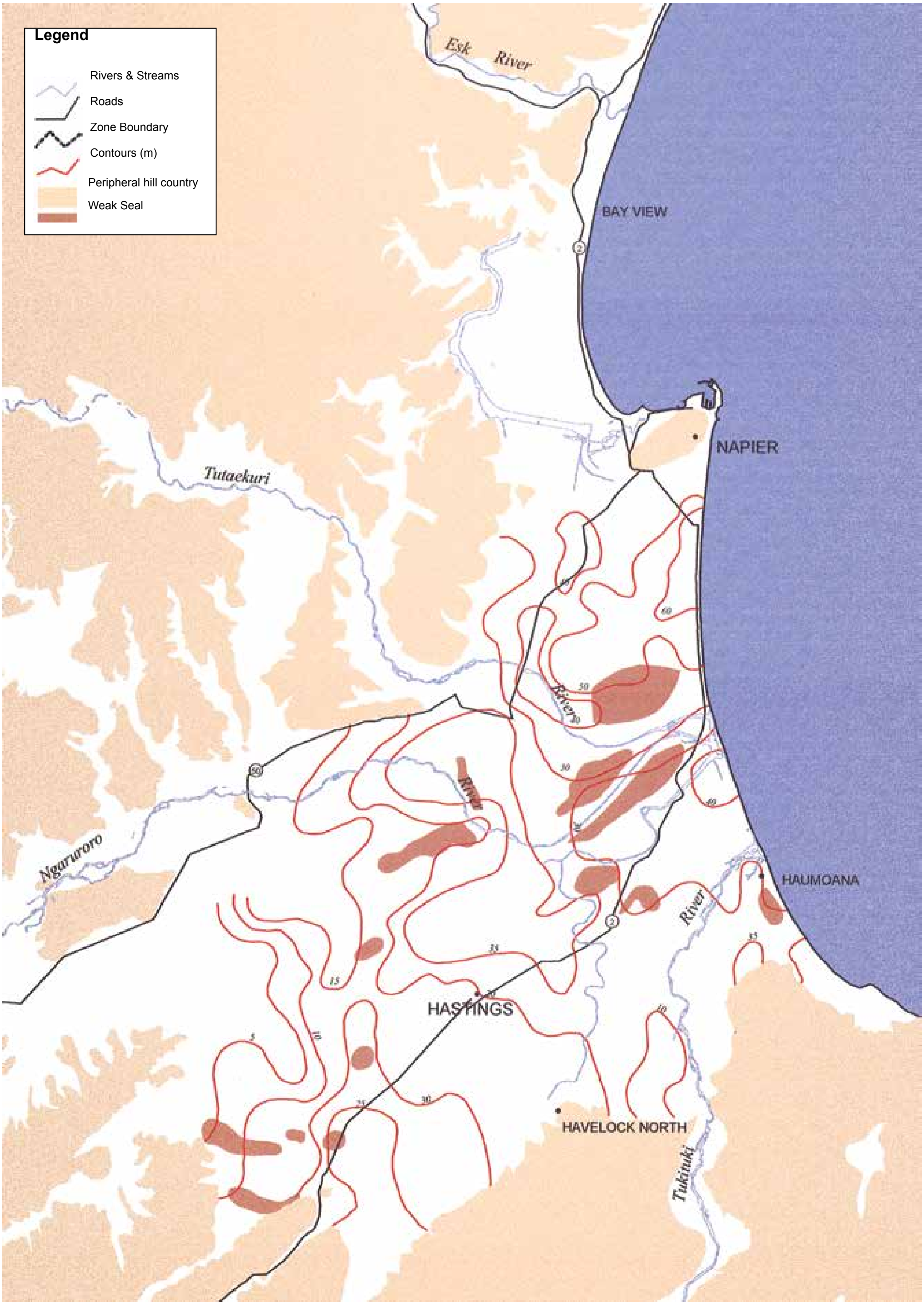


Figure 5.2 Contour map showing the thickness (m) and inland extent of the confining strata overlying the main aquifer system and the areas of weak confining seal.

5.3.1 Aquifer Configuration

The lithologic logs of the three deep exploratory testbores - Flaxmere, Tollemache Orchard and Awatoto provide information on depositional characteristics, ages, and regional aquifer sequence. A generalised cross section through these testbores and offshore out into Hawke Bay is illustrated in Figure 5.3._

The main aquifer constitutes a multilayered leaky aquifer system interconnected to the Ngaruroro River recharge zone. In the inland Plains the main aquifer pressures reduce with depth suggesting potential for downward leakage. Further east there is an interconnected aquifer and aquiclude/aquitard configuration. At the Awatoto coast the main aquifer pressure increases with depth which suggests upward flow of groundwater from the deeper aquifers.

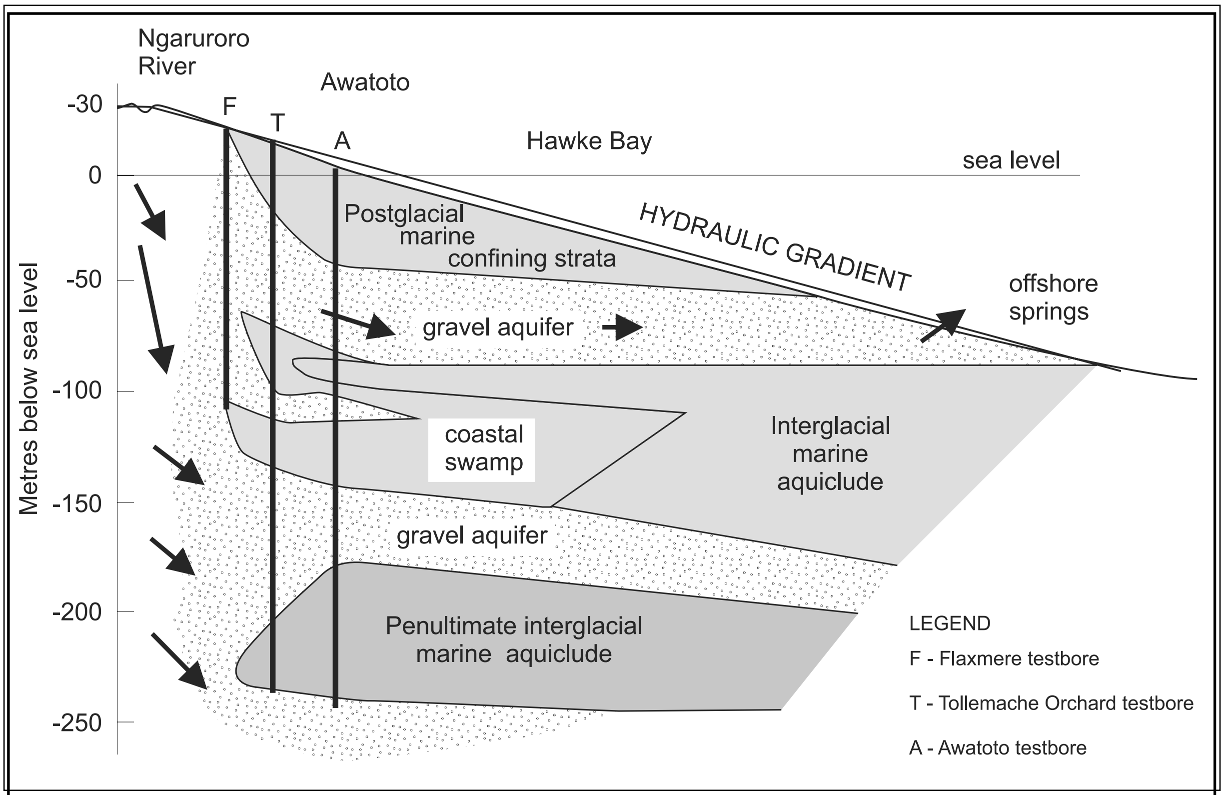


Figure 5.3: Generalised cross section through Flaxmere, Tollemache Orchard and Awatoto testbores.

The Flaxmere exploratory well located near the unconfined-confined aquifer boundary encountered groundwater in a predominantly gravel sequence to the final depth of 137 m. The resistivity survey undertaken by the MWD (Borgesius 1975) in the unconfined aquifer area suggested that the gravel aquifer extends to at least 150 m. The Tollemache Orchard bore located near Hastings was drilled to a final depth of 256 m. Five interconnected flowing artesian and one sub-artesian aquifers were encountered. The 254 m deep coastal Awatoto testbore penetrated six interconnected flowing artesian aquifers. The main aquifer system may extend below 250 m, but the combination of lower permeability and difficult drilling conditions due to increasing clay, silt and sand content, and high hydrostatic pressures, make it unlikely that production water wells would ever be drilled deeper than 200 m. The piezometric pressures in the Tollemache Orchard testbore show gradual decrease with depth whereas the piezometric pressures increase with depth in the Awatoto testbore. The increase of piezometric pressures with depth observed at the Awatoto testbore and bores in the south Napier area suggests the deeper aquifers have limited offshore extension. In the northern and eastern parts the Heretaunga Plains aquifers merge with the peripheral aquifer systems. In the aquifer overlap areas, the upwards piezometric pressure gradient in the main aquifer normally prevent seepage from shallow interbedded aquifer. However on the margin of the main aquifer system during the summer periods when there is increased groundwater abstraction, reversal of the upward hydraulic gradient occurs, thereby creating the potential for discrete groundwater mixing zones of local recharged shallow groundwater and underlying peripheral limestone aquifer groundwater with the intervening stressed main Heretaunga Plains aquifer system.

5.3.2 Aquifer Pumping Test Data

Pumping tests have been made on 55 wells at various sites on the Heretaunga Plains to assess the yield and hydraulic properties of the aquifer system. These tests usually involved pumping the aquifer continuously for up to 24 hours and monitoring water levels during and after pumping. Table 5.1 lists the transmissivities and specific capacity/storativity data obtained from the analyses of the pump tests. Transmissivities were obtained by employing Theis, Cooper, Jacob, or Huntush solutions for leaky and unconfined aquifer conditions. Figure 5.4 shows a plot of transmissivity contours for the Heretaunga Plains.

The transmissivity contour map shows a pattern of zones of relatively high transmissivities occurring in the central area of the aquifer system and aligned along paleochannels of the Ngaruroro River. The former channels of the Ngaruroro River, between Roys Hill and Fernhill and north of Fernhill are more permeable and have higher transmissivities (>20 000 m^2/day) than the channel south of Roys Hill towards Pakipaki which has relatively low transmissivities (<5000 m^2/day). Zones of very low transmissivities (<1000 m^2/day) occur in areas adjacent to the southern and western foothills and at the coast from Haumoana to Te Awanga.

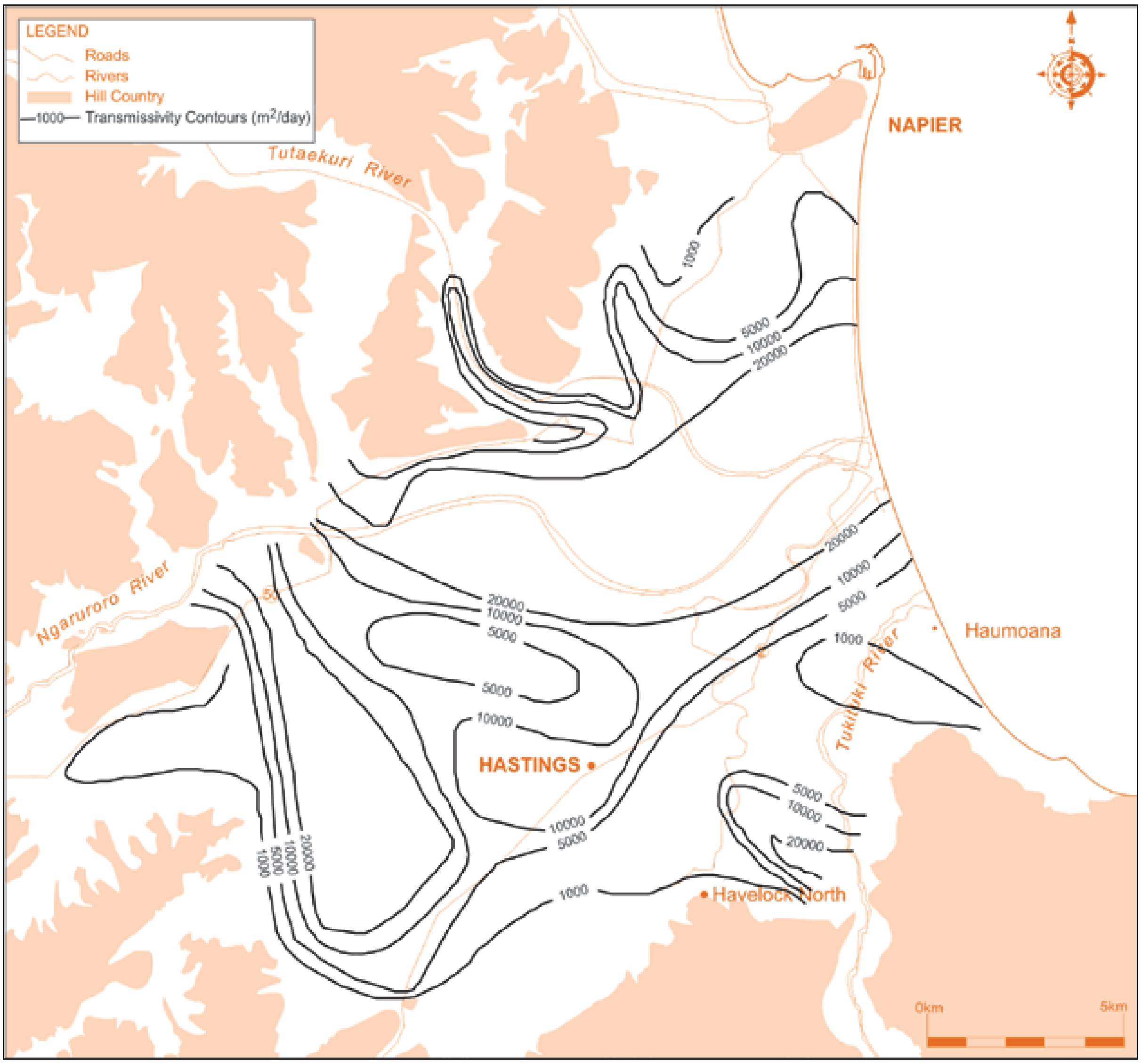


Figure 5.4: Transmissivity contour map for the Heretaunga Plains aquifers.

WellNo	Area	Map Ref	T (m2/day)	S	Aquifer Condition	AquiferMaterial
N10	Ngatarawa	V21/308671	250	1-2 x 10-4	Semi-unconfined	Gravel
RH9	Roys Hill	V21/320715	25000	0.027	Unconfined	Gravel
Test Well	Twyford	V21/344711	9500	1.8 x 10-4	Leaky	Gravel
439	Havelock North	V21/438661	222	2.2 x 10-3	Upper/Confined	Limestone
439	Havelock North	V21/438661	2229		Lower/Confined	Gravel
FM1	Flaxmere	V21/336700	8500	3 x 10-4	Leaky/Semiconfined	Gravel
FL8	Flaxmere	V21/334692	31000	8 x 10-4	Confined	Gravel
Well C	Pakipaki	V21/357614	5900	4.2 x 10-4	Confined	Gravel
1017	Havelock North	V21/443657	10000	1.2 x 10-4	Confined	Gravel
1401	Central Hastings	V21/397673	16400		Confined	Gravel
1017	Havelock North	V21/443657	10000	1.2 x 10-4	Confined	Gravel
1242	Havelock North	V21/420639	300	1 x 10-4	Confined	Gravel
480	Taradale	V21/410785	12600	5.6 x 10-4	Confined	Gravel
435	Haumoana	V21/486682	1000	4 x 10-4	Confined	Gravel
8469	Waiohiki	V21/390757	1200	6 x 10-3	Semiconfined	Gravel
8469	Waiohiki	V21/390757	2100	6 x 10-4	Confined	Gravel
1297	Pakipaki	V21/366601	600		Confined	Gravel
1284	Park Island	V21/413824	90		Semiconfined	Limestone
843	Meeanee	V21/452791	1430	4 x 10-4	Semiconfined	Gravel
1225	Roys Hill	V21/282680	2700		Unconfined	Gravel
1247	Bridge Pa	V21/285668	1000		Unconfined	Gravel
1348	Twyford	V21/259703	3000	2 x 10-3	Confined	Gravel
10025	Maraenui	V21/456803	5000	5 x 10-4	Two Aquifers	Gravel
3780	Taradale	V21/429798	3000	2 x 10-4	Confined	Gravel
1389	Greenmeadows	V21/421795	1500	1 x 10-4	Confined	Gravel
1276	St Georges Rd	V21/393633	1000	1 x 10-4	Confined	Gravel
1254	Park Island	V21/344652	100	1 x 10-4	Confined	Limestone

Table 5.1: Summary of aquifer pumping test data.

5.3.2.1 Storativities and Transmissivities

The storativity or storage coefficient of an aquifer is defined as the volume of water yielded per unit horizontal area and per unit change of water level for an unconfined aquifer or piezometric surface in the case of a confined aquifers. For unconfined aquifers, the storage coefficient is also called specific yield, which is the volume of water released from a unit volume of saturated aquifer material drained by falling water table. Storativities of Heretaunga Plains unconfined aquifers are in the range of 0.01 to 0.03 while for the confined aquifers it is in the order of 10^{-3} - 10^{-4}.

In the major recharge zone between Roys Hill and Fernhill the main aquifer is unconfined with a very high transmissivity (see Table 5.2) of 25 000 m^2/day and a storage coefficient of 0.027. In the minor recharge zone from Maraekakaho to Roys Hill in the Ngatarawa area, the aquifer is semi-unconfined with a low transmissivity typically 200 to 1000 m^2/day and a specific yield of 0.10 to 0.15. In the Ngatarawa area the low transmissivity is a result of thinner aquifers, shallow groundwater basement and low permeability aquifers. At Pakipaki, in the southwestern part of the Plains, an aquifer transmissivity of 5000 m^2/day and a storage coefficient of 4 x 10^{-4} has been measured. Near the aquifer unconfined-confined transition zone, the transmissivity is about 10 000 m^2/day and the storage coefficient is 2 - 3 x 10^{-4}. The aquitard permeability is 1 - 3 x 10^{-3} cm/s. In the confined aquifer pumping tests show the variation in aquifer characteristics reflecting the range in well yields that is typical of heterogeneous aquifer systems of river floodplain deposits and the variability introduced by different standards of screen selection, construction and emplacement and pre-test pumping development. Yields are poor near Havelock North with measured transmissivities of 200 to 2000 m^2/day and a storage coefficient of 2 x 10^{-3}. Some of the highest yields for the Heretaunga Plains aquifer are obtained from Hastings City wells at Frimley Park with aquifer transmissivities greater than 30 000 m^2/day. Table 5.2 shows a classification of the Heretaunga Plains transmissivity magnitude for various aquifer material together with the estimated groundwater supply potential.

5.3.2.2 Piezometric Surveys and Groundwater Flow

Since 1974 several piezometric surveys have been undertaken covering sections of the Heretaunga Plains unconfined and confined aquifer areas. The measured groundwater levels and the resulting piezometric surface has been mapped in terms of mean sea level to

Transmissivity (T) m^2/day	Class of Transmissivity Magnitude	Designation of Transmissivity Magnitude	Specific Capacity l/s/m	Groundwater Supply Potential	Aquifer Material
>20 000	I	Very High	25 to 35	Withdrawal of great regional importance	River channel gravel
10 000 - 20 000	II	High	15 to 25	Withdrawal of lesser regional importance	Gravel
1000-10 000	III	Intermediate	5 to 15	Withdrawal of local water supply, large scale irrigation	Floodplain gravel/ beach gravel
100-1000	III	Low	2 to 5	Smaller withdrawal for community and small farm irrigation water supply	Gravel/ limestone
10-100	IV	Very Low	1 to 2	Domestic water supply	Limestone,- mudstone/ siltstone
>10	V	Imperceptible	<1	Limited intermittent yields	

Table 5.2: Classification of the Heretaunga Plains transmissivity magnitude.

produce piezometric contour lines of equal groundwater pressures. The groundwater flow directions are at right angles to the piezometric contours.

Figure 5.5 is a compilation of the average 1974-77 winter piezometric contours and is typical for average winter conditions. On the weekend of 18 and 19 February 1995, the HBRC carried out a water level survey for a network of 450 wells on and adjacent to the Heretaunga Plains. At the time Hawke's Bay was experiencing a prolonged drought so the survey provided the opportunity to observe the response of the Heretaunga Plains aquifers to maximum groundwater abstraction. Figure 5.6 is the piezometric map of the Heretaunga Plains for the 1995 summer water level survey.

The following characteristics for the Heretaunga Plains aquifers can be deduced from the average 1974-77 winter, 1995 summer and other piezometric surveys:

- Groundwater flows from the Ngaruroro River towards the southeast but near the coast moves in a easterly to northeasterly direction out under Hawke Bay.

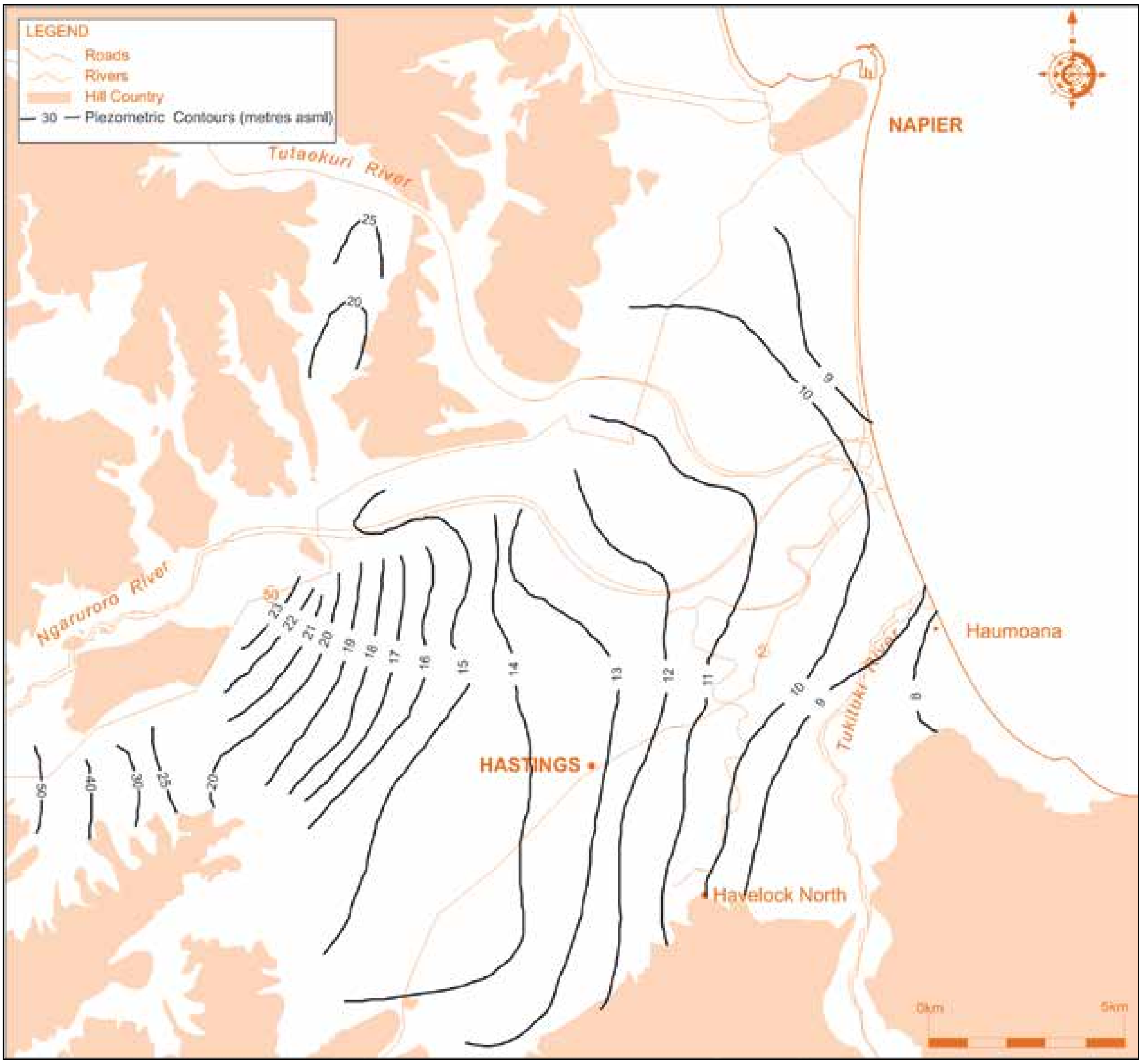


Figure 5.5: The Heretaunga Plains average winter (1974-77) piezometric map.

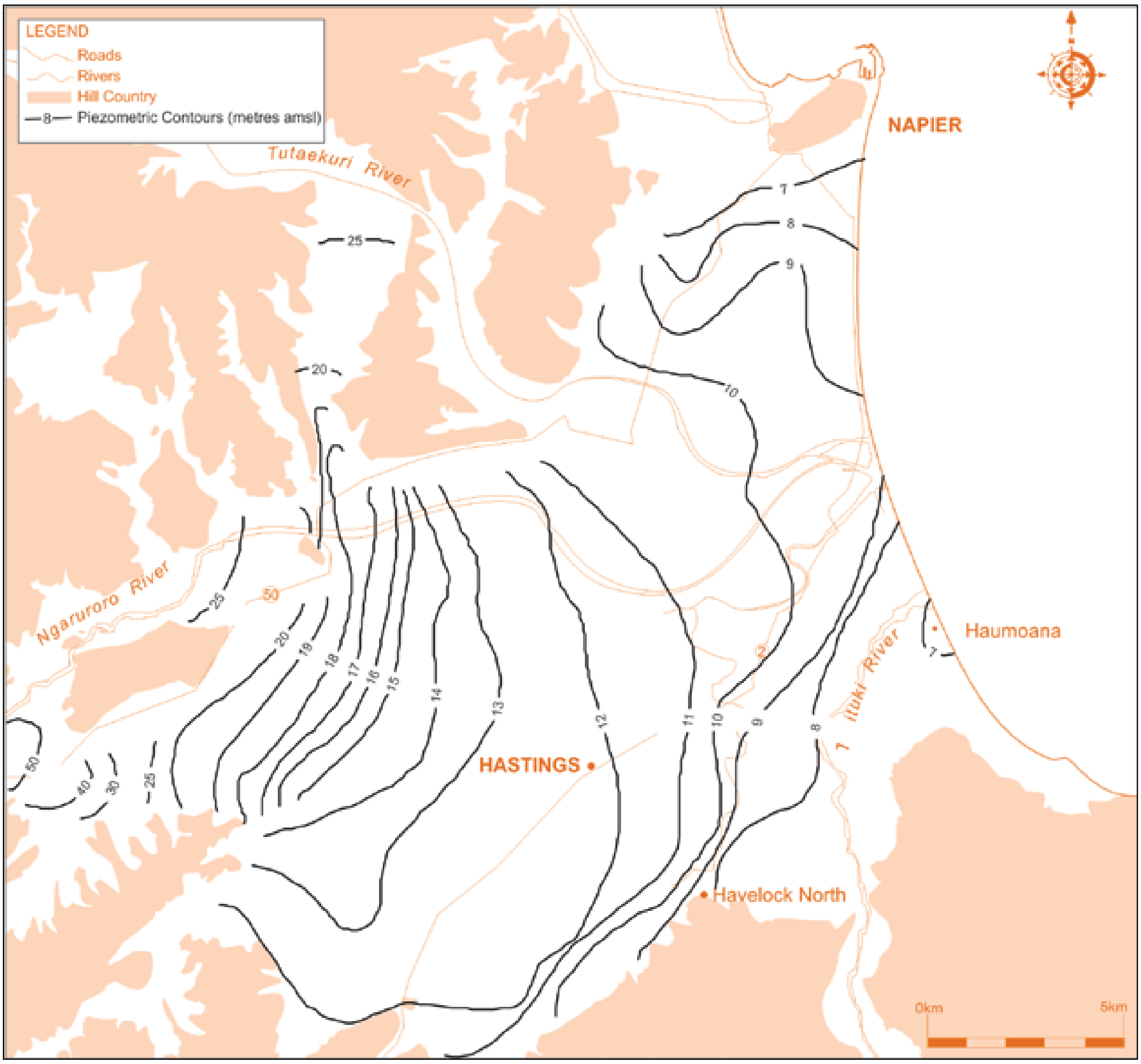


Figure 5.6: The Heretaunga Plains summer 1995 piezometric map.

- Over the entire aquifer system the piezometric surface during winter is about 1.5 - 2.5 m higher than during summer.
- In the Roys Hill - Fernhill major recharge area the piezometric gradients are very steep near the river being 27 x 10^{-3}. At a distance of 2 km from the river the gradient flattens to 2 x 10^{-3}. At 3 km from the river the gradient is 4 x 10^{-4} and remains essentially constant over the remaining confined aquifer area.
- In the Roys Hill-Maraekakaho minor recharge area the piezometric surface is about 3 m deep and gradually deepens to 12 m where it merges with the main flow.
- The piezometric surface coincides with the ground surface at about 2 km east of the unconfined - confined aquifer boundary and further to the east confined aquifer bores free flow at the surface. Free flowing bores occur over 70% of the Plains area (Fig. 5.2).
- The overall regional piezometric contour patterns is similar from winter to summer except for the outlying areas on the fringes of the main aquifer system where localised reversal of upward hydraulic gradients and of groundwater flow directions can occur. This is shown by the August 1980 piezometric contours (Fig. 5.7) for the Karamu area between Hastings and the Tukituki River.

Groundwater flow rates in the Heretaunga Plains have

Figure 5.7: Karamu area piezometric contours August 1980.

been derived from isotope studies, aquifer properties and groundwater flow equations and well to well tracer studies (Thorpe et al. 1982). The velocity of groundwater movement is about 150 m per day near the Ngaruroro River major recharge source. Near the unconfined-confined boundary the groundwater velocity is estimated to be 20 - 25 m per day and is about 10 m per day within the central part of the confined aquifer system. As typical of fluvial gravel channel aquifers, the measured groundwater velocities are extremely variable as a result of the presence of distinct paths of slow and fast moving groundwater. The average groundwater travel time from the recharge source to the coast is calculated at about 7 years (Grant-Taylor & Taylor 1967).

5.3.3 Long-term Groundwater Monitoring

Abstraction of groundwater from the Heretaunga Plains aquifer system is increasing (Fig. 1.13). It is important to predict the consequences of increasing use of the groundwater resource and predict and prevent any serious problems before they occur. Long-term fluctuations in groundwater levels are a direct measure of the change in groundwater storage and provide a record for comparison of the response of the system to increasing abstraction. Besides long-term groundwater level monitoring, long-term climate (particularly rainfall), and river flow records are important for comparison for analyses of the long-term trends.

The longest continuous record of rainfall on the Heretaunga Plains is available from Nelson Park, Napier where climatic data including rainfall, temperature and barometric pressure has been monitored since 1900. Figure 2.28 is a plot of the long-term rainfall record for this station.

The longest continuous record of river level is from 1952 to the present day for a gauging site on the Ngaruroro River at Fernhill. Other continuous level records for the Ngaruroro River are from gauging sites at Ohiti (1971 to present) and Chesterhope (1972 to present). There are also continuous river level records available for the Tutaekuri River at Puketapu (1978 to present) and the Tukituki River at Red Bridge (1968 to present) (see Fig. 5.8).

Most of the Heretaunga Plains groundwater recorder sites have operated for less than 3 years and there are gaps in the records. Figure 5.8 shows the locations of automatic river and well water level recorder sites. Tables 5.3 and 5.4 gives details of the recorder type and the data period.

Comprehensive groundwater investigations require long-term and good quality continuous water level data. Since 1968 continuous water level data has been collected by the HBCB and HBRC from the rivers and sporadically from wells tapping the unconfined and

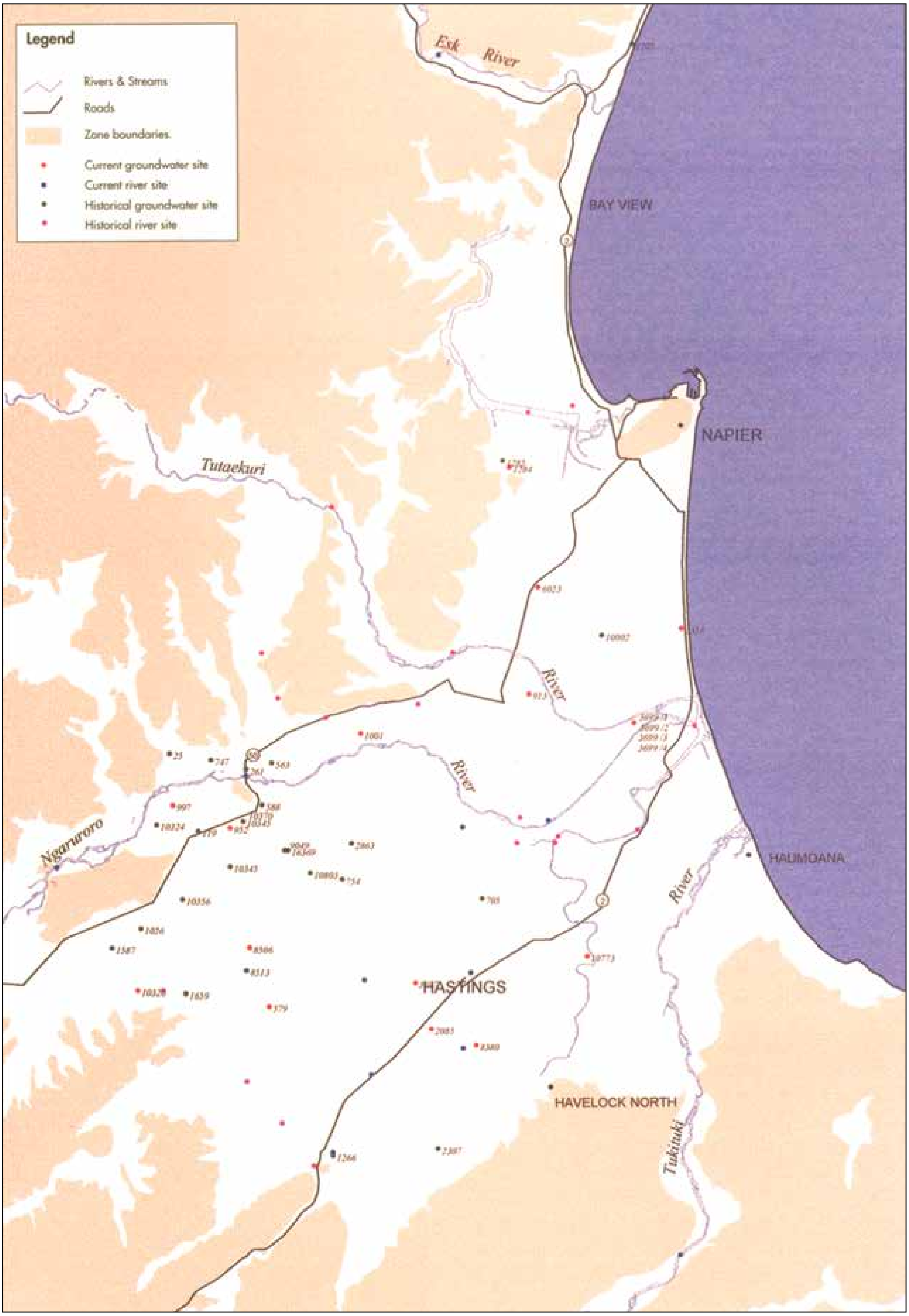


Figure 5.8: Heretaunga Plains continuous river and well water level recorder sites.

Site No.	Water Body	Site Name	Map Ref. NZMS 262	Start Date	End Date	Recorder
22802	Esk River	Waipunga Bridge	V20/391951	631111	0	Enc/Teletherm
1123149	Maraekakaho River	D/S Taits Road	V21/170668	830630	930106	Foxboro
23110	Ngaruroro River	Ohiti	V21/271701	710413	0	PT/Telem
23134	Karewarewa Str.	Talbots	V21/304663	720216	741223	Foxboro
23148	Lake Oinga	Outlet	V21/327745	760202	800714	Teletherm
23135	Karewarewa Str.	Rosser Road	V21/330635	720511	730326	Foxboro
23102	Ngaruroro River	Fernhill	V21/330729	520813	0	Enc/Teletherm
23145	Jims Drain	Swamp Road	V21/335767	740627	740926	Teletherm
23146	Tutaekuri -Waimate Str.	Tyronnes.	V21/340753	741001	771213	Teletherm
123150	Karewarewa Str.	Turamoe Road	V21/341622	781115	900430	L&S
23136	Awanui Stream	Pakipaki	V21/351609	720228	720508	Foxboro
23142	Tutaekuri-Waimate Str.	S.H. 50	V21/355747	740423	771115	Cambell
1123148	Awanui Stream	Flume	V21/357613	830928	0	PT/Telem
23032	Tutaekuri River	Pukatapu FW site	V21/357812	780413	0	Enc/Teletherm
23001	Tutaekuri River	Puketapu	V21/357812	681217	800604	Foxboro
23169	Irongate Stream	Clarkes Weir	V21/367666	780310	0	Stevens
1123156	Longlands Drain	Longlands	V21/369637	931026	0	Stevens
1023149	Tutaekuri -Waimate St.	Goods	V21/384751	780801	940830	Stevens
23002	Tutaekuri River	Redclyffe	V21/395767	661021	680916	Foxboro
1023181	Southland Drain	Norton Road	V21/398645	850719	0	Foxboro
23184	Raupare Stream	Ormond Road	V21/398713	820129	0	Stevens
23143	Raupare Stream	Pakowhai	V21/415708	721218	740223	Cambell
23139	Tutaekuri -WaimateStr.	Chesterhope	V21/416716	730104	740930	Teletherm
22903	Ahuriri lagoon	Causeway	V21/419841	770811	860609	L&S
23150	Ngaruroro River	Chesterhope Br.	V21/425715	761125	0	Logger
23138	Karamu Stream	Floodgates	V21/427708	720828	940915	Foxboro
1023194	Clive River	Packhouse	V21/428710	801128	820209	Teletherm
22917	Westshore Pond	Flaoon House	V21/433843	870413	880415	Cambell
1023193	Clive River	Tuckers	V21/453712	801128	810422	Telemetry
1023192	Clive River	Hohepa	V21/471744	801106	810112	Cambell
23201	Tutaekuri River	Red Bridge	V22/466581	680512	0	Telemetry

Table 5.3: The Heretaunga Plains continuous river level data.

confined aquifers underlying the Heretaunga Plains. There is also limited long-term and short-term water level data collected by the Napier City Council and Hastings District Council but these records have not been digitised and were largely unavailable for analyses for this report except for the records from Frimley pump station at Hastings.

The longest almost continuous record of well water levels is from 1968 to the present day for the ECNZ substation well (well no. 952), located on State Highway 50 near Fernhill. Other long-term records are available for wells AR4 (well no. 3746) Roys Hill, Communitor Station (well no. 3358) Awatoto, Lagoon Farm (well no. 1284) Park Island and the MWD well 7D (well no. 3737), Flaxmere (see front cover) as well as intermittent water levels and continuous recorder charts from a series of wells measured by the Napier City Council.

Unfortunately no long-term water levels are available for latter part of the last century and the early part of this century when domestic and municipal water supplies were first being developed. The reported artesian head of 6.1 m above ground level for the first well drilled on the Heretaunga Plains at Meanee in February 1867 (Knight 1995), is similar to artesian heads for wells at roughly the same location today. This suggests that groundwater pressures in the confined aquifer have not changed significantly in the last 125 years since the first artesian well was drilled. There are also other wells in the confined aquifer area where piezometric pressure measurements made during drilling at the start of the century are similar to present day levels. These include confined aquifer wells adjacent to McLean and Nelson parks and at Munroe Street in Napier, and in two wells at Pakowhai and Pakipaki (S. Cameron, HBRC, pers. comm.).

Site Name	Well No.	Well Depth (m)	Start Date	End Date	Map Ref.	Recorder
Whirinaki	1205	24.40	811209	870202	V20/452954	Stephens F
Lagoon Bore No.6	1285	30.00	870121	870803	V21/411826	F&P
Lagoon Bore No.4	1284	13.40	880223		V21/413824	Stephens F
Roys Hill	10324	7.30	671027	790707	V21/303720	Stephens F
Fernhill	588	6.10	720410	770706	V21/335720	Lea
Apatu	563	6.10	720316	770803	V21/338733	Lea
Bridge End	261	7.90	720525	770706	V21/330731	Lea
Well 7D (Flaxmere)	3737	29.17	740507		V21/344682	Enc/Telem
Well 7D2	3738	6.13	740606	780109	V21/344682	Stephens F
Well 2H	10805	21.20	730827	730903	V21/343716	No Charts
Kupa	747	6.10	720317	730514	V21/319734	Lea
Gunns	25	22.25	820322	830726	V21/306736	Stephens F
Fraser No.1	997	7.67	901123		V21/307720	F&P
Dumble	10002	58.22	751120	760507	V21/442772	Fox
Game Farm	6023	31.70	811223		V21/422787	PT/Psion
Waima	1001	21.64	920122		V21/366742	Stephens F
Gilligans	913	41.45	920930		V21/419754	PT/Psion
Comminutor Stn	3358	59.13	830128		V21/467774	PT/Psion
Awatoto No.2 (Analogue)	3699 /1	163.00	950829		V21/452745	PT/Psion
Awatoto No.3 (Digital)	3699 /2	100.50	950829		V21/452745	PT/Psion
Awatoto No.4	3699 /3	58.50	950915		V21/452745	PT/Psion
Awatoto No.5	3699 /4	58.50	950918		V21/452745	PT/Psion
Wellwoods	164	4.88	681020	860826	V21/251673	Stephens F
Well NG4	3739	21.34	750609	790611	V21/275666	Stephens F
Substation	952	13.18	681020		V21/325713	Stephens F
Twyford Farm (150mm)	16369	8.23	681015	730111	V21/343706	Lea
Twyford Farm (300mm)	9049	11.59	730111	790615	V21/342706	Lea
Kamaka	8513	7.70	721018	790615	V21/330669	Lea
Kilton Main	3740	8.54	681020	720315	V21/316678	Lea
Well OA	10345	30.10	730518	770630	V21/329715	Stephens F
Well OA2	10370	7.31	730921	740121	V21/329715	Stephens F
Well 4G	10803	23.83	730330	780726	V21/350699	Stephens F
Well 4G2	3741	6.06	730330	780726	V21/350699	Stephens F
Well 2F	10356	30.39	730828	740507	V21/310691	Stephens F
Well 2D	10345	59.23	730906	740507	V21/325701	Stephens F
Saleyards	3742	8.23	700812	821201	V21/314716	F&P
Well NG6	3743	35.00	750917	790612	V21/289680	Stephens F
Omahu	754	6.10	681020	710616	V21/360697	Lea
Well NG10	3744	23.93	750411	771116	V21/308670	Stephens F
Well NG8 (Sowersby)	1026	27.43	750515	870409	V21/297682	Stephens F
Well NG7 (Talbots)	10326	23.44	750915		V21/296663	Stephens F
Pakipaki	1266	19.81	751107	790511	V21/357612	Foxboro
Well NG9	1659	25.30	750429	790612	V21/311662	Stephens F
Morven Hills	1587	15.85	681022	700728	V21/288676	Stephens F
Well 7A (Golf Club)	8506	29.92	730601		V21/331676	Stephens A71
AR2	3745	19.00	830801	870116	V21/299709	F&P
AR4	3746	11.88	830801		V21/302709	Enc/Logger
AR5	3747	21.00	830801	860730	V21/304709	Stephens F
AR1	3748	11.12	830801	941017	V21/296707	Stephens F
Fraser No.2	10324	12.20	901123	920228	V21/302714	F&P
Fraser No.3	474	17.80	901122	920319	V21/317717	F&P
Fraser No.4	119	10.96	901122	940913	V21/315712	F&P
Fireshed	579	16.76	910828		V21/337658	Stephens F
Coker No.2	3148	27.40	950707	950728	V21/293676	PT/Psion
Curtis	2307	28.30	820106	870729	V21/390614	Rustrak
Hawea	705	40.54	830119	930810	V21/404691	PT/Psion
Well 6K	2863	26.79	900214	950130	V21/363708	PT/Psion
D'Ath	2085	62.80	920225		V21/388651	PT/Psion
Glade Park	10773	56.69	921027		V21/437673	PT/Psion
Walsh	8380	32.30	930610		V21/402646	PT/Psion
D'ath Deep Well (Tollemache) D1	3697	48.00	950424		V21/383665	PT/Psion
D'ath Deep Well (Tollemache) A2	3697	88.00	950314		V21/383665	PT/Psion
Anderson Park	3781	35.00	951026		V21/420797	PT/Psion
W. Paxie	3779	64.00	951130		V21/459824	PT/Psion
Richardson	3749	39.00	811218	910812	V21/485704	Rustrak

Table 5.4: Heretaunga Plains continuous well water level data.

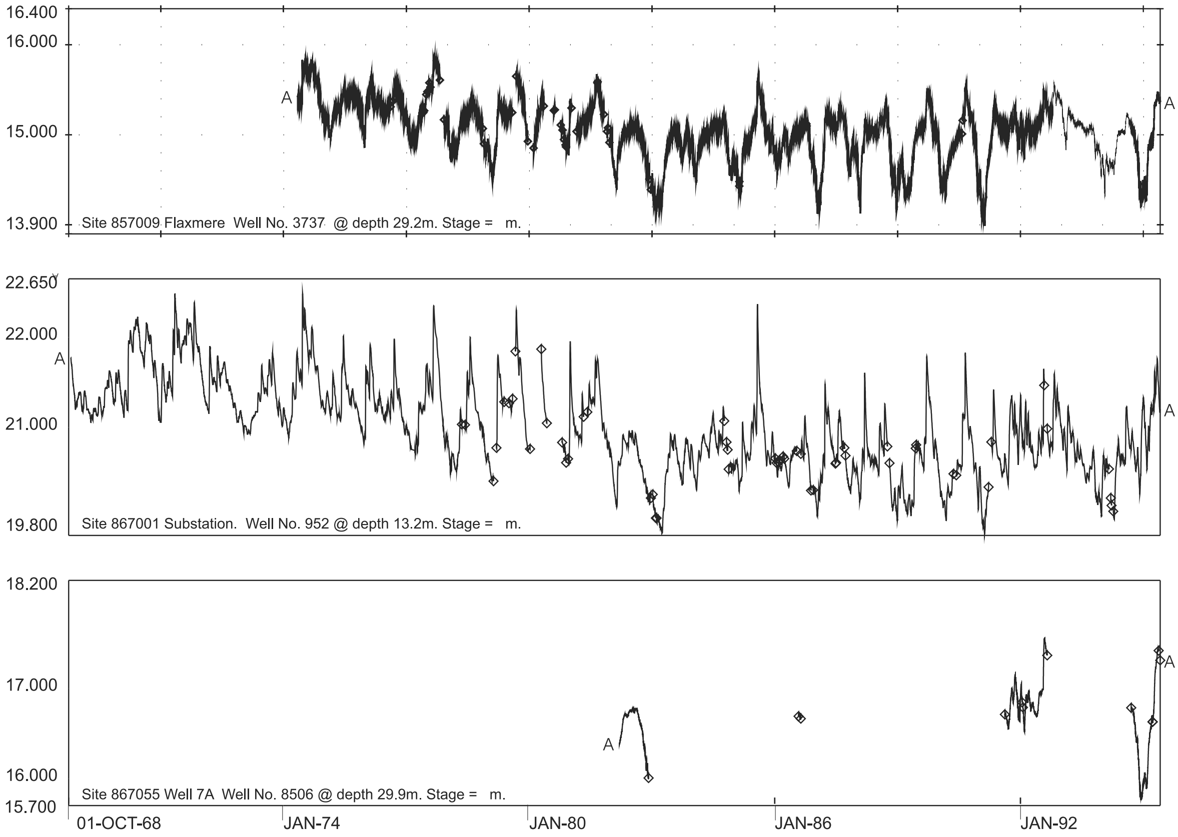


Figure 5.9: Comparison of continuous water levels from wells tapping unconfined and semi confined aquifers - well 7A, well 7D and substation well.

Figure 5.9 shows the multiplot of the continuous water levels from three wells tapping the unconfined and semiconfined aquifers at well 7A (well no. 8506), well 7D (well no. 3737) and substation (well no. 952). The well 7A is located at the Flaxmere golf course, about 6 km from the Ngaruroro River. The Fernhill substation well is located at the ECNZ substation on State Highway 50 about 1 km from the Ngaruroro River and well 7D is located in Portsmouth Road, Flaxmere about 6 km from the Ngaruroro River.

The long-term fluctuations of water levels for these three wells which are located in the unconfined aquifer (well no. 952) adjacent to the major river recharge area, and at the transition boundary between the unconfined and confined aquifer (well nos. 8506 and 3737) show the prevailing seasonal trend of lowest water levels during the summer period (December to April) which is the period of maximum groundwater abstraction, lowest rainfall and minimum river flows. Highest water levels occur during the winter period (June to October). The overall trend for the period 1974 - 95 shown by the long-term river flow, rainfall and well hydrographs is one of relatively minor variation in rainfall and river flow compared with a small but significant decline in groundwater levels in the unconfined Heretaunga Plains aquifer.

Figure 5.10 shows the water levels from three wells tapping confined aquifers at Hawea well, Tomoana (well no. 705), Richardson well, Haumoana (well no. 3749) and the Game Farm well, Greenmeadows (well no. 6023). The Hawea well is located on the northwest edge of Hastings City on the corner of Evenden and Maraekakaho roads in Tomoana. The Richardson well is located at the coast at Haumoana. The Game Farm well is located in Burnese Road, Jervoistown.

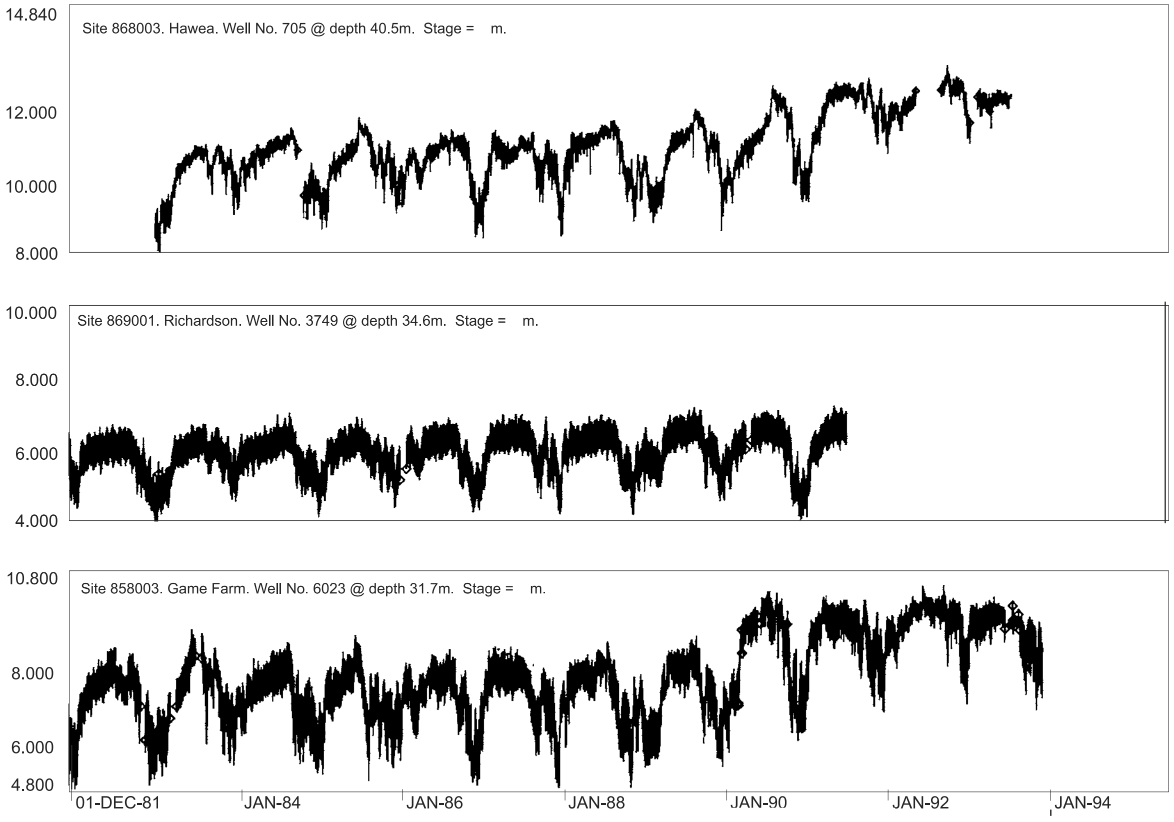


Figure 5.10: Comparison of continuous water levels from wells tapping the confined aquifer - Hawea well, Richardson well and Game Farm well.

The Game Farm well has the longest continuous record of groundwater piezometric pressure for the Heretaunga Plains confined aquifer (1981 to present). The Hawea well has been monitored from 1983 to 1993 and except for two minor breaks in 1983 and 1992 the record is complete. The plot of piezometric pressure from all three wells shows seasonal fluctuation of lower pressure during summer and higher pressure during winter period. These water level records suggest there might be a trend of increasing piezometric pressure during both summer and winter seasons in the 1990's. While the observation period (1981 to present day) is too short for this increase in the pressure to be considered important it is perhaps significant that it corresponds to four years (1990 - 1993) of above average annual rainfall (see Fig. 2.28 - annual rainfall departure from long-term mean at Nelson Park, Napier from 1900 - 1995).

The implied difference in long-term water level trends in the confined and unconfined sector of the Heretaunga Plains aquifer may be the consequence of the changing hydrological regimes across the unconfined - confined aquifer boundary. The piezometric pressures in the confined aquifer appear to be unchanged in the 125 years of well drilling and groundwater abstraction, while the shorter term monitoring record (1982 to present day) suggests that piezometric pressures increase during periods of prolonged above average rainfall. This is in contrast to the unconfined and semiconfined aquifers where water level monitoring (1968 - 1995) suggests a decline in groundwater levels (Fig. 5.9).

This contrast could be a product of several factors:

- ✏ Maintenance of groundwater inflow to the confined aquifer to replace increasing quantities of abstracted groundwater is impacting on the groundwater stored in the unconfined - semiconfined aquifer.
- ✏ Increasing abstraction of groundwater from the unconfined sector of the Heretaunga Plains compared to the confined aquifer.
- ✏ A decline of groundwater recharge in the unconfined aquifer from the Ngaruroro River and local rain due to changes in the river course and bed, and landuse on the Heretaunga Plains.

- The response (recovery) of piezometric levels to the sealing and capping of old, damaged and unused flowing artesian wells over the last 25 years to prevent groundwater flowing to waste.
- The long-term development of wells tapping the confined aquifer is occurring as a result of the gradual flushing of sand and silt suspended in groundwater pumped or flowing from the well, has enhanced hydraulic contact.
- Structural damage has occurred to aquifers, aquitards and aquicludes as a result of groundwater withdrawal exceeding recharge and the removal of sand and silt suspended in groundwater.

There is no data that identifies a specific factor contributing to the contrast in long-term groundwater level trends between the unconfined and confined sector of the Heretaunga Plains aquifer system. HBRC groundwater abstraction data show 237 groundwater take consents for 3.883 m^3/s from the unconfined - semiconfined aquifer and 1929 groundwater take consents for 33.740 m^3/s from the confined aquifer. Of the total 1116 groundwater take consents approved in the last 5 years, 52 are for the unconfined - semiconfined aquifer and 1064 for the confined aquifer (S. Cameron and C. McLellan, HBRC, pers. comm.). The Heretaunga Plains estimated groundwater use during 1994 - 1995 was about 66 million cubic metres. Of this about 20 million cubic metres was pumped from the unconfined part of the aquifer and about 46 million cubic metres from the confined aquifer (based on average 10 hr/day and 200 day/year pumping) (see 6.5).

The most likely factor that is affecting piezometric levels is therefore increased abstraction throughout the Heretaunga Plains aquifer system. The maintenance of levels in the confined aquifer without any obvious decline for the last 125 years is unusual. Long-term (100 year) water level monitoring of wells tapping artesian aquifers underlying the city of Christchurch at the coastal margin of the Canterbury Plains, show that a significant (1 m) decline in artesian levels occurred at the turn of the century when at least 5000 wells had been drilled. Since then at Christchurch piezometric levels have fluctuated with cycles of decline during extended dry periods followed by a recovery of levels during wet periods. The main trend in artesian levels over the last 90 years has been the increasing amplitude between summer lows and winter highs (Brown & Weeber 1992). The Heretaunga Plains confined aquifer has maintained the original water levels which suggests that groundwater flow at the confined - unconfined boundary is primarily controlled by recharge of the confined aquifer. The impact of increasing groundwater abstraction is shown by the decline of water levels in wells in the unconfined - semiconfined sector.

There is no other long-term monitoring data to support this theory. One obvious monitoring strategy would be to regularly or continuously measure the outflow of groundwater at the confined - unconfined boundary, that forms the springs that are the source of water in the coastal Heretaunga Plains streams and drains. This “overflow” from the groundwater system should be sensitive to a pattern of over-withdrawal of groundwater from the unconfined - semiconfined aquifer. The other factors listed above that could be related to the contrasting trends in groundwater levels are speculative at this stage but should be considered in the planning of a long-term monitoring programme.

Figure 5.11 shows the water levels from three wells - Wellwood well (well no. 164) a water table well, and Talbot well NG7 (well no. 10326) and Pakipaki well (well no. 1266) penetrating the semiconfined aquifer at the southern margin of the Heretaunga Plains. These show increasing amplitude of seasonal fluctuation and little or no long-term change in the aquifer pressures during the period of record.

The Wellwood well is a water table well located immediately adjacent to the Ngaruroro River in the minor recharge area. The water level responds to river flow and seasonal fluctuations in groundwater related to abstraction. Talbot or NG7 well at Bridge Pa, shows seasonal fluctuations in water level due to groundwater abstraction and low water levels for the period 1982 - 1985, a period of low rainfall (see Fig. 5.11). The short record from the Pakipaki well tapping the semiconfined aquifer on the southern margin of the Heretaunga Plains also shows water level fluctuations due to seasonal groundwater abstraction for irrigation. The seasonal fluctuations in the Pakipaki well have a greater amplitude than the well at Bridge Pa, perhaps due to Pakipaki being on the fringe of the Heretaunga Plains aquifer system and as a result the aquifer is more susceptible to changes in groundwater storage related to abstraction. These three wells are located at the southern edge of the Heretaunga Plains aquifer system where increasing demand for a groundwater resource is limited by the capacity of the aquifer. This produces interference between wells and declining water levels during the summer irrigation season. This problem of summer groundwater depletion is suggested by the

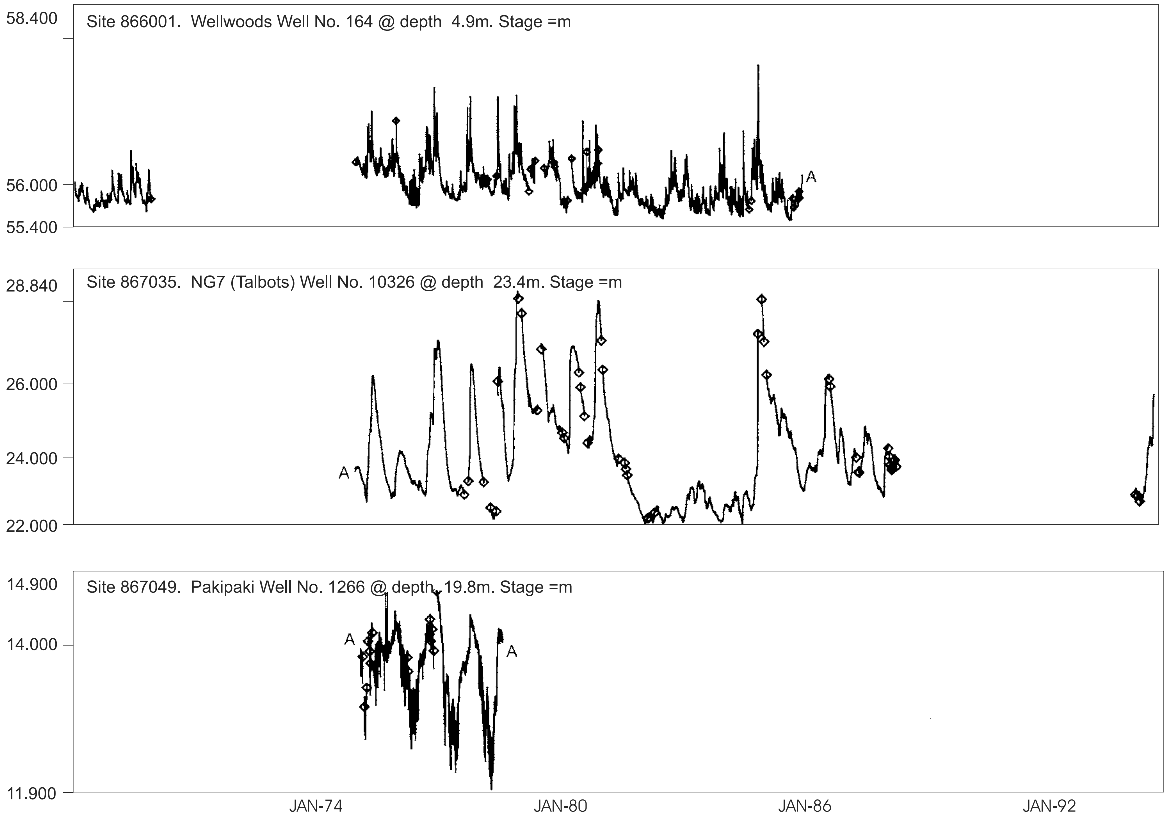


Figure 5.11: Comparison of water levels from Wellwood well, Talbot well and Pakipaki well.

Pakipaki well hydrograph which shows a progressive decline in summer water levels for the measurement period (summer 1976 to winter 1979). There is an urgent need to resume groundwater level monitoring on this or an equivalent well in the Pakipaki area.

5.3.3.1 River Aquifer Interaction

The concept that the groundwater in the Heretaunga Plains aquifers was derived from seepage from the rivers flowing over the Plains was first put forward by Hill (1887). Fluctuations of well water levels in response to high flows in the Ngaruroro River had been observed in wells about Hastings. Seepage from the Ngaruroro River was identified as the major source of recharge to the main aquifer system by Grant (1965). Gaugings of the surface flow along the Ngaruroro Riverbed were begun in March 1957 and losses of flow were identified in two stretches of river course. These stretches of the Ngaruroro River were termed the minor (between Maraekakaho and Roys Hill) and major recharge (between Roys Hill and Fernhill) areas based on the extent of flow losses from the Ngaruroro River. Water infiltrates from the river bed into the unconfined aquifer, and then flows through the subsurface gravel river channels to the hydraulically connected confined aquifer. The system of coalescing buried river channels act as conduits for relatively rapid groundwater infiltration and flow to the main aquifer system. The Ngaruroro River gaugings suggest a river loss between Maraekakaho and Fernhill in the order of 5 m^3/s with the main component (4.2 m^3/s) occurring between Roys Hill and Fernhill.

Continuous water level data from the Ngaruroro River and wells tapping unconfined and confined aquifers provide some information on the processes of groundwater recharge from the response of aquifers to flood events in the river. The lagged and damped response to river flow relates to the distance of the monitored well from the river channel and the depth of the aquifer. The transmission of pressure waves associated with rain and river flood events is a complex process and is likely to produce different responses in the unconfined and confined Heretaunga Plains aquifers depending on the location of wells in relation to the river.

Water level data obtained from wells in the groundwater recharge areas suggests that a flood in the Ngaruroro River creates three near simultaneous pressure waves which are transmitted at differential rates along three main buried groundwater recharge channels. The major recharge channels between Roys Hill and Fernhill and underlying Flaxmere have a very high transmissivity in the order of 20 000 to 30 000 m^2/day (Fig. 5.4), and are able to transmit a large volume of groundwater to the confined aquifer. In the unconfined aquifer area the recharge channel is at least 137 m thick and between Roys Hill and Fernhill (2 km), this channel could be up to about 1 km wide. The transmissivity contour map (Fig. 5.4) suggests other high transmissivity recharge channels occur northeast of Fernhill through to the Awatoto coast. The transmissivity of this channel is less (< 20 000 m^2/day) than the main channel but still very high in terms of volume of water stored and transmitted to the confined aquifer.

The minor recharge channel between Maraekakaho and south of Roys Hill is carved in the mudstone basement and intersects the major recharge channel near Flaxmere (see Fig. 4.2). Several bores on the southern margin of the Heretaunga Plains encounter the mudstone basement at a depth of about 30 to 40 m (see Fig. 5.39). Fine sand and silt in the matrix in the gravels in the Maraekakho - Ngatarawa area result in a low transmissivity in the order of 100 to 3000 m^2/day. Within the unconfined aquifer, gravels are often well sorted with minimal silt content, but there are commonly irregular localised lens shaped sandy clay layers distributed throughout the aquifer horizon especially near the ground surface, which impede groundwater flow and reduce transmissivity.

Figure 5.12 illustrates the transmission of a pressure wave transmitted along paleochannels south of Roys Hill towards Flaxmere and Ngatarawa in groundwater in the minor recharge area between Maraekakaho and Roys Hill. The Ngaruroro River gaugings suggest a river flow loss between Maraekakaho and south of Roys Hill in the order of 0.8 m^3/s (see 6.3.1.1). Flooding in the Ngaruroro River results in increased infiltration into groundwater recharge channels and groundwater levels in the unconfined aquifer adjacent to the river show a steep rise. The effect is similar to an increase in bank storage when the river is in flood.

Wellwood well (well no. 164) located immediately adjacent to the river in the minor recharge channel shows a response to a flood in the Ngaruroro River with a steep rise in well water level almost equal to the increase in river stage followed by a relatively slow decline in water level. However wells NG4 (well no. 3739), NG9 (well no. 1659) and NG10 (well no. 3744) located in the minor recharge area all show a rise in well water level more than the amplitude of increase in river stage. The maximum rise in well water level occurs in well NG4, which is located immediately adjacent to a water race about 500 m south of Roys Hill, with an increase almost twice that of increase in river stage. The hydrograph of well NG4 also shows that the subsequent decline in water level is delayed. The rise in well water level in well NG9 is less than NG4 but increases by about 50% more than the amplitude of the river stage. The well water level in well NG9 declines more rapidly than for NG4 and NG10. The recession is slowest in well NG10. The wells NG9 and NG4 are located adjacent to a major water race.

A number of inferences can be drawn from the above observations on transmission of the recharge pulse, the nature of the recharge channel and the permeability of aquifer material. The anomalously large rise and decline in well water level in well NG4 could be due to several factors:

- Susceptibility of the aquifer at this location on the fringe of the Heretaunga Plains aquifer system to be more affected by changes in groundwater storage related to abstraction (as occurs at Pakipaki (see 5.3.3)).
- Increase in bank storage and differential rate of dispersion.
- Leakage from the water race.
- Limited channel capacity.

The well NG10 is located on the edge of the major recharge channel and therefore the well water level is probably affected by excess water spilled out of the main recharge channel. More observations are necessary in order for recharge and the propogation of recharge pulses in the minor recharge area to be investigated.

Pressure waves also originate from high Ngaruroro River flows in the major recharge area between Roys Hill and Fernhill. Figure 5.13 shows a wavefront induced water level fluctuation in well 7D, Portsmouth Road, Flaxmere. A pressure wave effect emanating from the recharge area would be expected to show lagged and dampened water level fluctuations in wells along

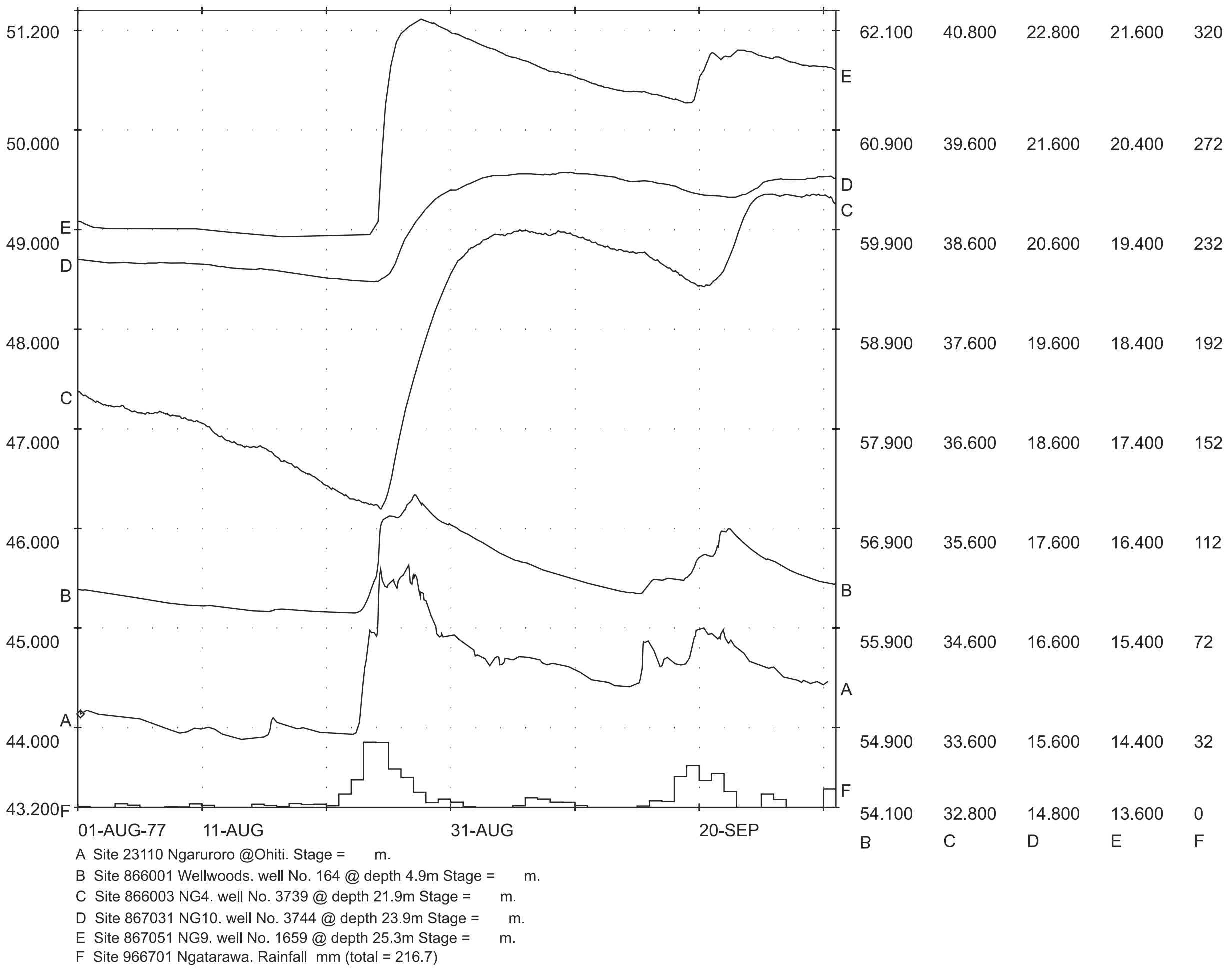


Figure 5.12: Propogation of recharge pulse along the paleochannels south of Roys Hill towards Flaxmere and Ngatarawa.

an old river channel and would be barely detectable in wells in the confined aquifer sector. A difficulty in detecting recharge pressure waves is that river floods are often accompanied by rain on the plain (see Figs. 5.12 and 5.13) and a resulting decrease in groundwater abstraction as irrigation and home garden watering is replaced by rain. Continuous water level data showing response of well water levels to flood events in the river suggests that the amount of water infiltrating into the groundwater system depends on how long the river remains in flood and on the water level in the adjacent aquifer at the time. Once water levels have risen as a result of groundwater recharge during a river flood event, subsequent flood peaks only produce small additional pressure waves and small increases in well water levels, and the pressure wave transmitted through the aquifer is of smaller amplitude.

Wells penetrating the confined aquifer also show a rise in water level when the Ngaruroro River is in high flow (Communitor well no. 3358, Awatoto - Fig. 5.13), but the rise in level is not simply just due to a pressure wave caused by recharge. High flows in the Ngaruroro River are the product of rain in the river catchment. This rain can also fall on the Heretaunga Plains resulting in a decline in groundwater abstraction for irrigation on the Plains and for garden watering in urban areas. Water levels in wells tapping confined aquifers fluctuate

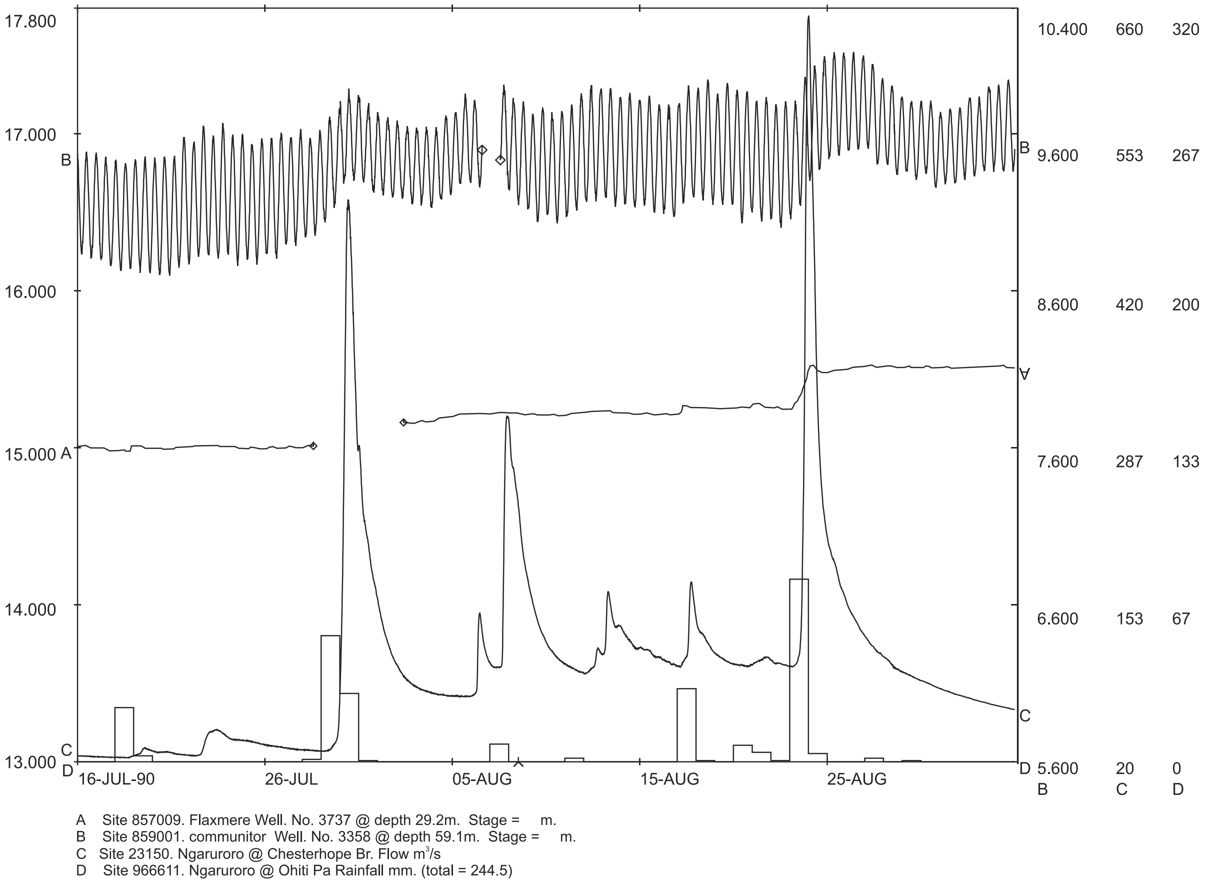


Figure 5.13: Propagation of recharge pulse along the paleochannel between Roys Hill and Fernhill and Flaxmere and water level fluctuation in a well at the Awatoto coast.

almost immediately in response to loading or pressure effects. These include atmospheric pressure, ocean tides, loading from soil moisture increase in the surface confining layer caused by rain, and loading due to the increased weight of the flooding river when the well is located adjacent to the river. In Figure 5.13, the Communitor well is clearly responding to ocean tides. Also a rise in water level caused by loading from flooding in the nearby Tutaekuri and Ngaruroro rivers and from local rain, and a response to decreased groundwater abstraction are imposed over the tidal fluctuations. In addition, because Awatoto is an industrial area, there is likely to be a component of industrial pumping affecting the entire continuous hydrograph record. This is demonstrated by Figure 5.14 which shows detailed hydrographs of three wells tapping the confined aquifer at Paxie well (well no. 3779), South Napier, a Napier City water supply well at Anderson Park, (well no. 3781) and the Game Farm well, Greenmeadows (well no. 6023), during a 11 day period when there was local rain and a flood event in the Ngaruroro River. A rise in well water level has occurred in response to decreased groundwater abstraction due to the rain and to loading due to rain and river flooding. Superimposed on this rising water level are the effects of municipal and industrial abstraction with declining levels during the day and recovery at night.

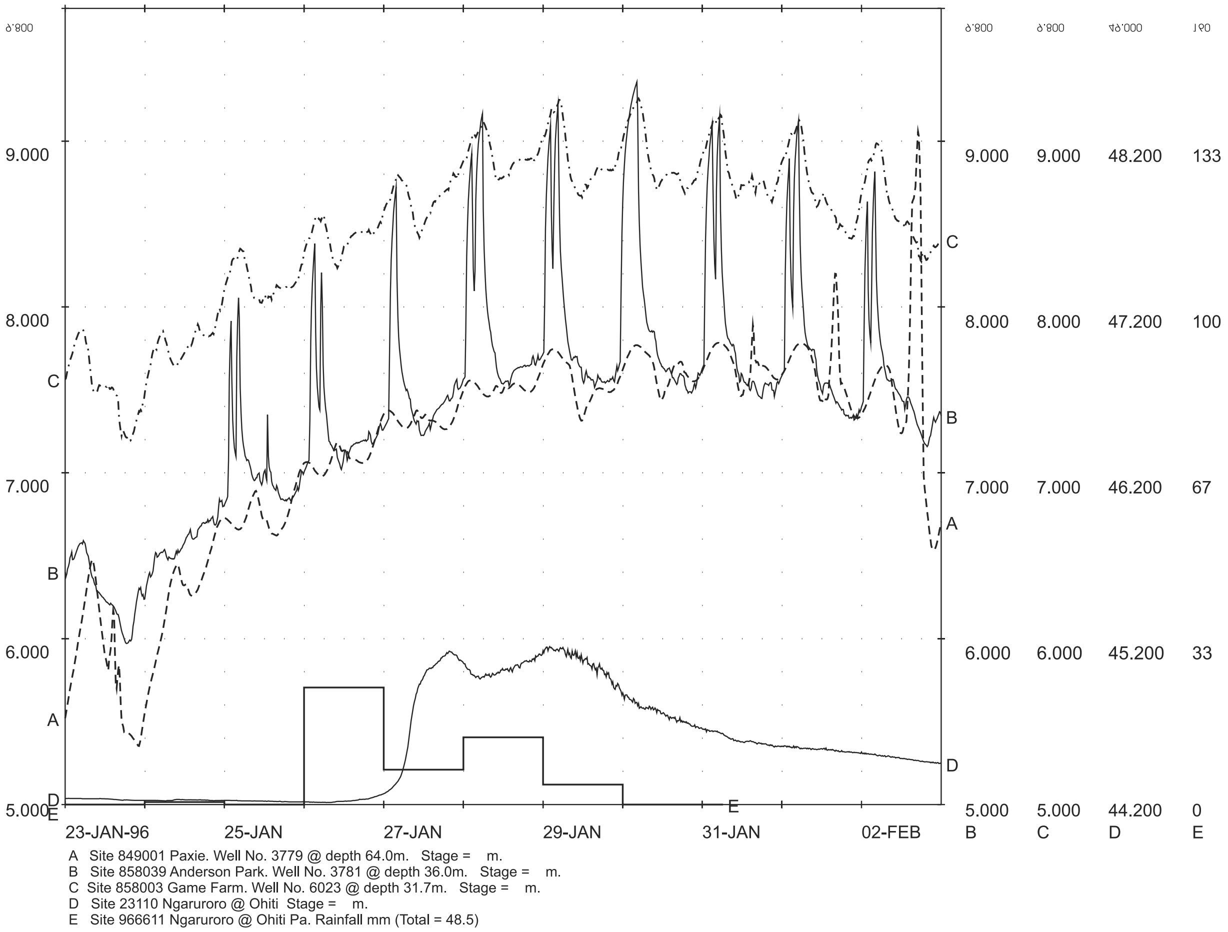


Figure 5.14: Propagation of recharge pulse along the paleochannel from Omahu north of Fernhill towards south Napier.

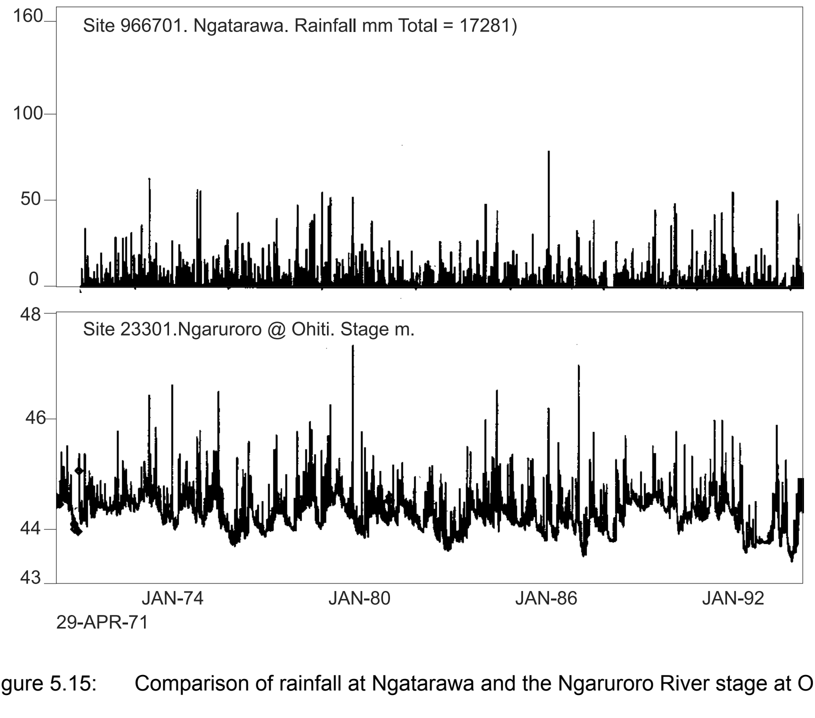


Figure 5.15: Comparison of rainfall at Ngatarawa and the Ngaruroro River stage at Ohiti.

Figures 5.16 and 5.17 are long-term multiplots of the Ngaruroro River stage at Ohiti and rainfall at Ngatarawa on the Heretaunga Plains during the period 1974-95. Rainfall in the Ngaruroro River catchment produces an increase in river flow. Rainfall as measured at Ngatarawa Station (V21/294660) usually matches rain in the Ngaruroro River catchment as is shown by the close agreement of river flow and Ngatarawa rainfall measurements in Figure 5.15.

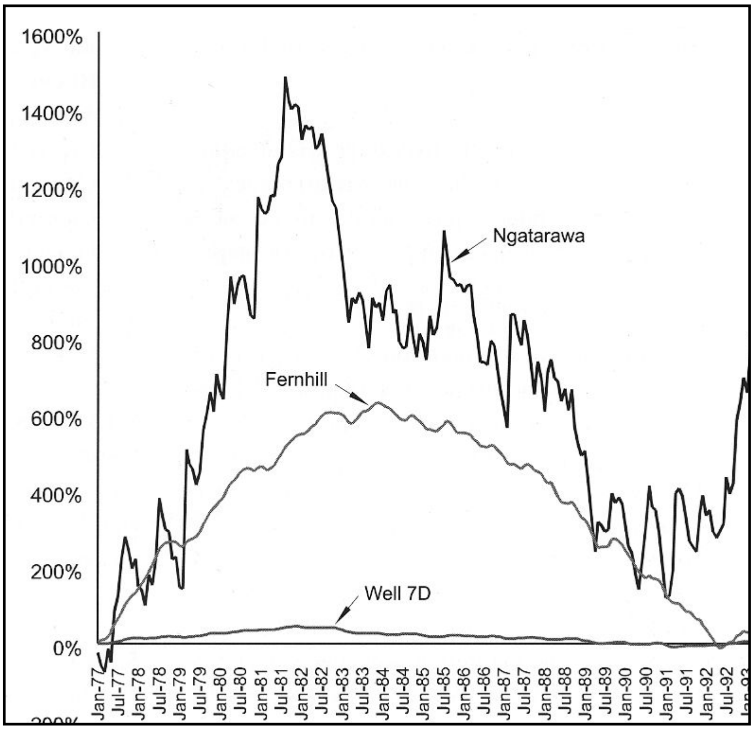


Figure 5.16: % cumulative monthly mean deviation from long-term mean Ngatarawa rainfall, Ngaruroro River stage at Ohiti, water level in well 7D.

Figure 5.16 shows the cumulative monthly mean deviation from mean of Ngaruroro River level (stage), Ngatarawa rainfall and water levels in well 7D, Flaxmere. The plots have been produced by accumulating the positive and negative departures from the monthly means. The Ngatarawa rainfall and the Ngaruroro River stages at Fernhill suggests that rain and river levels were above average from 1977 to 1982 before they began to decline. There is agreement between the graphs for the Ngaruroro River level, the Ngatarawa rainfall and well 7D water levels which emphasise the river recharge - groundwater level relationship.

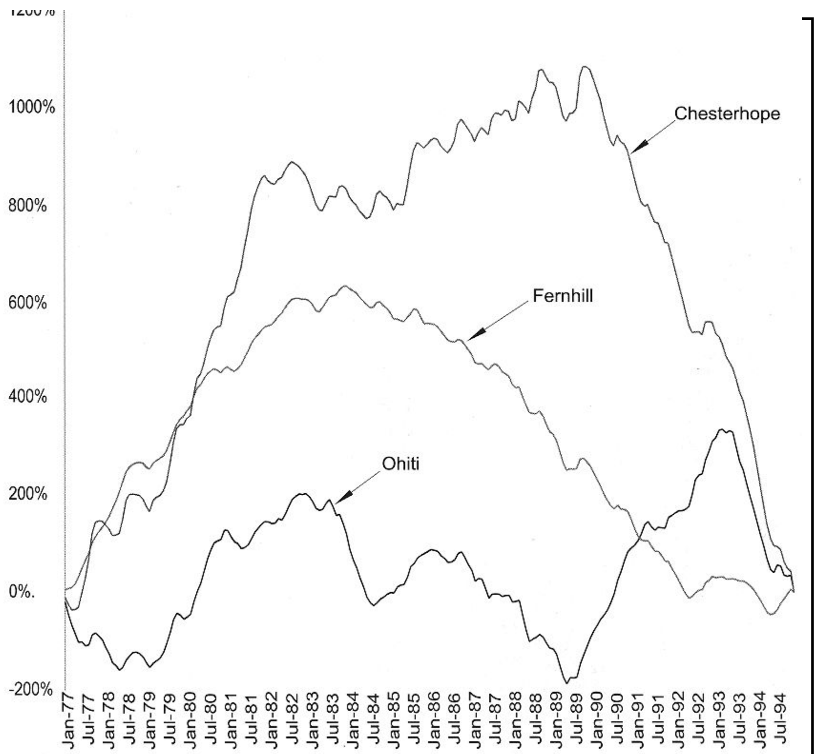


Figure 5.17: % cumulative monthly mean deviation from long-term mean Ngaruroro River stages at Ohiti, Fernhill and Chesterhope.

Figure 5.17 shows the cumulative monthly mean deviation from the Ngaruroro River stage at Ohiti, Fernhill, and Chesterhope. The plot of the % cumulative deviation from the long-term mean for the Ngaruroro River stages at Chesterhope and Fernhill are similar whereas the plot for Ohiti is different.

At Ohiti, the Ngaruroro River flow was below average for 1977 - 1979, 1983 - 1984 and 1987 - 1989, and at Fernhill for 1990 to the present day. This is different to the downstream river stage at Fernhill which shows a prolonged period (1977 to 1984) of above average stage followed by a decline with minor fluctuations to the present day. The plot of Ngaruroro River stage at Chesterhope suggests above average stage from 1977 to 1982 followed by slightly above average stage to 1990 and a below average period to the present day.

The contrast in the graph of the river stage at Ohiti compared with the graphs of the downstream stages at Fernhill and Chesterhope is probably due to a combination of factors, which make comparison of river stages at the three stages meaningless:

- The infiltration of a proportion of the Ngaruroro River flow into adjacent unconfined aquifers reduces the surface flow of the river which in turn reduces the capacity of the river to transport the sediment load downstream. As a result the river may aggrade in this stretch of its course and forms a wide bed with meandering and constantly changing braided river channels which make comparative stage measurements difficult to achieve. Between Maraekakaho and Fernhill, it is estimated that c. 5 m^3/s of a Ngaruroro River flow of up to 35 m^3/s infiltrates to groundwater. This probably varies depending upon the river flood level and the water levels in the aquifer adjacent to the river.
- The Tutaekuri River losses of 0.8 m^3/s to groundwater in the Moteo Valley contributes to the flow of the Tutaekuri - Waimate Stream, which joins the Ngaruroro River flow up stream of Chesterhope Bridge. The contribution of the Tutaekuri - Waimate Stream and other surface flows and the springs to the Ngaruroro River between Fernhill and Chesterhope will result in variations to the Chesterhope stage.
- Gravel extraction from the Ngaruroro River bed at Fernhill and between Ohiti and Fernhill may affect the Fernhill stage by causing changes to the riverbed profile and river channel configuration (see 2.9).

5.3.4 Short-term Groundwater Level Trends

Short-term water level fluctuations are due to both natural and manmade causes and include seasonal, weekly and daily fluctuations responding to tidal cycles, municipal, industrial and irrigation abstraction interference, and earthquake shaking.

5.3.4.1 Seasonal Fluctuations

Heretaunga Plains aquifer groundwater levels fluctuate due to increased summer groundwater abstractions, and lower summer rainfall and river flow. The normal seasonal trend for the Heretaunga Plains unconfined (Fig. 5.9) and confined (Fig. 5.10) aquifers is a summer decline followed by a winter recovery. Figure 5.18 illustrates the seasonal fluctuation for the confined aquifer observed at the Communitor well (well no. 3358)

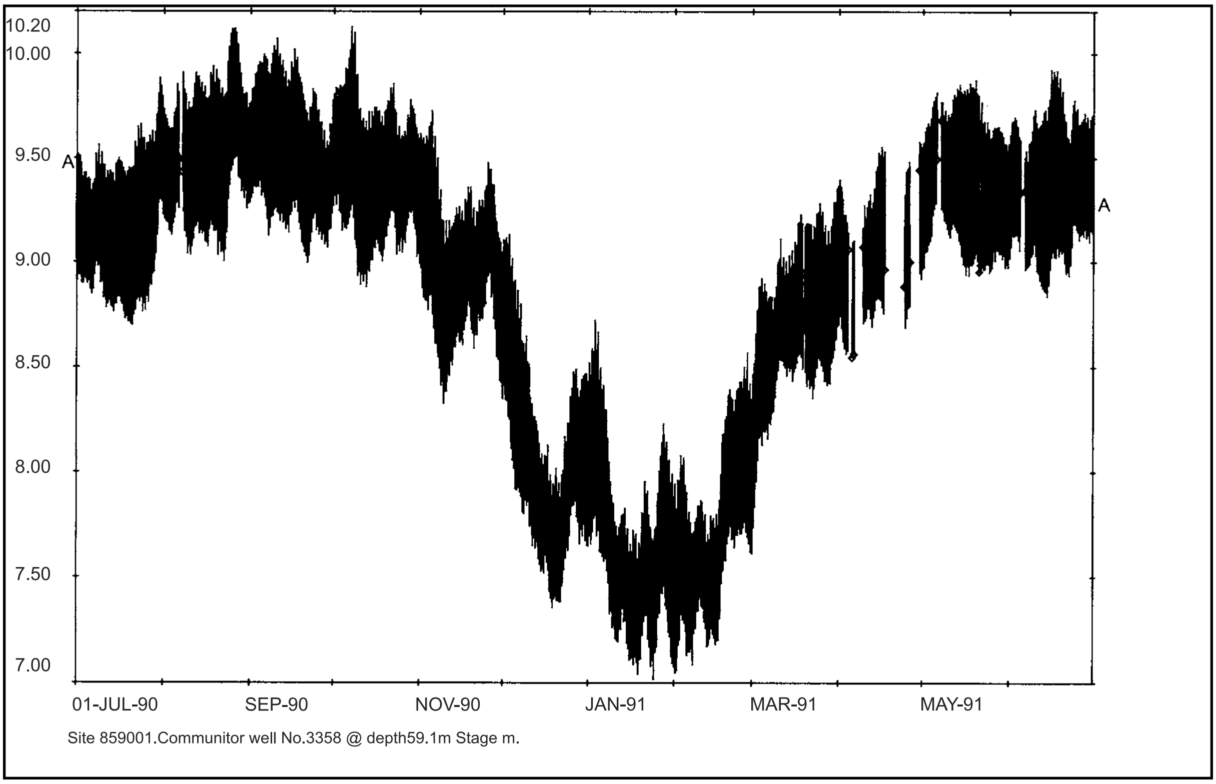


Figure 5.18: Seasonal water level fluctuations observed at Communitor well Awatoto.

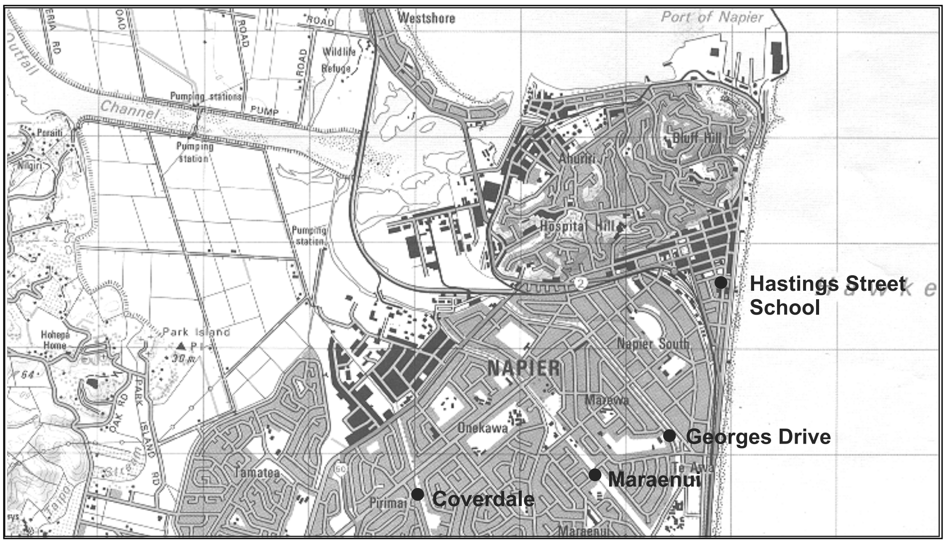


Figure 5.19: Location of wells showing tidal induced fluctuations.

at Awatoto during the July 1990-June 1991 period and Fig. 5.10 shows comparison of long-term continuous water levels from three wells tapping the confined aquifers. Generally during the summer the piezometric surface is about 1.5 - 2.5 m lower than during the winter.

5.3.4.2 Tidal Fluctuations

The rise and fall of oceanic tides produce tidal fluctuations in the water levels of wells as a function of the changing pressure (weight) on the Hawke Bay sea bed. The changes in pressure are transmitted through the elastic and incompetent confining strata, aquifers and aquicludes. Within aquifers part of the pressure is borne by the gravel and sand sediments and part by the confined groundwater, and is transmitted to the coastal onshore sector of the Heretaunga Plains aquifer system.

Near the coast, tidal induced fluctuations are observed in water levels for the confined aquifer. Figure 5.19 shows the location of wells showing tidal induced fluctuations

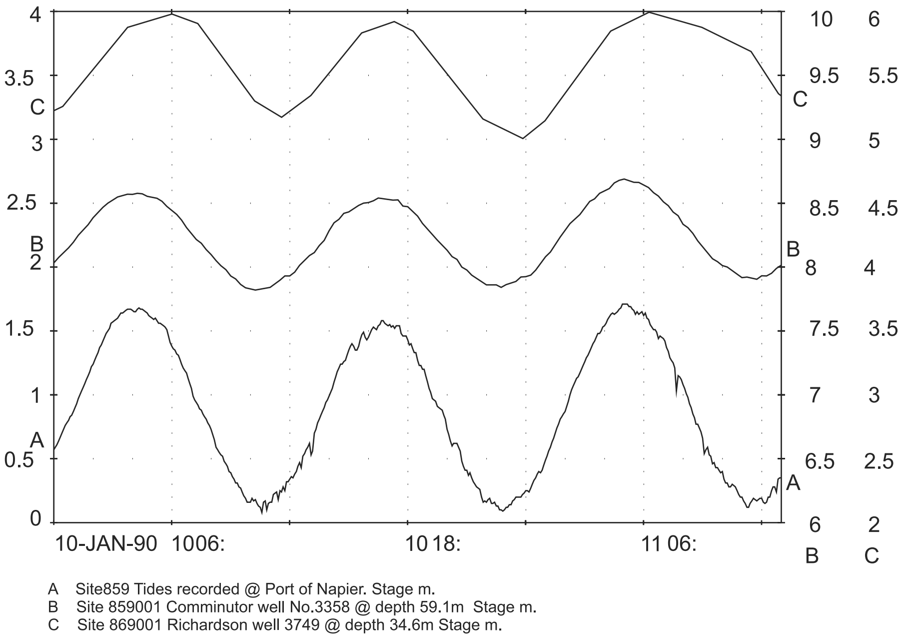


Figure 5.20: Tidal influence on coastal bores in Communitor well Awatoto and Richardson well Haumoana.

at Napier and Table 5.5 lists the mean tidal range and tidal effeciency.

Figure 5.20 illustrates tidal response on coastal bores near Awatoto and Haumoana. Price & Hawkins (1979) used the continuous water level data from four Napier City Council wells tapping the confined aquifer to analyse the tidal influence on water levels in terms of mean tidal response, mean tidal range and tidal efficiency. Table 5.5 shows the result of this analyses.

Well Name	Grid Reference	Well Depth (m)	Mean Tidal Response-(m)	Mean Tidal Range (m)	Tidal Efficiency-(%)	Distance-from Coast (m)
Hastings St. School	V21/468826	95	0.52	1.4	37	180
Georges Drive	V21/465810	66	0.4	1.1	36	400
Maraenui	V21/457808	64	0.18	1.2	15	1300
Coverdale Street	V21/440806	77.7	0.15	1.2	13	2800

Table 5.5: Tidal Influence on aquifer levels.

At a distance of 180 m from the coast the magnitude of tidal fluctuation is 0.52 m with a tidal effeciency of 37% and at about 2.8 km from the coast the magnitude of tidal fluctuation is reduced to 0.15 m and the tidal effeciency is 13% (Table 5.5 and Fig. 5.21). The circular chart from the continuous water level recorder illustrating the tidal influence is reproduced in Figure 5.20. The Napier Harbour Board has monitored tide levels since 1940. The tide gauge is sited at Napier Harbour on a concrete pier.The tidal fluctuations recorded at the Port of Napier have been drawn on the chart.

Figure 5.21 illustrates a graphical plot of mean tidal response to the distance from the coast. Figure 4.13 illustrates the effect of tides on four piezometers (39, 59, 101 and 163 m depth) from the Awatoto groundwater testbore (well no. 3699). The water level in all piezometers fluctuate with tides, but with the fluctuation amplitude decreasing with depth. Progressively damped tidal fluctuations with depth, in theory, suggest aquifer outlet areas at different locations offshore.

The existence and location of offshore aquifer outflow areas in Hawke Bay is an important factor for the Heretaunga Plains groundwater resource management. If the aquifers have an outlet beyond the Hawke Bay coastline, the groundwater pressure should be balanced

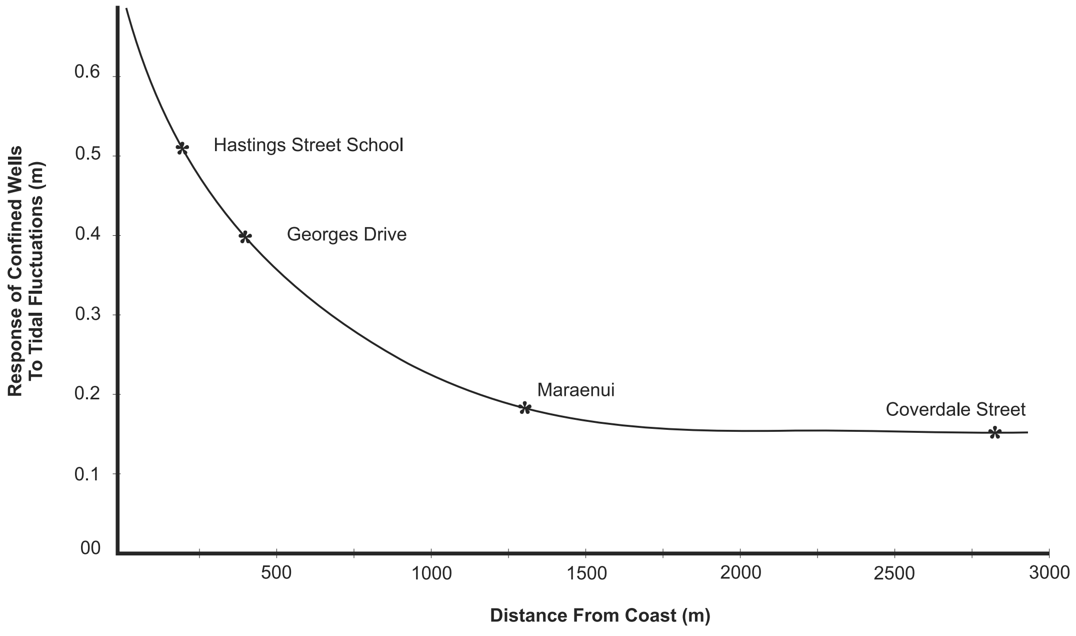


Figure 5.21: Graphical plot of mean tidal response to the distance from the coast.

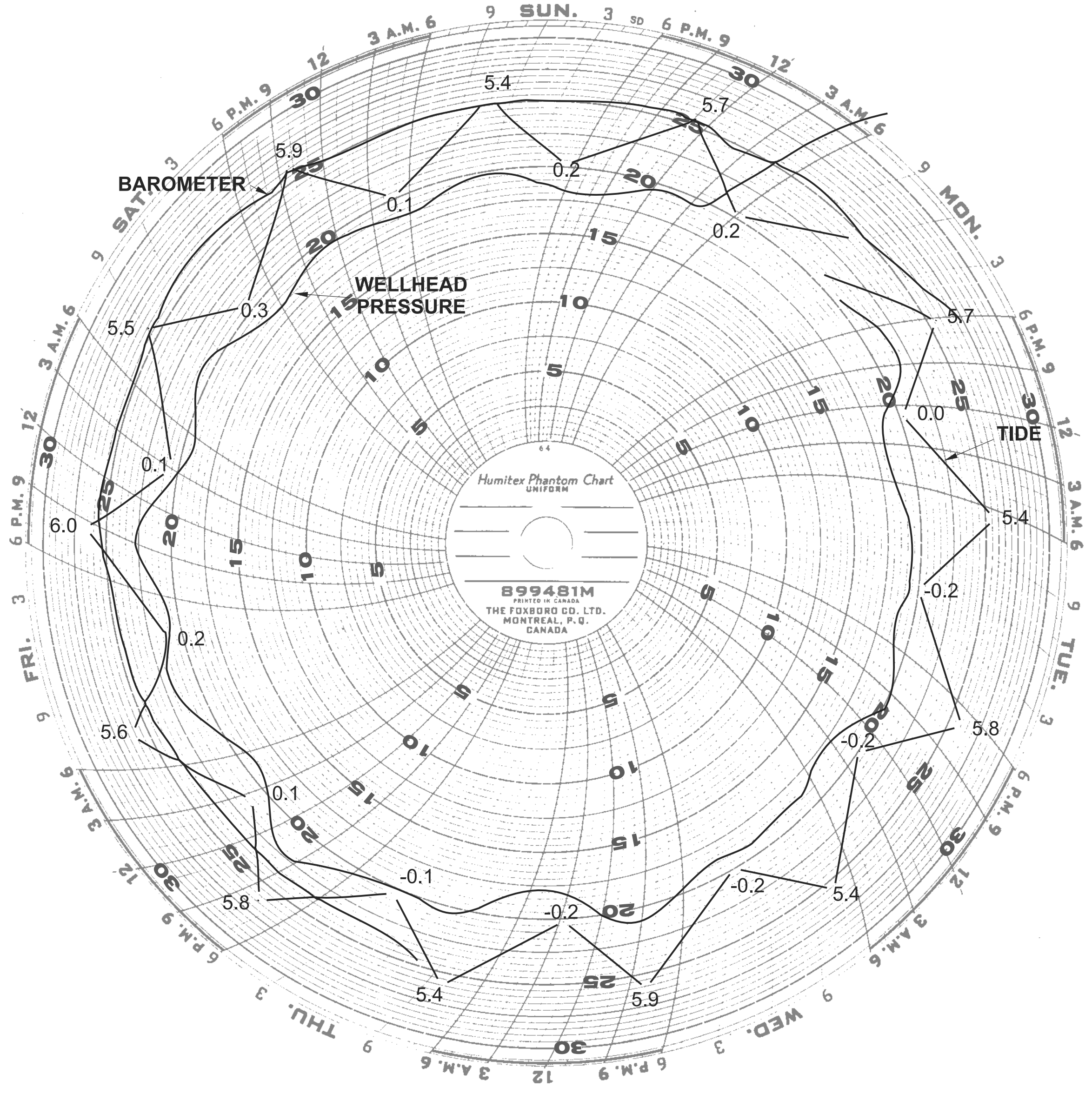


Figure 5.22: Tidal influence on the Georges Drive, Napier bore on 28.06.65.

by inward pressure of sea water at the offshore outcrop of the aquifers. If onshore abstraction exceeds recharge, the boundary between sea water and fresh water in the aquifers would be moving towards the coast (westwards) and would eventually result in sea water intrusion into the onshore sector of the aquifers. The tidal fluctuations measured at various depths in the Awatoto testbore provide more information on the onshore outflow.

In 4.2.2 it was concluded that the relatively low gradient of the confined aquifer make it likely that only the upper levels of the aquifer would outcrop in Hawke Bay and provide a source of freshwater for the submarine springs (Fig. 2.25). The Awatoto testbore water level fluctuations for the four piezometers (39, 59, 101 and 163 m depth) are all in phase with tidal fluctuations but the fluctuation amplitude is dampened with depth (Fig. 4.13). This supports the concept of a common offshore outlet as would occur for a low gradient confined aquifer. If the deeper aquifers outcropped further from the shore the peak levels corresponding to high tide would be expected to lag behind the shallow aquifer water level peaks because of the greater distance onshore for transmission of the pressure wave.

Onshore the tidally induced water level fluctuations in wells also occur in phase regardless of well depth and distance from the coast. Tidal efficiency varies with distance and well depth suggesting that factors such as well construction and aquifer transmissivity may dampen the response. This contrasts with the results of a study of tidal fluctuations in wells of various depths in the Christchurch artesian system where all aquifers were affected simultaneously and equally by tidal fluctuations and time lag and tidal effeciency decreased equally for all aquifers inland from the coast (Oborn 1960). The Christchurch aquifers are moderately-to-highly incompetent and elastic (Oborn 1960), whereas the Heretaunga Plains aquifers seem to be more unpredictable in their response suggesting heterogenuities of lithology, permeability and thickness of aquifer channels, aquicludes and confining beds, which results in variation of elasticity.

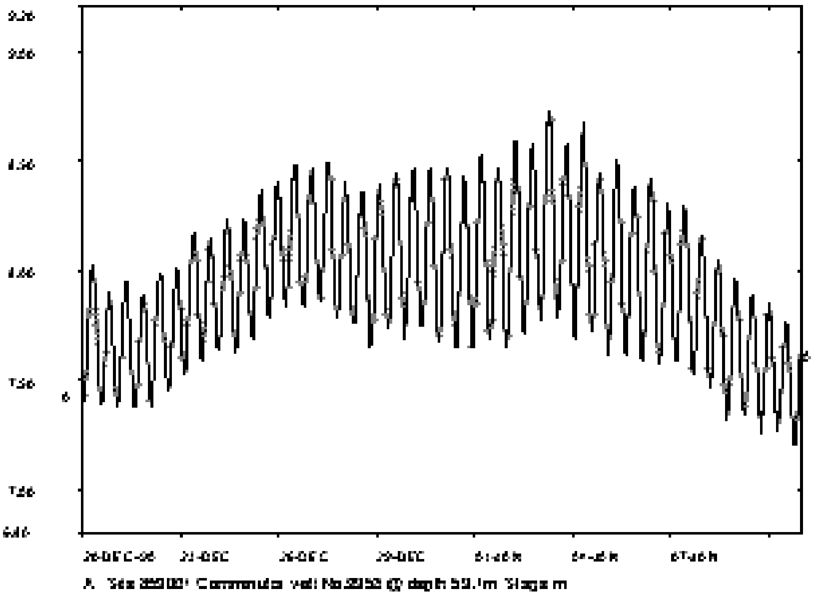


Figure 5.23: Fluctuation due to industrial pumping, abstraction, and rain and river loading rise in water level in Communitor well Awatoto.

The inferences are that the Heretaunga Plains coastal confined aquifers have a common outflow in Hawke Bay with the tidal fluctuations being a result of aquifer loading which is transmitted over 2.8 km inland from the coast with tidal efficiency of 13% affected by well, aquifer and lithologic variability

5.3.4.3 Fluctuation due to Pumping

Besides the long-term and seasonal fluctuations in well water level produced by groundwater abstraction, localised abstraction fluctuations in water levels occur in confined and unconfined aquifers as a result of pumping interference by adjacent wells or groups of wells. These are most obvious for wells tapping confined aquifers as water level reflects changes of groundwater pressure transmitted through the aquifer system as a result of abstraction, recharge and loading influences.

Figure 5.23 shows detailed tidal fluctuations in the Communitor well (well no. 3358) located in the industrial area near Awatoto. Imposed on the tidal fluctuations are a rise in water level associated with the shut down of industry over the Christmas - New Year holiday period and abstraction and loading rises produced by local rain and flooding in the nearby Tutaekuri and Ngaruroro rivers.

Figure 5.24 shows the water level in the Paxie well (well no. 3776) located in Vigor Brown Street fluctuating with pumping interference from a Napier City water supply well. The early morning high tide peak shows in the well water level after a delay of about 2 hours and a tidal efficiency of about 35%. However the city water supply well (probably a Napier City water supply well in Nelson Park) is pumped from about 0800 hours to 2400 hours each day and completely masks the tidal peak that would have been associated with the early afternoon high tide. The “spikes” in the water level record are probably a result of temporary recoveries while pumping wells at Nelson Park are being changed.

The Paxie well is also affected by industrial pumping. Figure 5.25 shows the Paxie well hydrograph where the daily decline in water level due to abstraction is less from the afternoon of Friday 23 December at the start of the Christmas holidays through to the end of the holidays on Tuesday 28 December, a period when most industry would be closed down. Over this period water levels rose. This in part was also aided by local rain and a flood in the Ngaruroro River on 24 December.

Figures 4.10 and 5.26 shows fluctuations in the piezometers in the Tollemache Orchard well on the western edge of the confined aquifer system and in well 7D in the semiconfined aquifer area. There is a suggestion in the hydrographs that the Tollemache Orchard well might be responding to tidal fluctuations. However the main pattern is that of a decline in water

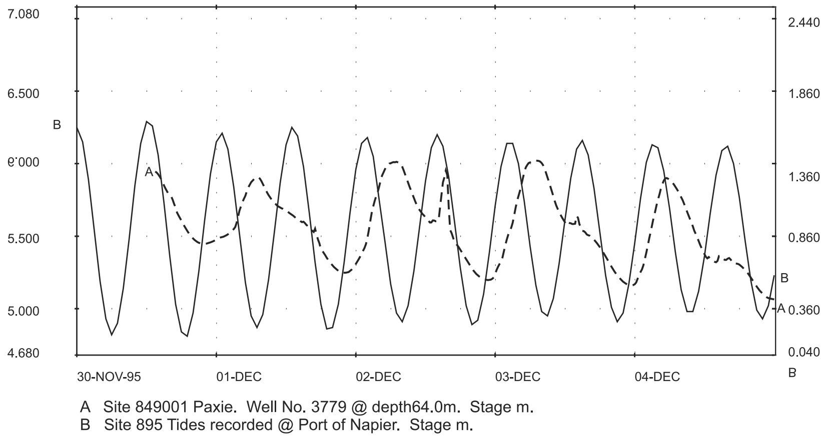


Figure 5.24: Municipal pumping affecting tide induced fluctuations.

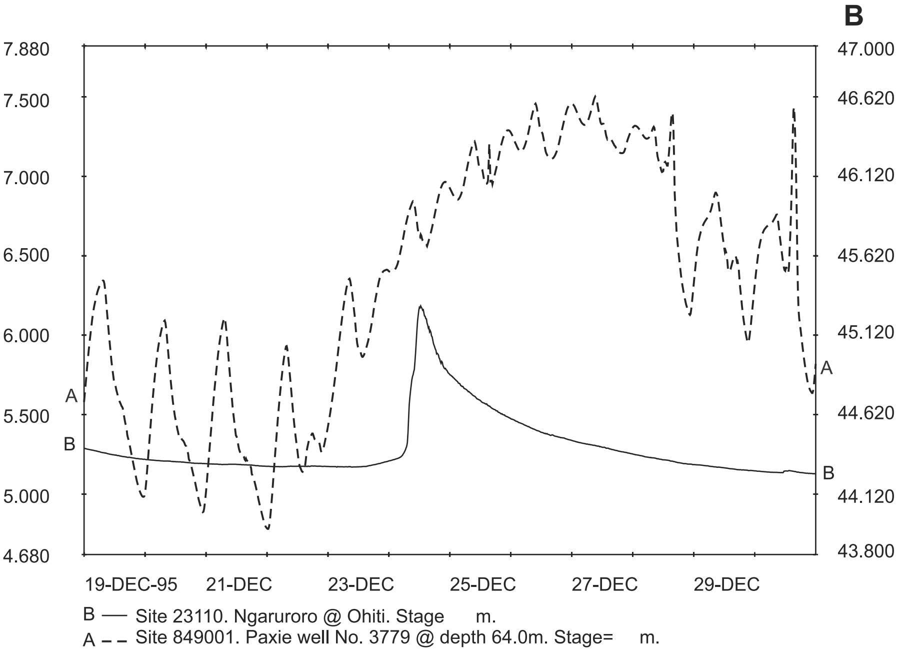


Figure 5.25: Recovery of water level associated with industry shut down over Christmas.

level in the early hours of the morning. The period covered by this record is spring when groundwater is abstracted and sprayed on to fruit trees to prevent frost damage of blossom. This early morning decline in water level could be related to local frost protection abstraction. Well 7D (well no, 3737), Portsmouth Road, Flaxmere is located on the boundary between the unconfined and confined aquifer. In Fig. 5.26 the well 7D hydrograph shows declining water levels responding to daytime pumping from the aquifer and a recovery of water level at night. This demonstrates that pumping interference fluctuations are also shown by wells tapping unconfined and semiconfined aquifers.

5.3.4.4 Earthquake Induced Fluctuations

Long-term continuous water level data from three wells tapping the unconfined and semiconfined aquifers of the Heretaunga Plains were examined to study the effects, if

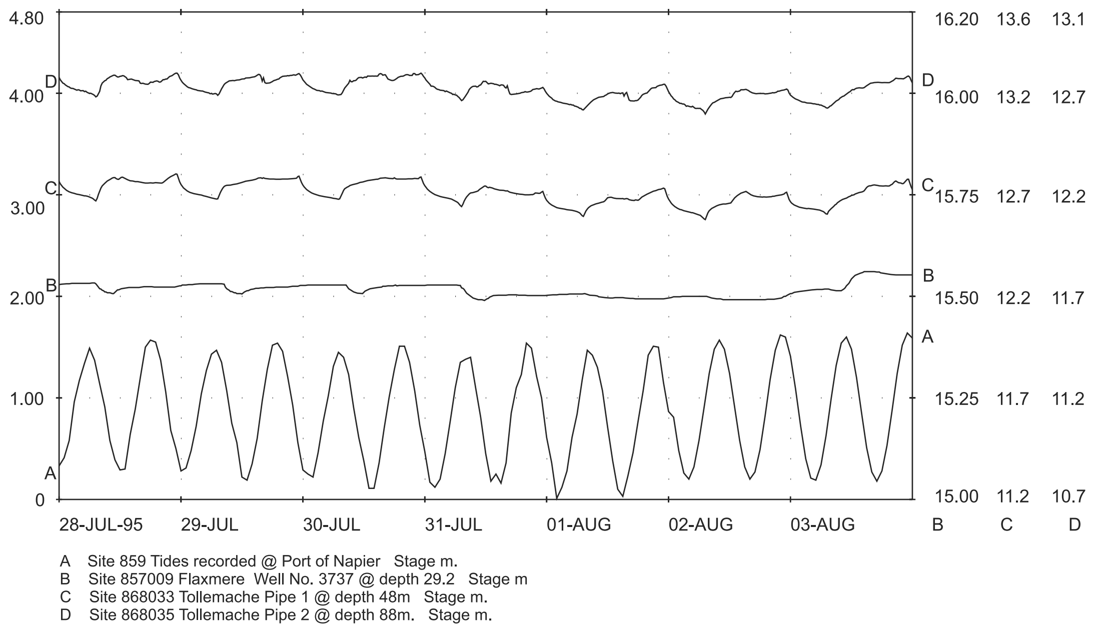


Figure 5.26: Frost protection pumping affecting water levels in the early hours of the morning.

any, of earthquakes on water level and artesian pressure. Table 5.6 summerises the results of earthquake response and Table 5.7 relates Richter scale magnitude to earthquake intensity (modified Mercalli).

The earthquake data on location, depth, Richter scale magnitude, modified Mercalli intensity were obtained from the Seismological Observatory, Institute of Geological and Nuclear Sciences for all the earthquakes felt in the study area during 1973 - 1994. The water level at substation well (well no. 952) located in the unconfined aquifer area (V21/325713) responded most; to six earthquakes, out of which, five earthquakes were more than 5 on Richter scale magnitude. The maximum response observed in the water level was a 69 mm fluctuation as a result of an earthquake on 21 February 1973 centred near Pakipaki with Richter scale magnitude of M5.4 (Fig. 5.27).

Lagoon Farm well (well no. 1284) on the western margin of the Ahuriri Lagoon penetrates a shallow semiconfined aquifer and responded with a water level fluctuation of 11 mm to an earthquake with a magnitude of M5 centred near Hastings on 11 April 1993. The Waima well (well no. 1001) located on the north bank of the Ngaruroro River east of Omahu, penetrates a semiconfined aquifer and showed a 45 mm fluctuation in water level to the same earthquake.

The fluctuations in well water levels due to earthquakes does not appear to follow any obvious pattern nor result in permanent change in the water level. There is no suggestion of permanent change (depletion or increase) in aquifer storage which would be a product of structural damage to the aquifer - aquiclude sequence.

The 1931 Hawke's Bay earthquake provides the only historical record of the effect of a major earthquake on aquifers, wells and groundwater supply for a coastal alluvial plain layered aquifer system in New Zealand. Henderson (1933) summarises some of the observations of the effects of the earthquake on the Heretaunga Plains:

"At several points, all of them near the mouths of streams, the beaches are ridged and furrowed, probably by adjustments in the softer and less compact mud underlying the masses of sand and gravel on the surface.

During and after the earthquake large quantities of water, sand, and mud issued from fissures in the alluvial flats. The origin of these sand vents is to be sought in the water-saturated layers at different depths below the surface. These water-bearing layers are the source of artesian supplies so abundant in the Heretaunga

Date	Lat.	Long.	Depth (km)	Mag.	Intensity	Area	Sub Station Response in mm	Lagoon Farm	Waima
730105	39.10	175.20	173	7.0	5	Napier	61	-	-
730221	39.70	176.80	12	5.4	5	Hastings, Napier	69	-	-
771030	39.60	176.90	33	5.0	5	Napier	NSR	-	-
300703	40.40	176.90	33	5.2	5	Hastings	MR	-	-
301005	39.70	176.90	30	5.6	3-8	Hastings (Int=6) Napier	MR	-	-
320205	40.70	175.90	33	5.2	5	Hastings	NSR	-	-
320902	39.70	176.90	41	5.4	6	Hastings	NSR	-	-
340308	38.20	177.40	75	6.4	5	Hastings	18	-	-
340817	39.60	176.60	84	5.3	5	Napier	NSR	-	-
370302	37.89	176.80	10	6.0	5	Hastings	60	-	-
380906	40.41	176.81	64	5.1	5	Hastings	NSR	NSR	-
900219	40.47	176.44	34	5.9	-		52	NSR	-
910415	39.99	176.79	26	4.7	-	Hastings, Napier	NSR	NSR	-
910712	39.31	175.97	70	6.2	4	Hastings, Haumoana	NSR	NSR	-
910901	39.84	177.01	47	4.3	4	Hastings, Napier	NSR	NSR	-
910908	40.24	175.17	87	6.3	5	Whakatu	NSR	NSR	-
911023	36.98	177.26	217	6.0	6	Napier	NSR	NSR	-
911116	37.13	176.89	264	6.4	4	Hastings, Napier	NSR	NSR	-
911122	39.41	177.09	23	4.4	4	Hastings	NSR	NSR	-
920302	40.43	176.60	37	5.8	4	Hastings, Havelock N.	40	NSR	NSR
920304	39.60	177.83	45	4.7	4	Hastings, Napier	NSR	NSR	NSR
920318	40.42	176.50	42	4.4	-	Porangahau	NSR	NSR	NSR
920819	38.90	177.06	51	4.3	-	Napier	MR	NSR	NSR
921107	39.76	176.83	28	4.0	4	Bridge Pa	NSR	NSR	NSR
930211	40.15	176.54	46	4.6	4	Hastings, Npr. Whakatu	NSR	NSR	NSR
930216	40.08	176.97	40	5.1	4	Hastings, Napier	NSR	NSR	NSR
930411	39.72	176.70	34	6.1	5	Hastings, Napier	NSR	11	45
930505	39.49	177.37	26	4.8	4	Napier. Taradale (Int=3)	NSR	NSR	NSR
930516	39.98	176.96	32	4.4	4	Hastings, Npr, Whakatu	NSR	NSR	NSR
930802	37.40	176.90	234	5.9	-	Napier	NSR	NSR	NSR
930810	38.52	177.93	40	6.3	4	Hastings, Haumoana	NSR	NSR	63
930902	39.81	176.89	45	3.9	4	Havelock N., Whakatu	NSR	NSR	NSR
930922	39.51	176.90	16	3.6	-	Napier	NSR	NSR	NSR
931116	39.97	176.24	46	4.7	-	Havelock North	NSR	NSR	MR
940517	39.76	177.16	53	3.8	-	Napier	NSR	NSR	NSR
940703	39.55	176.87	21	3.1	-	Napier	NSR	NSR	NSR
940910	37.98	176.87	126	5.9	3	Napier	NSR	NSR	MR
941003	39.38	176.86	56	3.7	-	Napier	NSR	MR	MR

NSR - No significant response.
MR - Missing record

Table 5.6: Earthquake response of Heretaunga Plains well water levels and artesian pressures.

Richter Scale Magnitude	Expected Modified Mercalli Max. Intensity (@ epicentre)	Effect
2	I-II	Usually detected by instruments only
3	III	Felt Indoors
4	IV - VII	Felt by most people, slight damage
5	VI - VII	Felt by all. Damage minor-moderate
6	VII - VIII	Damage moderate - major
7	IX - X	Major damage
8+	X - XII	Fatal major damage

Table 5.7: Comparison of earthquake magnitude and intensity.

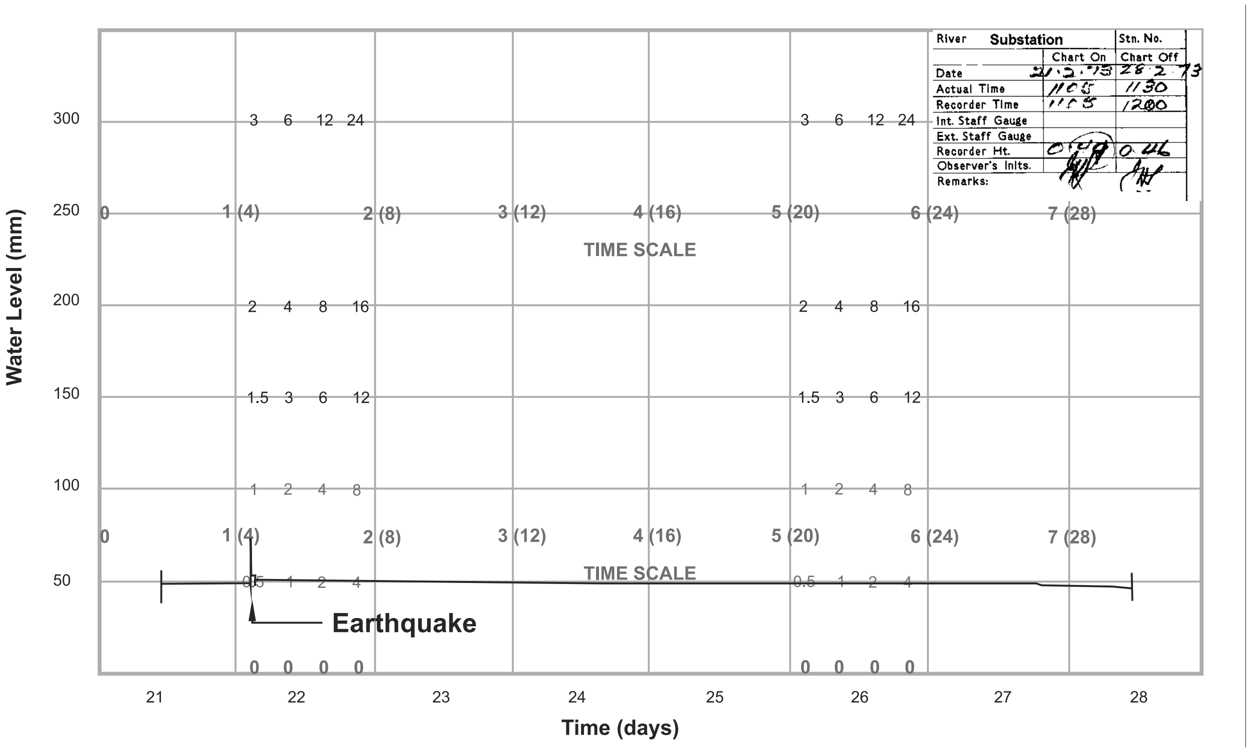


Figure 5.27: Effect of earthquake on aquifer level at substation well Fernhill.

Plains. As was to be expected, the earthquake choked some artesian wells, broke the pipes of others, and in places so altered the underground circulation that water ceased to flow. At Mangateretere a farmer, endeavouring to get a well to flow again, found that a crowbar lowered 80 ft below the surface was on withdrawal too hot to hold".

Callaghan (1933) reviewing the effects of the Hawke's Bay earthquake on water supply noted that -

"The Sanitation and Water Committee dealt with the provision of an adequate water-supply for drinking and washing purposes. Owing to the fact that the reservoirs had been wrecked, and the reticulation had been destroyed, safe supplies of drinking-water were not readily available, and in order to avoid risks arising from the outbreak of disease it was essential that steps be taken to control what water was being used. Fortunately, there were in existence a number of artesian wells which were not destroyed by the earthquake, and from these the residents were furnished with supplies of water at specified points. Nevertheless, as an additional precaution, and acting on the advice of the Health Department, arrangements were made to chlorinate all water in use, a plant for the purpose having been secured from Auckland".

The shaking and possible disruption of the offshore extensions of aquifers was not specifically noted during the Hawke's Bay earthquake. Observers on ships anchored offshore from Napier Harbour at the time of the earthquake (10.17 am on 3 February 1931) noted that the sea become "muddy" immediately offshore but was clear further out from the coast (Henderson 1933). Displacement of the sea floor occurred and Pania Rock which is about 4 km northeast of Napier harbour in Hawke Bay showed a rise of 1.5 m (Marshall 1933). Pania Rock is shown to be 7 feet (2.1 m) at L.W. (low water) on the Poverty Bay to Castle Point and continuation to Cape Palliser chart (Hydrographic Office of the Admiralty 1857 with corrections to 1952).

After the 1931 Hawke's Bay earthquake, R.J. Findlay of the HBCC inspected and reported on damage to wells on the Heretaunga Plains. The main conclusions of Findlay's handwritten report are:

- Piezometric pressures from several artesian bores did not suggest any trend of declining water level in 50 years of groundwater use.
- Water wells in many areas (Meeanee to south Napier, Twyford, Farndon-Pakipaki) were structurally damaged, and in most instances the damage was below ground level.
- The majority of wells damaged during the 1931 earthquake were old bores with corroded casing.
- Springs formed adjacent to Stock and Irongate roads, Mangaroa did not exist prior to the earthquake.
- Springs feeding the Raupare Streams developed after the earthquake.
- There was a substantial increase in flow from many Heretaunga Plains drains immediately following the earthquake.
- The development of large seepage areas near Farndon in sandy soils, occurred after the reported blow out of the confining strata during the earthquake.
- There were two instances of hot/warm water gushing from springs and wells reported in Mangateretere and Farndon areas.

Findlay's 1931 Hawke's Bay earthquake conclusions and the following observations (Kaliser 1979) of the effects of a magnitude 6.4 earthquake centred near San Fernando, California on 9 February 1971, are pertinent for earthquake mitigation planning for water supply wells on the Heretaunga Plains. At San Fernando there were 21 wells ranging from 19.2 to 187 m deep that were in the epicentral area. All these wells penetrated valley alluvial sediments. Kaliser (1979) records that:

- Only one well was severely damaged. Cased wells in loose, valley fill sediments are normally capable of withstanding severe ground motion, short of ground rupturing, without irreparable damage to the casing.
- Metallic well casing may withstand some change in shape due to ground compression. Riveted, welded and stovepipe telescoping types of casing joints are normally capable of resisting, without rupture, lateral displacement and direct compression due to horizontal shifting and vertical uplifting of the ground.
- Wells situated within the (fault) zone of deformation will likely be rendered unfit for further use due to shearing of casing, joint rupturing or severe distortion of the casing.
- The major impact on the wells was postearthquake contamination. Distances that wells are sited from sewage systems should be determined based upon hydrologic criteria (such as aquifer geometry and characteristics, nature of the shallow geologic material and presence of faulting). A requirement should exist for inspection of all sewer connections (laterals) from buildings located within a specified distance and for replacement of all defective pipe.
- Principal distress was cracking and lateral shifting of concrete pads attached to the pumps. Pump mounting should be designed with provision for a type of slip joint which would permit some vertical and horizontal movement of the pump and pump column pipe without causing cracking of the concrete pad or tilting and twisting of the pump assembly.

5.3.4.5 Atmospheric Pressure Induced Fluctuations

Atmospheric pressure induced water-level fluctuations are a loading effect which affects the land surface and the underlying aquifers. The response in well water level depends on the elasticity of the aquifer transmitting the pressure changes. Confined aquifers are generally more sensitive to pressure changes than unconfined aquifers. This has been demonstrated by observations of water-level fluctuations with changes of atmospheric pressure in wells of different depths at Lincoln on the

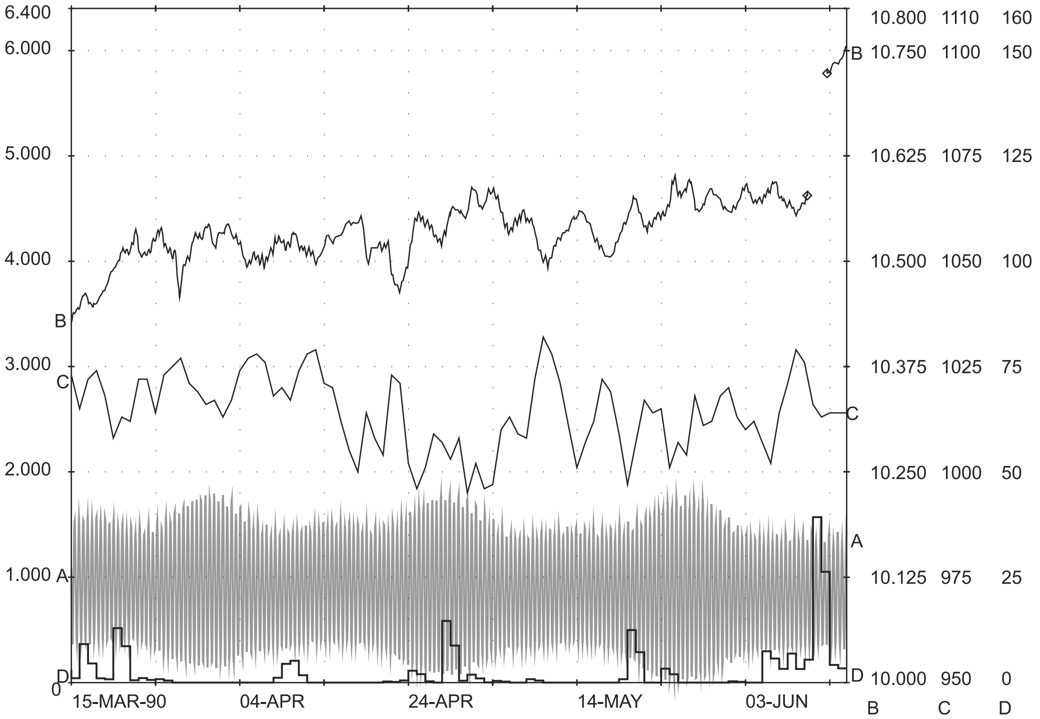
Canterbury Plains. At Lincoln College piezometric pressure in a 105 m deep flowing artesian well rose four times as much as the barometer fell, while a nearby 18.3 m deep well tapping a semiconfined aquifer only showed a water level rise equal to the barometer fall (Hilgendorf 1926).

At Park Island, on the northern margin of the Heretaunga Plains aquifer system a continuous water level recorder is installed at the Lagoon Farm well (well no, 1284) which is 13.4 m deep and taps a semiconfined aquifer. Figure 5.28 compares water level in the Lagoon Farm well with tide, barometric pressure and rain. The water level in the well responds to the tidal cycles and there is longer term fluctuation correlation with rainfall and barometric pressure. Low barometric pressure corresponds with high water levels but low pressure fronts also result in rain at the Hawke Bay coast. However there are low pressure periods when there was no coastal rain (e.g. 14 May 1990 - Fig. 5. 28) but there was still a rise in well water level. This suggests that a proportion of the groundwater in the semiconfined aquifer may be derived from an underlying confined limestone aquifer which responds to the reduced barometric pressure by increased upward leakage.

5.3.4.6 Manual Water Level Network

The Heretaunga Plains current manual water level network includes 48 wells for which water levels have been measured once a month. The details of the network wells are given in Table 5.8. Twenty of these manual network wells have water level data since 1991. Due to limited extent of manual water level data, the data from 15 continuous water level recorder sites were also incorporated. The findings of this study are given in Table 5.9. Based on the maximum seasonal fluctuation in water levels during 1991 - 1995, a contour map was prepared, (Fig. 5.29) of seasonal fluctuation in water level and piezometric pressures during 1994/95 period.

The water level fluctuations range between 0.80 to 5.05 m. The maximum range in seasonal water level fluctuations occur in wells on the southern margins of



A Site 859 Tides recorded @ Port of Napier Stage m.
B Site 848003 Lagoon Farm. Well No. 1284 @ depth 13.4m Stage m
C Site 964801 Barometric pressure @ Napier Airport. Hecto Pascals
D Site 965901 Napier Rainfall mm (Total = 223.3)

Figure 5.28: Lagoon Farm well, Park Island water level, rainfall and barometric pressure relationship

Site Name	Well No.	Well Depth	Map. ref. NZMS 262 Sht V21	Beg. Date
Burns	7980	20.12	345720	910213
Lowecroft	1703	16.30	33742	950111
Waima II	2237	22.55	343734	950111
Grassmere (1001)	1412	56.69	445780	910214
Molenaar (1002)	271	50.50	429775	910214
Montana Twin Rivers	931	41.45	419753	910214
Solbaer Farm	1053	37.49	421720	910214
Brookfields	1417	53.61	444756	910222
Evergreen Orchards	1153	48.77	415743	910214
Golden Del Ltd	1713	50.00	395749	910214
Gorden Holdings	764	26.55	409762	950111
Gornes	1450	46.00	441738	910214
Grocorp Tywford	1738	40.23	369730	950101
Mackie (Farndon Rd)	299	32.31	441714	950101
NCC	3736	no data	407790	950101
Parker (Woodbank Park)	127	22.86	376717	950101
Pedlow	1700	66.44	457791	910214
Wilkinson	1490	35.75	388732	910214
Ammos-Phos	704	31.30	467760	910219
Belt	840	42.63	468729	910219
Hotel California	811	35.94	481718	910219
Awatoto No.1	3699	25.50	452745	950111
Glazebrook (NG2)	3396	27.50	261666	910222
Turamoe	605	18.29	316631	910322
Woodbury Farm	1596	30.50	336628	910226
Fatman	1501	26.04	344613	910219
Blackmore	1659	19.65	311663	910219
Bateman	1038	32.00	332646	910125
Silverdale	995	35.50	392643	910219
Hillwell Orchards	1674	38.00	386700	910412
Nu-Lands	990	36.58	365643	910219
Oliver	1030	38.16	365679	910218
Allenby	724	45.61	418706	910218
Bricklebank	917	31.20	405703	910214
Collings	1025	32.69	416645	910219
Craufaud Orchard	1459	39.20	421655	910219
Curtis New Bore	2307	no data	390614	910219
Elmlea Farm Ltd	131	23.83	381607	910219
Koenders	1083	40.50	365624	910219
Miller	1276	41.75	394631	910219
Omahuri	915	40.54	365654	910219
W's	184	42.98	389694	910219
Woodham	938	26.75	481696	910219
Te Mata Mushrooms	1129	22.92	450644	910219
Harrison	379	19.51	472679	910219
MAF	1758	34.74	459700	910219
Te Kohu	9049	21.33	449644	910219
Yorrtt	1922	28.40	450685	910219

Table 5.8:
Heretaunga Plains current manual water level network.

Site Name	Well No.	Map Ref NZMS 260 Sheet V21	1991-92	1992-93	1993-94	1994-95	Maximum Fluctuation (m) 1991 - 95
Ammos-phos	704	467760	1.30	1.30	1.35	2.10	3.4
Brookfields	1417	444756	1.35	1.30	2.90	2.65	3.55
Burns	7980	345720	0.70	0.55	0.80	1.00	1.4
Curtis	2307	390614	1.85	2.10	2.30	no data	2.9
D'ath	2085	388651	1.80	1.00	1.55	5.40	5.4
Fatman	1501	344613	1.30	1.00	1.40	2.55	4.05
Gilligans	913	419754	2.55	1.00	1.20	1.95	3.75
Cornes	1450	441738	1.20	1.15	1.15	2.65	2.8
Grassmere	1412	445780	1.50	1.20	3.95	2.85	2.85
Hill Well	1674	386700	1.30	0.85	1.15	1.70	1.8
Lagoon Farm	1284	413824	0.65	0.50	0.50	0.90	1.15
Molenaar	271	429775	1.45	1.25	1.55	2.40	3.25
Nu-Lands	990	365643	1.35	1.00	1.40	2.55	2.65
Oliver	1030	365679	0.65	0.75	1.15	1.80	1.85
Silverdale	995	392643	1.75	1.45	1.20	3.10	3.1
Solebar	1053	421720	1.25	1.05	1.35	2.75	2.75
Te mata Mushroom	1129	450644	0.95	0.75	0.60	1.10	1.45
Turamoe	605	316631	1.15	0.65	1.35	2.20	2.3
Woodham	938	481696	1.35	1.10	1.10	2.30	2.6
Woodbury	1596	336628	1.25	0.95	1.35	2.65	2.95
Fraser 1	997	307720	no data	0.55	no data	no data	0.9
Richardson	3749	485704	1.30	1.20	1.60	2.35	2.6
Communitor	3358	467774	no data	no data	no data	2.00	2
Glade Park	10773	437673	1.70	1.25	1.45	2.05	2.45
Hawea	705	404691	0.75	1.10	no data	2.10	2.15
Game Farm	6023	422787	1.10	no data	1.95	3.05	3.05
Substation	952	325713	0.60	0.40	0.80	1.10	1.9
Talbots	10326	293662	2.75	3.80	1.05	3.85	5.05
Waima	1001	366742	0.55	0.45	0.65	0.75	0.8
Walsh	8380	402646	no data	no data	1.85	3.15	3.2
7A (Golf Club)	8506	331676	0.85	no data	no data	1.80	1.85
7D Flaxmere	3737	344682	0.90	0.45	0.65	1.25	1.85
2F	10356	310691	0.45	0.30	0.90	1.70	2
6K	2863	363708	0.75	0.80	1.00	1.30	1.95
Note: Continuous water level network wells are highlighted.							

Table 5.9: Heretaunga Plains manual network maximum and minimum water level during 1994/95 period.

the Heretaunga Plains and minimum fluctuations occur in wells in the central part of the Plains.

The contour map shows:

- Minimum water level fluctuations in the range of 1 to 2 m occur in the Taradale, Greenmeadows and Napier areas at the northern margin of the Heretaunga Plains aquifer system suggesting possible input from other sources (upward hydraulic flow from deeper fluvial gravel and limestone aquifers) to supplement the Heretaunga Plains aquifer system.
- Minimum water level fluctuations in the range of 1 to 2 m occur in the major recharge area through to Flaxmere, then from Pakowhai to Clive at the coast. This is the area of high to very high transmissivity (see Fig. 5.4).
- Up to 3 m seasonal fluctuation in groundwater levels occur in the Greenmeadows and Meeanee areas.
- Moderate fluctuation of water levels in the range of 1 to 3 m occur between Hastings and Havelock North.
- Moderate fluctuations in the range of 2 to 3 m occur between south of Awatoto and Haumoana areas.
- Maximum water level fluctuations in the range of 3 to 5 m occur in central and south Hastings probably in response to the concentrated abstraction of groundwater for the Hasting's city water supply, industry and irrigation.

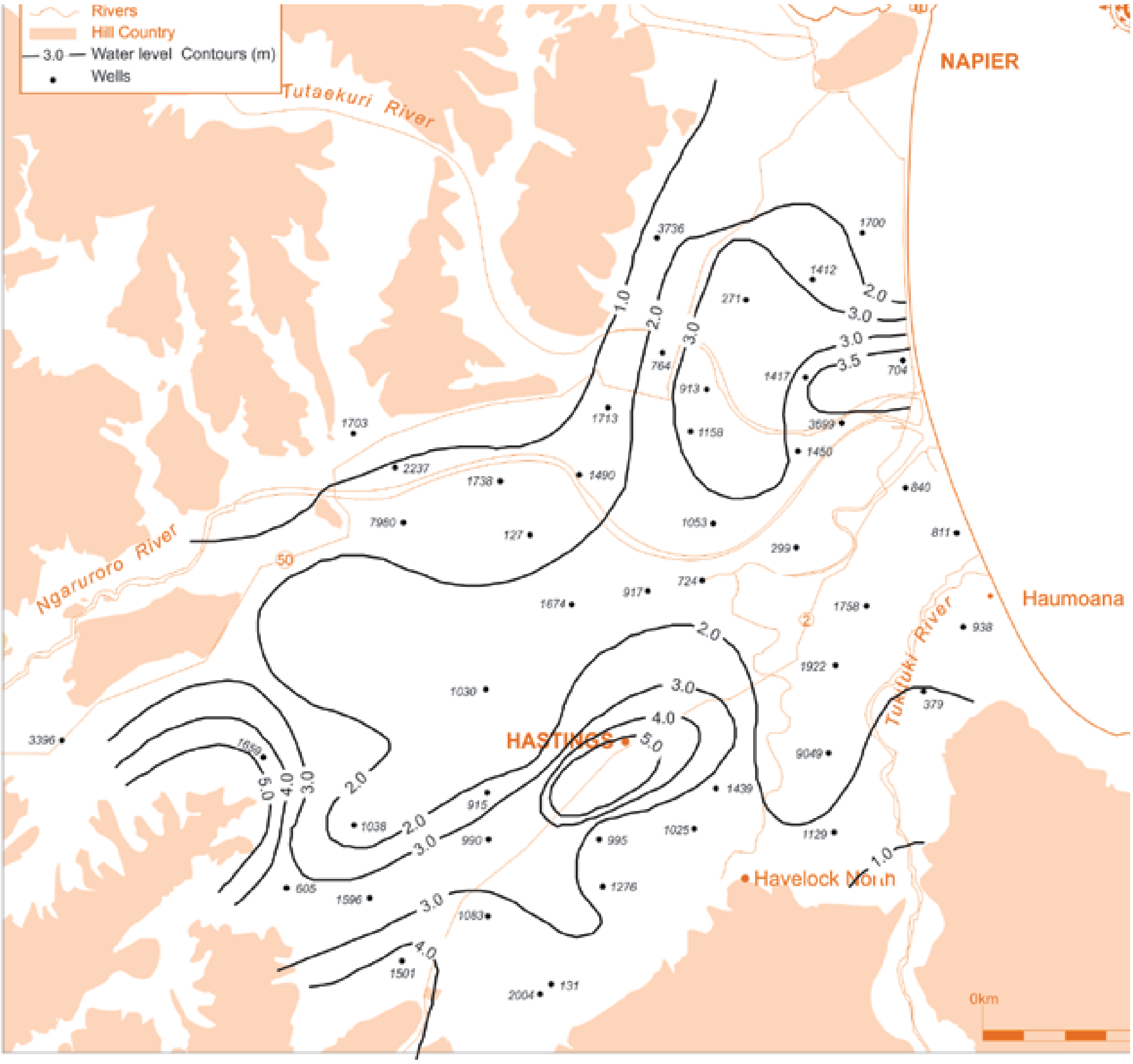


Figure 5.29: The Heretaunga Plains manual water level network and contour map showing maximum seasonal fluctuation in water levels during 1991/95 period.

- Maximum water level fluctuations of 3 to 5m occur in an area extending from south of the Ngatarawa Valley to Pakipaki and Pukahu areas on southern fringe of the aquifer system. In contrast to the northern (Napier) margin of the Heretaunga Plains aquifer there is not significant input of groundwater from deeper aquifers at the southern margin.

5.4 PERIPHERAL AQUIFER SYSTEMS

5.4.1 Moteo Valley Aquifer System

The Tutaekuri River recharges a discontinuous shallow aquifer system along its former buried channels in the Moteo Valley which extends south from the present Tutaekuri River valley upstream of Puketapu to near Fernhill on the Heretaunga Plains. The gravels of these buried channels form a shallow (<30 m depth) discontinuous semiconfined and confined aquifer system.

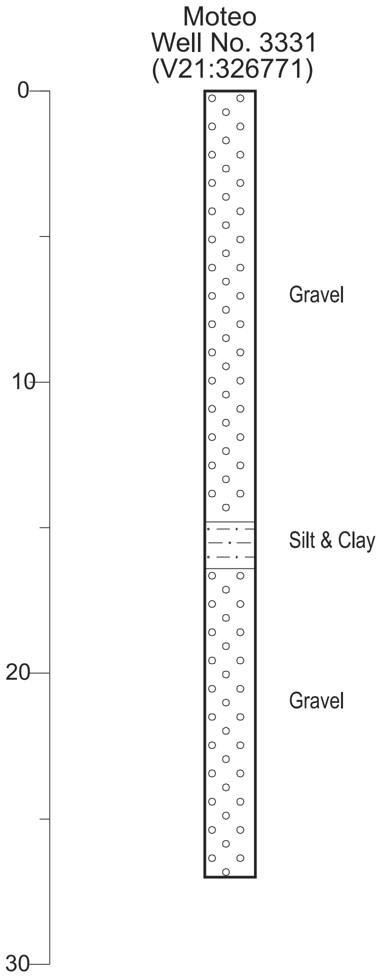


Figure 5.30: Typical well log from the Moteo Valley.

Well logs from the Moteo Valley (Fig. 5.30) show that there are two distinct water bearing gravel aquifers. There is a shallow 3 to 6 m thick, red and brown water bearing gravel layer underlying 5 m of clay, silt and peaty material. Static water levels in this shallow aquifer rise above the top of the aquifer which suggests semiconfined aquifer conditions. There is also a deeper (>15 m depth) blue and brown water bearing gravel underlying clay strata. The deeper gravel channel deposits form a flowing artesian aquifer.

Piezometric contours of well water levels in the Moteo Valley suggest the general direction of groundwater flow is down the valley and out beneath the Heretaunga Plains to contribute to the flow of the Tutaekuri - Waimate Stream (Fig. 2.31). The shape of the piezometric contours also suggests that a component of the groundwater is derived from the mudstone-limestone catchments flanking the Moteo Valley (Figs. 5.5 and 5.6).

The Moteo Valley aquifers are part of a Tutaekuri River aquifer system which extends down valley to Redclyffe and out beneath the Heretaunga Plains where the groundwater blends with the predominantly Ngaruroro River deposited and recharged Heretaunga Plains aquifer system. The extent of the area where the Tutaekuri River derived groundwater is present is impossible to define and probably varies seasonally in response to recharge and abstraction.

5.4.2 Tukituki Aquifer System

At the southeast coastal margin of the Heretaunga Plains, the Tukituki River contributes water to a shallow semiconfined to confined fluvial gravel aquifer system overlying the deeper Ngaruroro River aquifer system. The shallow gravel deposits that form the aquifer are Tukituki River channel gravels deposited during the last 6000 years. Figure 5.1 shows the approximate extent of this aquifer system which is recharged by the Tukituki River. The terrace east of the Mangateretere-Havelock North Road marks the western limit of the Tukituki aquifer system. The coastal beach gravel deposits from Haumoana south to Te Awanga merge into the Tukituki aquifer system at the eastern boundary of the aquifer system.

Well logs, cross sections (see Figs. 5.31) and pump test data suggest that there is no impermeable boundary between the main Heretaunga Plains aquifer and the Tukituki aquifer. Pump tests undertaken on the wells tapping the Tukituki aquifer system suggest a semiconfined leaky aquifer with a transmissivity in the range of 10 000 to 15 000 m^2/day and a storativity of 0.015.

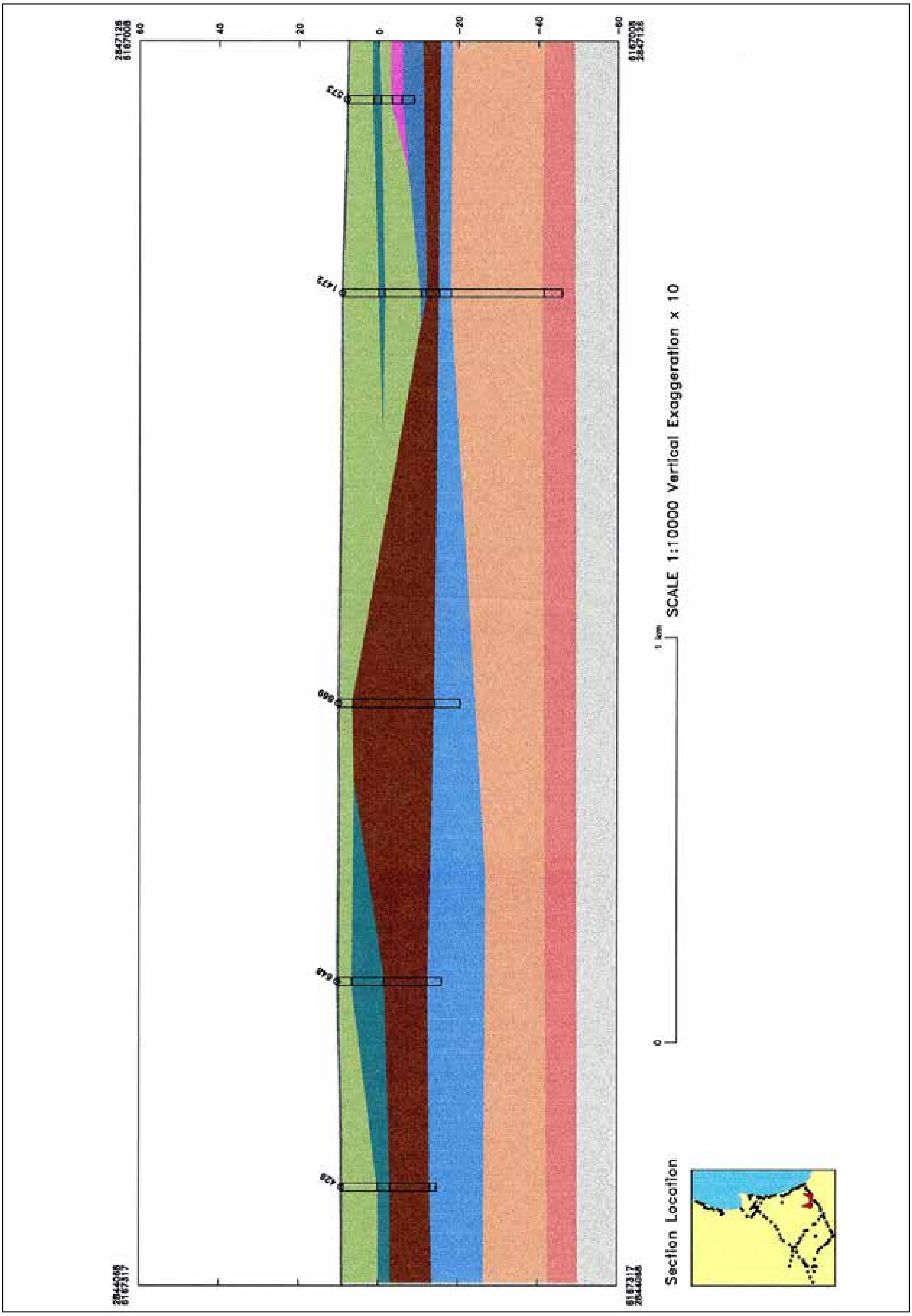


Figure 5.31: Karamu geological section.

Logs of wells in the area east of Karamu Stream through to Havelock North show an aquifer at about 50 m depth which grades laterally into the Tukituki aquifer system. [geological cross section (Fig. 5.31)] shows the Tukituki and the main aquifer systems merging in an area of aquifer overlap from Thompson Road to the Karamu Stream.

Figure 5.32 shows a multiplot of the Ngaruroro and Tukituki river stages, Richardson well (well no. 3749) Haumoana piezometric pressure, and rainfall at Lawn Road, Clive. It is impossible to specifically reconcile piezometric level fluctuations in the Richardson well with Tukituki River derived groundwater recharge. Both Ngaruroro and Tukituki river stages show similar patterns of fluctuations related to rainfall in the river catchments. The Richardson well responds to the daily tidal cycle and the local rain.

Wells located between Karamu Stream and Havelock North penetrate an aquifer at about 80 m depth on the edge of the Heretaunga Plains aquifer system. Well no. 439 in Grasmere Road, Karamu, (V21/438661) drilled for water supply to Havelock North penetrated an aquifer at 80 m containing high concentrations of dissolved iron and manganese suggesting prolonged residence time. The casing was pulled back and better quality water from 50 m was utilised for water supply. Pump tests undertaken on wells tapping the 50 m aquifer suggest leaky conditions with high transmissivity in the range of 10 000 to 25 000 m^2/day.

A piezometric survey of water levels in wells adjacent to Karamu Stream in August 1980 by the HBCB and the Heretaunga Plains piezometric survey undertaken in February 1995 showed the direction of groundwater flow to be from west to east across the Plains towards the Tukituki River rather than directly to the Hawke Bay coast in a northeasterly direction (Fig. 5.6).

The August 1980 piezometric survey involved 30 bores in the Karamu area and provides a more detailed

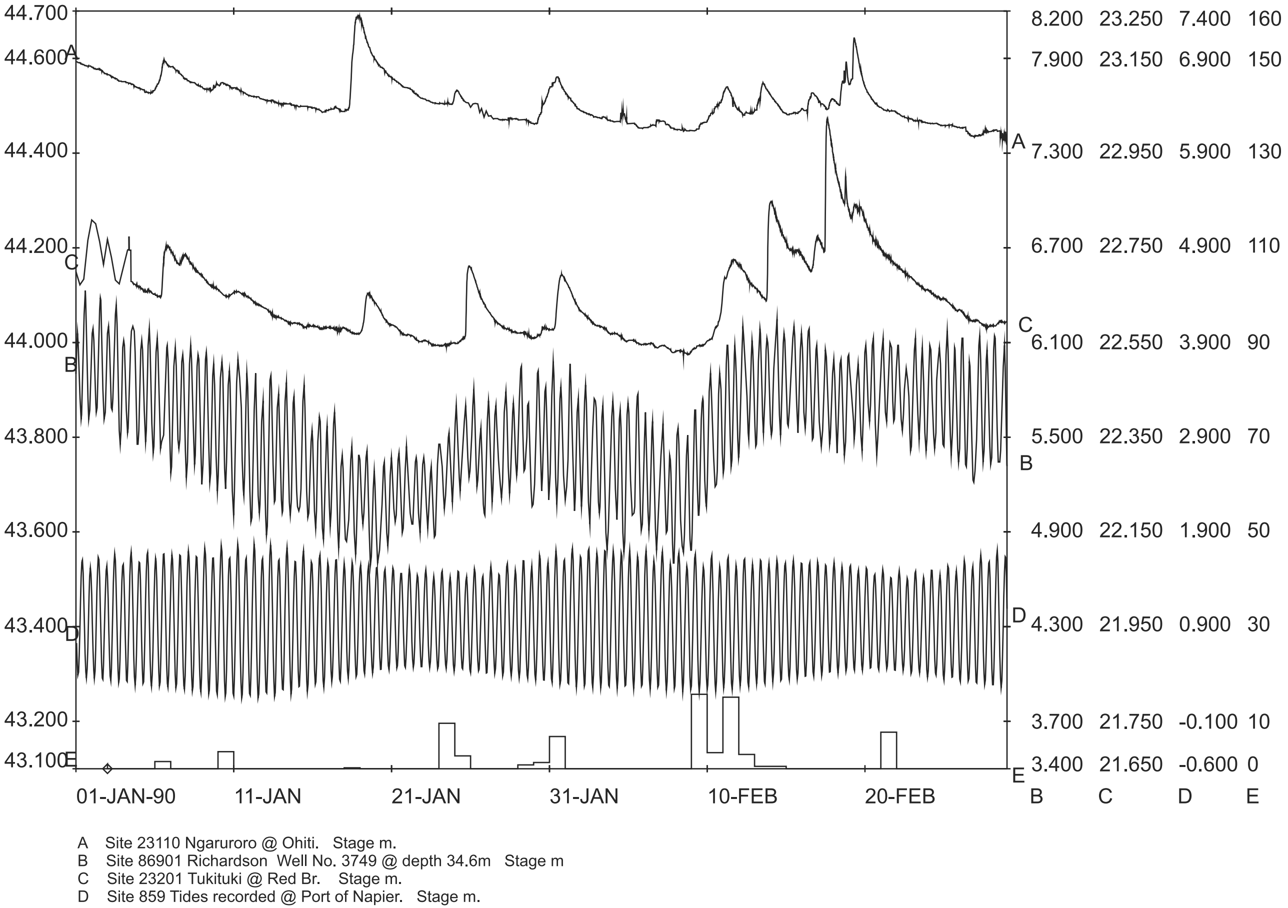


Figure 5.32: Multiplot of Ngaruroro and Tukituki river stages and water levels from wells Communitor well, Awatoto, Richardson well, Haumoana, and rainfall at Lawn Road, Clive.

picture of localised and subtle variations in direction of groundwater movement. The August 1980 piezometric survey suggests a very sudden drop in groundwater pressures from 10 to 9 m above mean sea level occurring just north of Havelock North and adjacent to the Karamu Stream. A possible explanation for the sudden drop in groundwater pressure is that there is a significant loss of water from the aquifer by way of extractions, leakage between aquifers or loss to the surface. A low pressure area occurs around the Thompson Road area and toward the Tukituki River. In this area springs contribute to the flow of the Mangateretere Stream and may result in lowering of the groundwater pressure. Seismic surveys (Melhuish 1993) undertaken in this area suggest a near surface active fault that strikes to the northeast and could dislocate the aquifer between Pukahu and Havelock North . The springs contributing to the flow of the Mangateretere Stream may be linked with a line of springs running from Tennants Road to the sea south of Haumoana near the southeastern boundary of the main aquifer system and could be formed as a result of fault dislocation of the aquifer.

The winter piezometric pressure from deep (>70 m depth) bores adjacent to and west of the Karamu Stream is about 2 m above ground level. Water wells in the area east of the Karamu Stream are generally not drilled as deep because high yields of groundwater are obtained from the aquifer within 50 m of the surface. Further east adjacent to the Tukituki River and west of Haumoana, most wells are less than 25 m deep and tap the semiconfined to confined multilayered Tukituki aquifer system. The piezometric pressure in the shallow bores tapping the Tukituki aquifer system is about 1.5 to 2 m above ground level and similar to the underlying Heretaunga Plains aquifer system. Groundwater from the deeper aquifer system may vertically recharge the shallow Tukituki aquifer system in a mixing zone of groundwater in aquifer overlap areas in the vicinity of Thompson Road. During summer increased groundwater abstraction for irrigation can result in the piezometric pressures in the main aquifer system declining below the level of the overlying Tukituki aquifer system. The reversal of hydraulic gradient produces a downward flow of groundwater from the Tukituki River recharged aquifer system to the underlying Heretaunga Plains aquifer system.

Figure 5.33 illustrates a multiplot of Mangateretere Stream discharge, Tukituki River stage at Red Bridge, Ngaruroro River stage at Ohiti and water levels at well 7D (well no 3737) Flaxmere. The Mangateretere

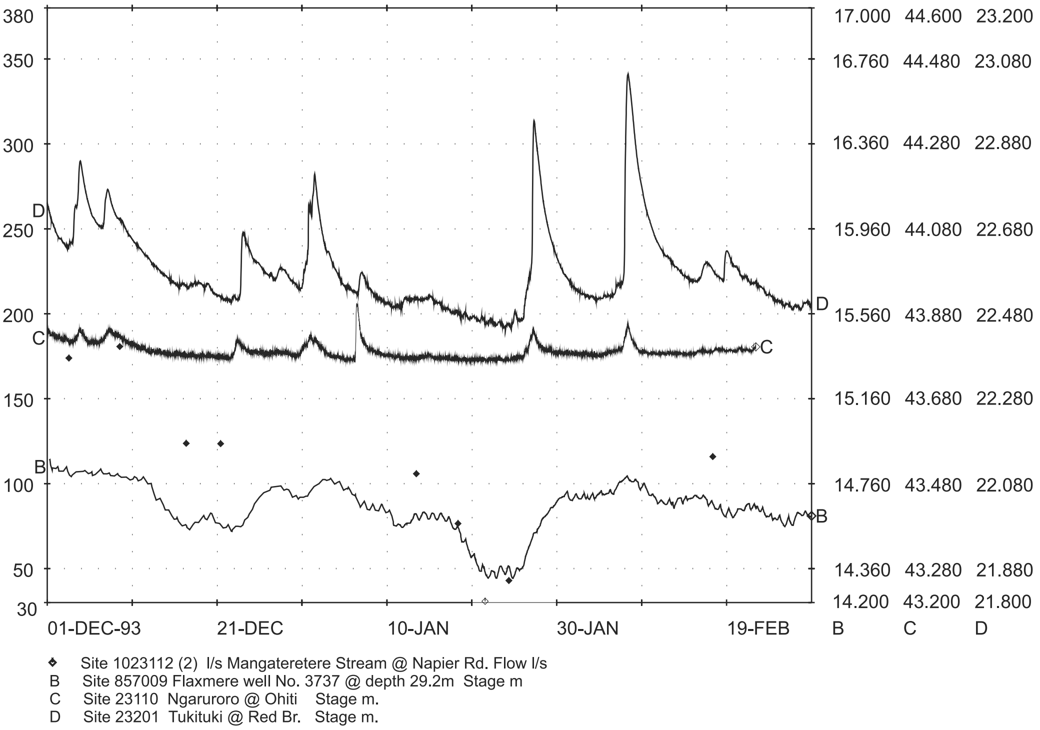


Figure 5.33: Multiplot of Mangateretere Stream discharge, Tukituki River stage at Red Bridge, Ngaruroro River stage at Ohiti and groundwater level at well 7D Flaxmere.

discharge is affected by abstraction from the main aquifer system shown by receding water levels in well 7D. This suggests that spring outflow in the Thompson Road area from the main aquifer system provides a proportion of the Mangateretere Stream flow. There is also a spring flow contribution derived from the Tukituki River seepage. The contribution coming from each source will vary depending upon the groundwater aquifer pressures. The available data suggests that the Tukituki gravels merge and overlie gravels deposited by the Ngaruroro River and there is a mixing zone of waters where the aquifers merge.

5.4.3 The Valley Aquifer Systems

Before the Ngaruroro and Tutaekuri river courses cross the Heretaunga Plains their river valleys and adjacent flood Plains and tributary valleys are underlain by shallow (<15 m depth) gravel aquifers. The valley aquifer areas are shown in Fig. 5.1.

5.4.4 The Esk (Whirinaki - Bay View) Aquifer System

Coastal and valley aquifers extend from Napier Hill - Park Island north to Bay View and across the Esk River to the Whirinaki area. These are unconfined in the coastal area and become progressively confined inland grading into a multilayered system along Valley Road. Most coastal bores are less than 10 m depth (Fig. 5.34) and the static water level fluctuates with tides and is generally between 4 to 6 m below the ground level. Well no. 1207 at the south end of the cross section (Fig. 5.34) plots above the section line as it is located in Onehunga Road, Bay View at an altitude of 30m a.m.s.l.

The Westshore well log (Fig. 5.37), an unsuccessful attempt to find groundwater by New Zealand Government Railways in 1915 (Holmes 1917), shows postglacial marine deposits (beach gravels, marine progradational, marine transgressive) overlying fluvial deposits which can either be Esk River pre-marine transgression (6500 years BP) floodplain deposits, or Tutaekuri or Ngaruroro river deposits that overlie the promotory that connected Scinde Island to the mainland in the Onekawa area (Fig. 2.24).

Groundwater levels suggest that the general direction of groundwater movement is from the Esk Valley and floodplain in the west to the Whirinaki coast to the east. A pump test conducted by the HBRC at the Whirinaki Pulp Mill in April 1990 suggested an average transmissivity 1000 m^2/day and an estimated

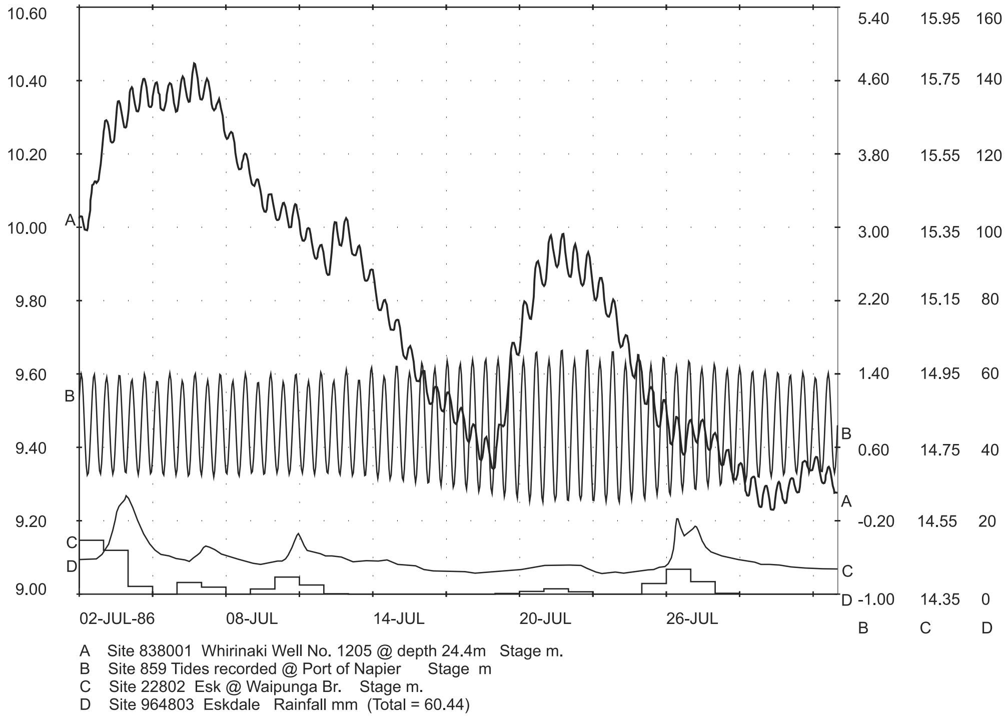


Figure 5.35: Multiplot showing Esk River stage at Waipunga, water level at Whirinaki well (well no. 1205), and tides recorded at Napier.

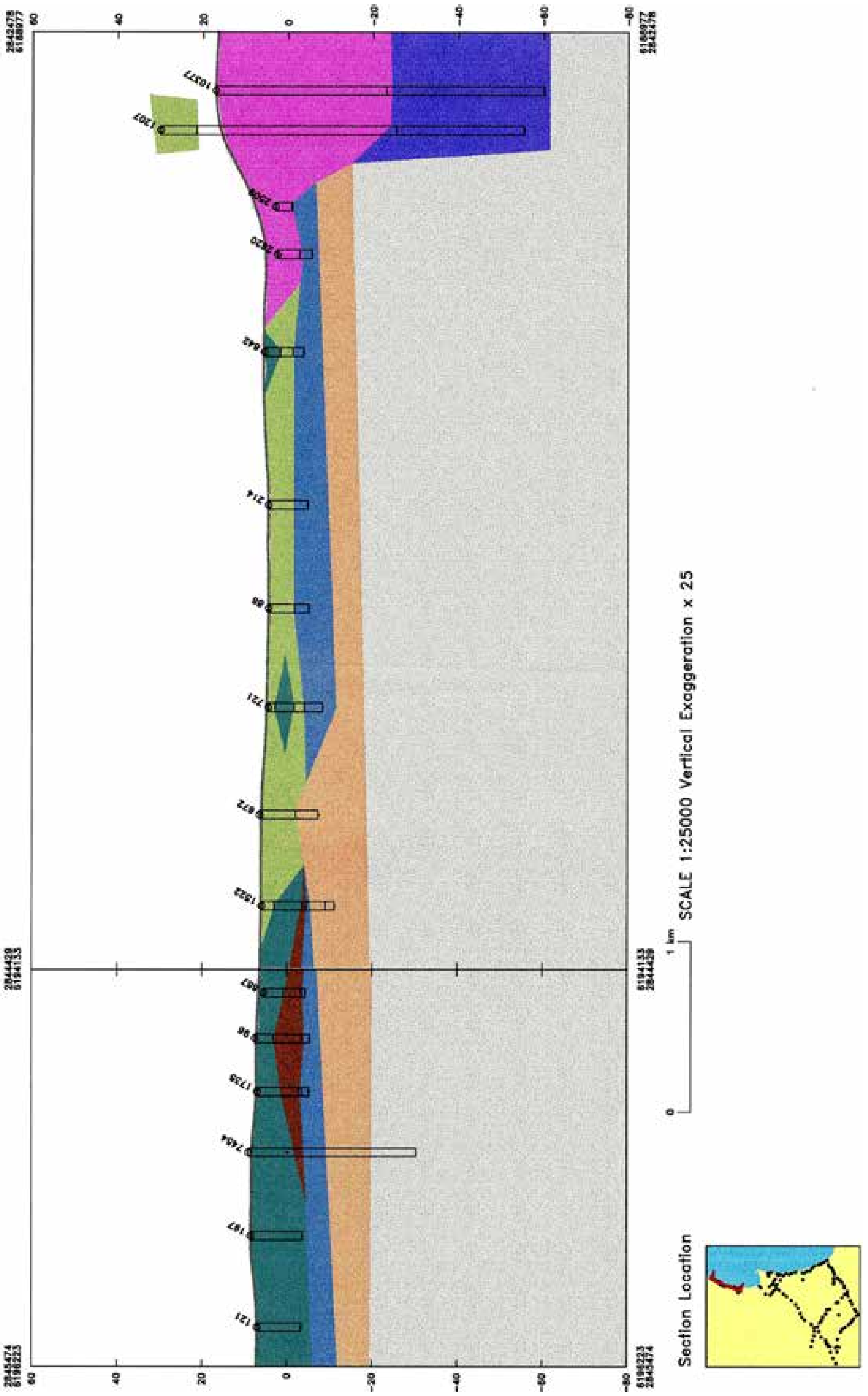


Figure 5.34: The Esk (Whirinaki - Bay View) cross section

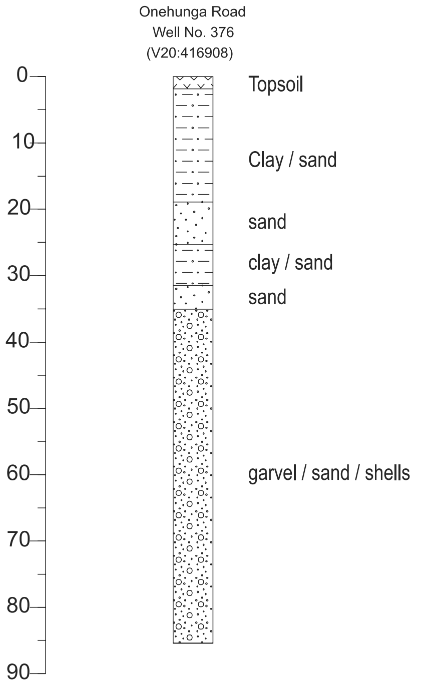


Figure 5.36: Typical bore log from Onehunga Road area.

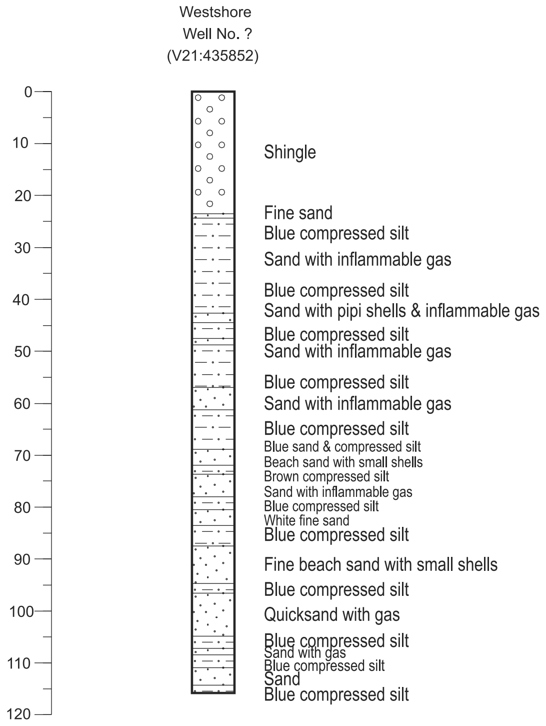


Figure 5.37: Typical bore log from Westshore area.

storativity of 0.2. The ground surface is about 8 to 9 m above mean sea level at most well sites along the coast. Piezometric surveys undertaken on 28 February 1995 show summer piezometric levels at the coast are approximately 0.5 m above mean sea level.

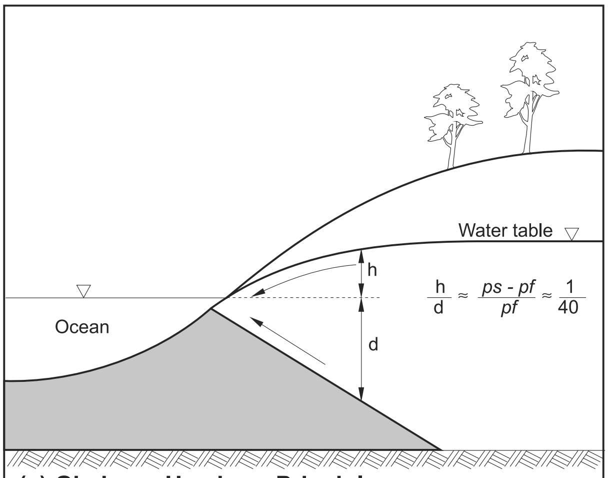
Salt water contamination of wells has been reported by several residents in the past at the northern end of the Whirinaki Beach Road. Groundwater sampling undertaken during the February 1995 piezometric survey also suggested groundwater quality deterioration due to sea water intrusion at two bores in the northern end of the Whirinaki Beach Road.

In an ideal unconfined coastal aquifer with steady flow and uniform permeability, a theoretical result known as the Ghyben-Herzberg principle indicates that the depth below sea level to the saltwater-freshwater interface is approximately 40 times greater than the elevation of the water table above sea level (Bear 1979). This situation as illustrated in Fig. 5.38 could apply to the coastal unconfined aquifer from Whirinaki to Bay View. The February 1995 water level of 0.5m above mean sea level would indicate a saltwater - freshwater interface at 20m below mean sea level at the Whirinaki, Hawke Bay coast (Fig. 5.38b). Winter water levels are about 2m above mean sea level and the saltwater - freshwater interface would be about 80m below mean sea level. Saltwater intrusion into the aquifer inland of the coast occurs when the water level in coastal wells declines below mean sea level. According to Whirinaki well owners this has occurred during several summers 1983 through to 1995.

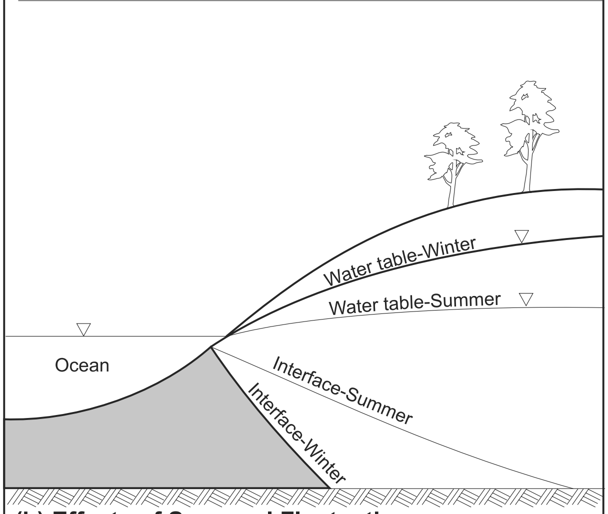
5.4.5 Peripheral Limestone Aquifer System

The limestone deposits that form the hills on the southern and western margin of the Heretaunga Plains and which underlie the northern edge of the Heretaunga Plains between Napier Hill and Park Island, (Fig. 5.40) also contain groundwater. The peripheral limestone aquifer system is characterised by a sequence of weakly to moderately cemented muddy and sandy limestone aquifers separated by impermeable mudstone beds (Fig. 5.39). The limestone - mudstone sequence in the southern and western margins of the Heretaunga Plains have gentle dips due north (10°)and east (5°) respectively (Kingma 1970).

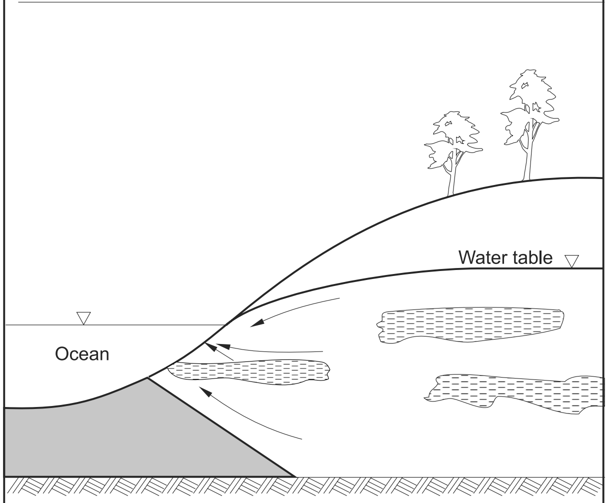
Well yields typically range from 0.2 to 2 l/s but can be as high as 10 l/s in wells situated around the foothills. In general highest yields are obtained from the wells located at the bottom of valleys and the lower yielding wells are on the ridge crests. This suggests localised groundwater flow from beneath the ridges into the valleys. Also the valley groundwater quality is inferior



(a) Ghyben - Herzberg Principle



(b) Effects of Seasonal Fluctuations



(c) Effects of Heterogeneous Aquifer Properties

▤ Clay lense or other less permeable zones

▩ Saline Groundwater density *ps*

☐ Fresh groundwater Density *pf*

← Flow of Groundwater

Figure 5.38: Ghyben-Herzberg saltwater-freshwater interface.

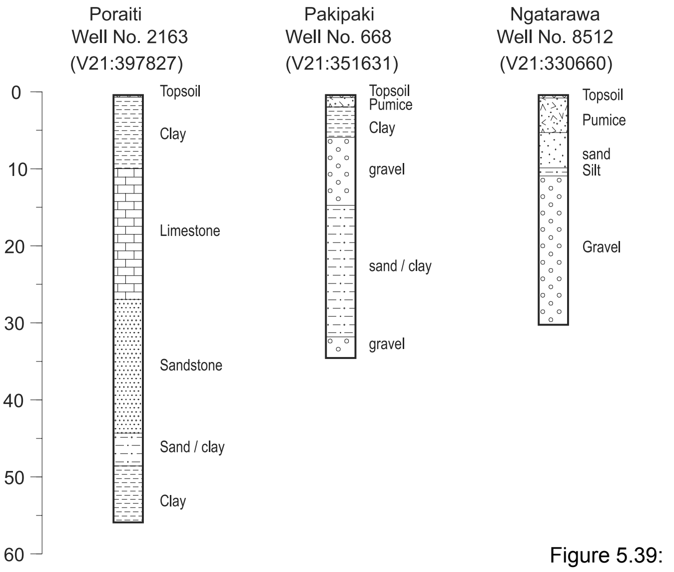


Figure 5.39: Three typical bore logs (Poraiti, Ngatarawa and Pakipaki) from the peripheral limestone aquifer areas.

possibly due top infiltration of farm runoff and irrigation seepage from the adjacent slopes. Pump test and geological log data indicate that the aquifer system is semiconfined. Test pumping has shown an average transmissivity of the limestone aquifers to be 100 to 600 m^2/day.

The February 1995 piezometric survey based on 30 wells in the Poraiti area suggests the direction of groundwater flow is towards the east (Fig. 5.40). Recharge to the peripheral limestone aquifer system is by direct infiltration of rainfall and runoff. Isotope (tritium) data analysis suggests recent groundwater is present in the limestone aquifer system (table 7.8).

Long-term water level measurements show a fluctuation in the order of 0.8 to 1.4 m with highest levels occurring during the winter months when more rain usually falls and groundwater abstractions is least. A continuous water level recorder installed at the Lagoon Farm well which is 13.4 m deep and taps a semiconfined aquifer shows that short term water levels fluctuate in response to rainfall and barometric pressure (Fig. 5.28). Recharge to the peripheral limestone aquifer system is by direct infiltration of rainfall and runoff.

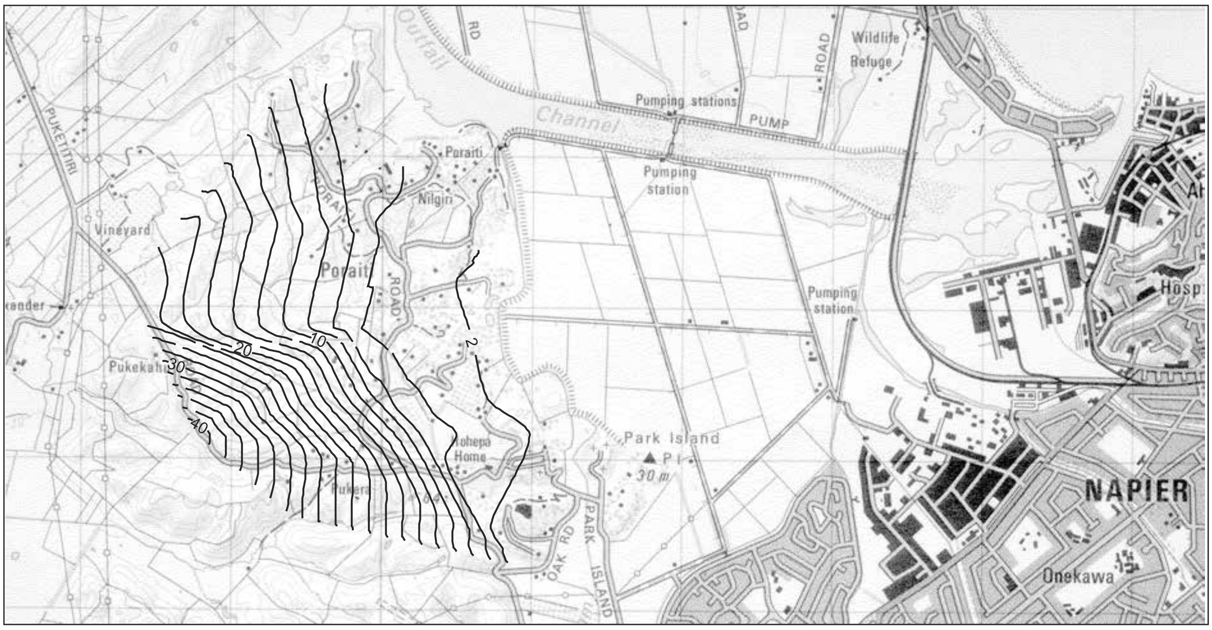


Figure 5.40: Piezometric map of limestone aquifer in the Poraiti area (February 1995).

Figure 5.41: Travelling irrigator in a paddock of squash near Pakowhai, Heretaunga Plains, February 1995. *(photo: Lloyd Homer, IGNS CN 34168).*

CHAPTER 6

GROUNDWATER BALANCE

6.1 INTRODUCTION

The water balance is fundamental to the management of a groundwater resource. The concept of water balance expresses the relationship between the groundwater recharge and discharge processes. If the recharge or inflow into a groundwater system from various sources is exactly equal to the discharge or the outflow from that system, then the groundwater storage remains constant. If recharge exceeds discharge, groundwater storage will also remain constant while the flow of natural outflows (springs) at the boundary of the unconfined - confined aquifers will increase. If discharge is greater than recharge, storage will decrease.

For the Heretaunga Plains aquifer system Ngaruroro River infiltration is the main source of the groundwater. The Ngaruroro River at the western margin of the Heretaunga Plains is perched above former gravel river channels that form recharge conduits to the adjacent unconfined aquifer. The groundwater derived from the river flows through the unconfined sector of the aquifer at rates in the order of hundreds of metres per day towards the coast and the area of aquifer confinement. At the unconfined - confined aquifer boundary most of the groundwater intersects the ground surface to form the springs, the sources of local rivers, streams and creeks, and swamps and ponds. Some of the groundwater flows into the confined aquifer to replace abstracted groundwater and maintain the aquifer through flow to offshore springs in Hawke Bay. Flow rates in the confined aquifer are in the order of metres per day.

The first priority of European settlement of the Heretaunga Plains was to drain the swamps and ponds, and attempt to control the flow and courses of the rivers, streams and creeks. The drainage of the wetlands was to provide fertile soils for agriculture and to speed up the flow of water to the sea to prevent surface flooding. These modifications of the hydrological cycle would have affected the groundwater component of the cycle in several ways:

- Changes of river course and river flow would change river infiltration to groundwater. The 1867 Ngaruroro River change of course would probably have reduced the quantity of river water seeping to groundwater by diverting the river away from channels overlying the unconfined aquifer.
- Changes of sedimentation processes in river beds with upstream erosion and downstream (floodplain) aggradation increasing the proportion of fine sediments in the river bed would reduce river infiltration to groundwater.
- Changes of river course length and gradient by cutting off meanders and excavating gravel from river beds would produce degradation and reduce river infiltration to groundwater.
- Drainage of wetlands, swamps and ponds on river flood plains would reduce the aerial extent of surface water available for recharging the confined aquifers.
- Increased urbanisation with buildings, sealed roads and courtyards, stormwater drainage, and intense crop production on the flood plains would reduce the rainfall component available to recharge groundwater.

When wells were drilled to tap the confined artesian aquifers the groundwater balance responded to the increasing groundwater abstraction by a decline in water-level in the unconfined aquifer and reduced outflow from springs, with increased groundwater throughflow to the confined aquifer to replace abstracted groundwater. The decline in the water levels in the unconfined aquifer may have already been an ongoing process as groundwater recharge and storage responded to the modifications to the hydrological cycle, to the draining and dewatering of the wetlands, swamps and ponds especially in areas adjacent to the unconfined - confined aquifer boundary, and to the increasing volume of groundwater abstracted from the Heretaunga Plains aquifer system.

The groundwater balance can be expressed in an equation considering changes in groundwater storage:

$$\nabla S = Q_r - Q_d$$

where ∇S is the change in groundwater storage, Q_r is sum of inflows to groundwater system, and Q_d is sum of outflows from groundwater system.

Change in storage = Sum of Inflows - Sum of outflows

This chapter discusses the methodology adopted to quantify the inflows to the groundwater system, the flow of water through aquifers and the outputs from the aquifer system.

6.2 GROUNDWATER STORAGE CHARACTERISTICS

The geological cross section and hydraulic characteristics of aquifers allow crude estimates to be made of the volume of water stored in the main and peripheral aquifer systems.

6.2.1 Main Aquifer System

6.2.1.1 Major Recharge Area

The major recharge area extends from between Roys Hill and Fernhill to Flaxmere, covering an area of about 30 km^2. The Flaxmere exploratory bore shows that the saturated gravels extend to a depth of at least 137 m (Brown 1993). Resistivity survey interpretations (McLellan 1985) suggest the thickness of the saturated gravel in this area might be 150 m (Fig. 4.2). On the pre-1867 Ngaruroro River channel between Roys Hill and Fernhill (V21/309319), the measured porosity of gravel was 0.22 (Thorpe 1977). Aquifer pumping tests undertaken at various sites throughout the major recharge area (see Table 5.1) show a high transmissivity in the order of 20 000 m^2/day. Based on the estimated thickness of saturated gravel, transmissivity and the aquifer extent, a rough estimate of the volume of groundwater stored in the major recharge area is 9×10^8 m^3 (900 million cubic metres).

6.2.1.2 Minor Recharge Area

The minor recharge area extends from south of Roys Hill to Maraekakaho along the Ngatarawa Valley covering about 15 km^2. The sediments of the Ngatarawa Valley area through to Pakipaki are older than the 1867 river channels of the major recharge area, not so well sorted and more weathered. Typical drill cuttings from the middle of the valley are brown weathered gravels in a yellow silty clay matrix. The resistivity interpretations suggest a relatively shallow groundwater basement at a depth of about 50 m (Fig.4.2). The wells drilled on the southern parts of the valley often penetrate papa or mudstones within 30 m. A number of well logs from this area suggest that the main aquifer is under semi-unconfined condition, a product of the altitude of the recharge area. Aquifer pump tests show low transmissivities ranging from 200 to 2000 m^2/day and an average specific yield of 0.15. The low transmissivity can be attributed to limited thickness of aquifer, relatively shallow groundwater basement, low permeability gravel river channel strata and restricted and tenuous hydraulic interconnection with the river and other groundwater recharge sources.

This hydraulic information together with the resistivity interpretation of channel geometry (Fig. 4.2), and geological cross sections (Figs. 4.19 and 4.22) allows a volume of groundwater stored in the minor recharge area to be calculated of the order of 9×10^7 m^3 (90 million cubic metres) using the same calculation criteria as for the major recharge area.

6.2.1.3 Confined Aquifer Area

The estimation of the quantities of groundwater stored in the series of interconnected confined aquifers of the Heretaunga Plains is difficult due to the complex distribution of aquifers in interconnected aquifer and aquiclude sequences. The deep exploratory well data suggests a decrease in aquifer permeability and increase in groundwater residence time with depth. The Tollemache Orchard and Awatoto testbores proved six interconnected flowing artesian aquifers within a depth of 250 m. The data from the three deep exploratory wells has been used to construct a generalised geological cross section across the Heretaunga Plains (Fig. 5.3). Isotope and geological data tentatively suggest groundwater flow in the upper aquifers occurs with offshore outflow through submarine springs in Hawke Bay. The aerial extent of the Heretaunga Plains confined aquifer including the offshore extension is about 300 km^2. Aquifer pump test data suggests (see Table 5.1) a transmissivity range of 2000 to 15 000 m^2/day and a storativity range of 1×10^{-3} to 1×10^{-4}. Based on an estimate of the total thickness of the confined aquifer to be 200 m and applying the hydraulic data, a volume of water stored in the confined aquifer of 60×10^6 m^3 (60 million cubic metres) is suggested.

6.2.2 Moteo Valley Aquifer System

The Moteo Valley, which was occupied by the Tutaekuri River a few thousand years ago, extends south from the present Tutaekuri River valley upstream of Puketapu to near Fernhill on the Heretaunga Plains. The uneven distribution of wells in the Moteo Valley area with most wells located at the northern end of the valley suggested that groundwater is more readily available and used in the northern (Tutaekuri River) end of the valley. Logs of wells along the valley suggest that the aquifer gets deeper and is confined down the valley (Fig. 5.30). The aquifer becomes flowing artesian about half way down the valley. This area is also characterised by a patchy confining layer above the aquifer and the groundwater leaks to the surface forming springs and swampy areas. The wells on the edge of the valley (well no. 1251, V21/328745) often do not penetrate gravel. No wells have been drilled to the basement limestone but based on geology, the thickness of gravel is unlikely to exceed 30 m in the deepest part of the valley. Taking an average depth of 20 m, and assuming a semiconfined to confined aquifer condition with storativity 0.01 extrapolated over 10 km^2 suggests a total groundwater storage in the order of 2 million cubic metres.

Seven sets of concurrent low flow measurements for the visible flow of the Tutaekuri River over a 7.2 km stretch of river bed between Hakowhai (7.2 km upstream of Puketapu) and Puketapu during 1965 and 1969 showed mean losses from the river of about 0.8 m^3/s (Grant 1970, see Table 6.4). Over the same period low flow gaugings undertaken between Puketapu and the coast on the Tutaekuri River do not show any further significant losses of surface flow (Grant 1970). Much of this Tutaekuri surface flow emerges as springs with a proportion being abstracted in the Moteo Valley for mainly irrigation and farm water supply wells which are not monitored. From the regional aquifer balance perspective, the Moteo Valley aquifer system does not contribute significant quantities of water to the main Heretaunga Plains aquifer system because of its geographical isolation and distinct hydrogeology.

6.2.3 Tukituki Aquifer System

The shallow gravel deposits that form the Tukituki River channel aquifer system were deposited during the last 6000 years. The terrace east of Mangateretere - Havelock North Road marks the western extent of the system and along the coast in the north the beach gravel deposits from south Haumoana to Te Awanga merge with the Tukituki aquifer system. Geological cross section (Fig. 5.31) shows the Tukituki and the main aquifer system merging in an aquifer overlap area between Thompson Road and Karamu Stream. Since the Tukituki River recharged aquifers merge and overlie the main aquifer system, and both systems are hydraulically interconnected, it is difficult to quantify the aquifer storage. Pump tests undertaken on the wells tapping the Tukituki aquifer system suggest semiconfined leaky aquifer condition with high transmissivity in the range of 10 000 -15 000 m^2/day and a storativity of 0.015. Taking the Mangateretere - Havelock North Road as the western limit, and Raymond Road in Haumoana as eastern limit, the extent of the Tukituki aquifer system is about 20 km^2. An average thickness of the Tukituki aquifer system would be about 20 m. This suggests a total groundwater storage of about 6 million cubic metres. Two sets of river flow measurements undertaken along the Tukituki River between Red Bridge and Black Bridge show a flow loss of 0.6 and 1.3 m^3/s. A proportion of this infiltrating surface flow emerges as springs along Mangateretere - Havelock North Road and as springs running from Tennants Road to the sea south of Haumoana and a part is abstracted for irrigation and farm water supply wells. These spring discharges and abstractions from the Tukituki aquifer system have not been monitored. From the regional aquifer water balance standpoint, the Tukituki aquifer system does not significantly affect the quantity of groundwater in the main Heretaunga Plains aquifer system because of its geographical isolation and distinct hydrogeology.

6.2.4 The Esk (Whirinaki - Bay View) Aquifer System

The Esk (Whirinaki - Bay View) coastal aquifer system extends north from Napier Hill - Park Island to Bay View and across the Esk River to the Whirinaki area. The aquifer is unconfined in the coastal area and becomes progressively confined inland. Extrapolating the estimated storativity of the Heretaunga Plains gravel of 0.2 to the Esk aquifer system, and assuming an average thickness of river gravels to be 10 m, and the aerial extent of aquifer of 5 km^2, suggest the volume of groundwater storage to be about 10 million cubic metres.

6.2.5 Peripheral Limestone Aquifer System

The quantity of groundwater in the peripheral limestone aquifer system on the southern, western and northern margin of the Heretaunga Plains varies depending upon a number of factors including the degree of compaction, presence of solution cavities and fractures in limestone. Assuming an average intergranular porosity of limestone to be 0.05 and the total thickness and area of the western peripheral limestone to be about 25 m and 10 km^2 respectively, the estimated groundwater storage of the limestone aquifers on the western margins is 12.5 million cubic metres. Wells drilled in the southern and northern peripheral limestone areas penetrate water bearing limestone at about 10 to 20 m depth before encountering the underlying impermeable mudstone. With a total aquifer extent of 30 km^2, an average porosity of 0.05, and a thickness of 10 m, groundwater storage of the limestone aquifers on the southern margins of the Heretaunga Plains is about 15 million cubic metres. Thus, the total groundwater storage of the limestone aquifers on the northern, western and southern margins of the Heretaunga Plains is 27.5 million cubic metres.

6.3 SYSTEM INPUTS

The principal inflows or input to the groundwater system are:

- river seepage;
- rainfall recharge;
- artificial recharge;
- irrigation seepage;
- leakage between aquifers.

6.3.1 River Seepage

6.3.1.1 Ngaruroro River

The Ngaruroro River is the principal recharge source for groundwater beneath the Heretaunga Plains (5.3.3.1). Infiltration of surface flow from the Ngaruroro River occurs into subsurface interconnected former river channels underlying the western sector of the Heretaunga Plains which act as conduits for relatively rapid groundwater infiltration and flow connecting to the main aquifer system.

Since March 1957 several series of streamflow measurements have been made along the Heretaunga Plains reach of the Ngaruroro River course. These have established that losses of river water takes place from the river bed between Maraekakaho and Fernhill. Over this stretch of river course, the major recharge reach extends from Ohiti, at the downstream end of Roys Hill to Fernhill (Fig. 6.2) and the minor recharge reach extends from Maraekakaho to Roys Hill. Each of the recharge reaches extends for a distance of about 3 km. The area of the unconfined aquifer adjacent to the major and minor recharge reaches are known as the major and minor recharge zones. Table 6.1 lists the Ohiti - Fernhill discharge data from 1957 to 1995. Figure 6.1 shows how the river flow gaugings below 35 m^3/s at Ohiti are related to the flow 3 km downstream at Fernhill.

The discharge relationship is established using a graphical statistical technique called regression analysis. This attempts to explain the variation in some observed quantity as a combination of some simple kind of dependence on values set by the experimenter, together with an error term. In regression analysis, it is often assumed that an observed value is a combination of determined true value together with an error term which is randomly distributed. When there is a linear correspondence between two set of variables it can be expressed by a linear regression equation with regression coefficient.

A regression analysis of the Ngaruroro River discharge data at Fernhill and Roys Hill (Fig. 6.1) produced a regression equation, Y=0.9949 X - 4267 where Y and X are discharges (measured in l/s) at Fernhill and Ohiti respectively. The correlation coefficient is 0.99, which suggests that there is a linear correlation between the two data sets. The regression line intercepts the X axis (horizontal) at 4267 l/s which suggests that the Ngaruroro River discharge at Fernhill is 4.267 m^3/s less than the discharge at Ohiti. Thus the regression equation defines a range of mean measured surface flow loss of 4.267 m^3/s in the major recharge reach from Ohiti to Fernhill.

Between June 1964 and January 1991 nine sets of low flow measurements have been carried out in the major and minor recharge areas. These are summarised in Table 6.2. Figure 6.2 shows the locations of gauging sites and the plot of 8 January 1991 gauging data to demonstrate the changes of flow associated with outflow of Ngaruroro River water to groundwater.

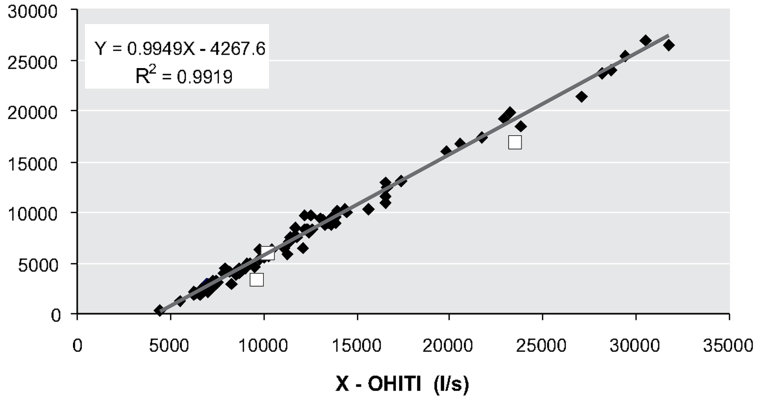


Figure 6.1: Ngaruroro River Ohiti and Fernhill discharge relationship from 1957 to 1995

	r O / 1/ 71701)	r r / 1/3307 9	r O / r /			r O / 1/ 71701)	r r / 1/3307 9	r O / r /
/03/57	9628	3398	6230		**/05/73**	8690	4354	4336
/01/ 0	10194	5947	4247		**7/05/73**	10406	6358	4048
/03/ 0	23503	16990	6513		**15/01/7**	12504	9633	2871
1 /0 / 1	12168	8240	3928		**7/0 /7**	9112	4997	4115
8/11/ 1	12884	8495	4389		**19/0 /7**	11415	7260	4155
13/1 / 1	16595	12459	4136		**17/0 /7**	13310	8719	4591
7/0 / 3	12184	9684	2500		**9/11/7**	17364	13040	4324
/03/ 3	8679	3964	4715		**1/0 /75**	13872	8918	4954
9/05/ 3	10314	5720	4594		**5/0 /75**	12431	8020	4411
/11/ 3	12573	8382	4191		**3/03/75**	16559	11583	4976
10/0 /	9035	4417	4618		**3/0 /75**	12363	8203	4160
13/0 /	7935	4389	3546		**/05/75**	20563	16706	3857
18/0 /	9749	5437	4312		**/1 /75**	11711	7701	4010
9/0 /	13606	8722	4884		**/03/7**	13430	8922	4508
8/10/ 5	27081	21322	5759		**5/03/7**	14420	9941	4479
8/10/ 5	23255	19822	3433		**/01/77**	14382	10295	4087
5/1 / 7	31771	26448	5323		**7/0 /77**	12275	8328	3947
/1 / 7	29408	25315	4093		**1 /0 /77**	11714	8394	3320
7/1 / 7	28634	24013	4621		**8/0 /83**	6236	1800	4436
8/1 / 7	28141	23729	4412		**15/03/83**	5514	1254	4260
19/1 / 7	30526	26901	3625		**9/03/83**	4409	277	4132
19/0 / 8	23844	18463	5381		**15/0 /83**	8503	3795	4708
/01/ 9	19831	16027	3804		**1 /0 /85**	8156	4191	3965
1/11/ 9	11278	5890	5388		**15/01/87**	8522	4050	4472
/11/ 9	16577	10930	5647		**0/01/88**	9993	5614	4379
0/01/7	11780	7532	4248		**7/01/88**	8692	4389	4303
/01/7	13167	9288	3879		**/0 /88**	7549	3014	4535
3/0 /7	12346	8382	3964		**/0 /89**	7460	2886	4574
10/0 /7	11100	6456	4644		**11/0 /89**	6966	2315	4651
1 /0 /7	11383	7023	4360		**18/0 /89**	7481	3145	4336
1/0 /7	9798	6371	3427		**/0 /89**	7008	2861	4147
3/03/7	21691	17330	4361		**1/0 /90**	16581	12873	3708
0/11/7	9231	4978	4253		**7/0 /90**	11475	7598	3877
13/1 /7	13715	9495	4220		**7/01/91**	7230	2989	4241
1 /1 /7	13059	9338	3721		**8/01/91**	7009	2160	4849
5/01/73	7267	3220	4047		**11/01/91**	7390	2730	4660
30/01/73	9523	4637	4886		**1 /01/91**	6239	2131	4108
10/0 /73	6639	1904	4735		**17/01/91**	6715	2398	4317
1 /0 /73	8728	4065	4663		**1 /0 /91**	7451	3228	4223
1 /0 /73	8239	2939	5300		**7/11/91**	22902	19193	3709
/0 /73	6485	2042	4443		**10/01/9**	15595	10357	5238
1/03/73	6324	1957	4367		**13/01/9**	13860	9462	4398
9/03/73	6960	2714	4246		**9/01/95**	7188	2750	4438
7/03/73	7882	3961	3921		**18/01/95**	7094	2391	4703
/0 /73	12081	6462	5619		**17/0 /95**	13953	10230	3723

Table 6.1: Ngaruroro River discharge data for the Ohiti and Fernhill major recharge reach.

N	. .	S N .	R r	S N m	r N S 1	9 . 19	r 19 8	1 r 1978	15 r 1983	3 r 1983	9 r 1983	1 1990	7 1990	8 1991	13 199	199
4	Minor	23155	Maraekakaho	Maraekakaho	208665		27.4	107.2								
7	Minor	23158/A	Ngaruroro	D/S Maraekak Confl.	211670			7198.4						6489.2		
8	Minor	23113/A	Kikowhero	Omapere Rd	212701			15.6		0.0	0.0			0.0		
13	Minor	23159/A	Irrig. Intake	D/S Control Gate	235667									74.4		
14	Minor	23154/A	Glazebrooks	S.H.50	239666									275.0		
17	Minor	23162/A	G/brooks Race	Site E	243669									722.0		
18	Minor	23145/A	Ngaruroro	Valley Rd	244673		8127.8									
21	Major	23166	Waitio Stm	Burial Ground	263709	198.2										
22	Major	23177	Ngat. W. R	S.H.50	268674									54.9		
23	Major	23110	Ngaruroro	Ohiti	271701		7671.0		5514.0		4409.0	16581.0	11475.0	7009.0	13860.0	
25	Major	23164	Waitio Stm	U/S Ohiti Pa W.R	275714	241.8										
26	Major	23163	Waitio Stm	Ohiti Pa W. R	276713	73.6										
27	Major	23165	Waitio Stm	d/s Te Kainga W.R.	278714	416.3										
28	Major	23158	Waitio Stm	Ohiti Road	287718	620.1	713.6			551.6	561.0	536.0	517.2		604.9	
29	Major	23160	Ngaruroro	Rifle Range Butts	288706		7079.2		4567.5							
	Major	Misc	Ngaruroro	U/S of Intake (Site 7)	290706										12968.3	
	Major	Misc	Recharge Infl.	Intake	291706										1272.0	
	Major	Misc	Ngaruroro	U/S of Intake (Site 6)	291707										11806.3	
	Major	MIsc	Rununga Out.	Ohiti Rd	292723							0.0			13.5	
	Major	Misc	Ngaruroro	Site 5	293712										10999.7	
30	Major	23152/B	Rech. Race	Control Structure	294707									456.0		1203.0
	Major	Misc	Rech. Outflow	Gate Structure	294706										707.4	
	Major	Misc	Ngaruroro	Site 4	298718										10668.6	
31	Major	23119/A	Water Race	Rifle Range	300708											66.5
32	Major	23131/A	Ngaruroro	Roys Hill Recorder	300720		5671.6									
33	Major	23162	Okawa	Kautuku	300745	175.6				130.3	124.2			114.2		
36	Major	23173/A	Ngaruroro	Mere Mere Road	304726				3530.0							
	Major	Misc	Ngaruroro	Site 3	310724										10278.8	
	Major	Misc	Ngaruroro	Site 2	310729										9974.8	
37	Major	23154	Okawa	Broughtons Br.*	312738					147.7		288.1	228.5		185.0	
	Major	Misc	Ngaruroro	Site 1	317730										9673.3	
38	Major	23143/A	Ngaruroro	d/s Roys Hill Recorder	317731		3215.7									
42	Major	23102	Ngaruroro	Fernhill	330729			1938.0	1254.0	833.0	277.0	12873.0	7598.0	2160.0	9462.0	
	Major	23149/A	Tut.-Waimate	Goods	384751					1800.0		1924.0		1902.0		
	Major	23184	Raupare	Ormond Rd	398713		441.7			456.0						

Table 6.2: HBCB / HBRC Ngaruroro River major and minor recharge concurrent gauging data (l/s).

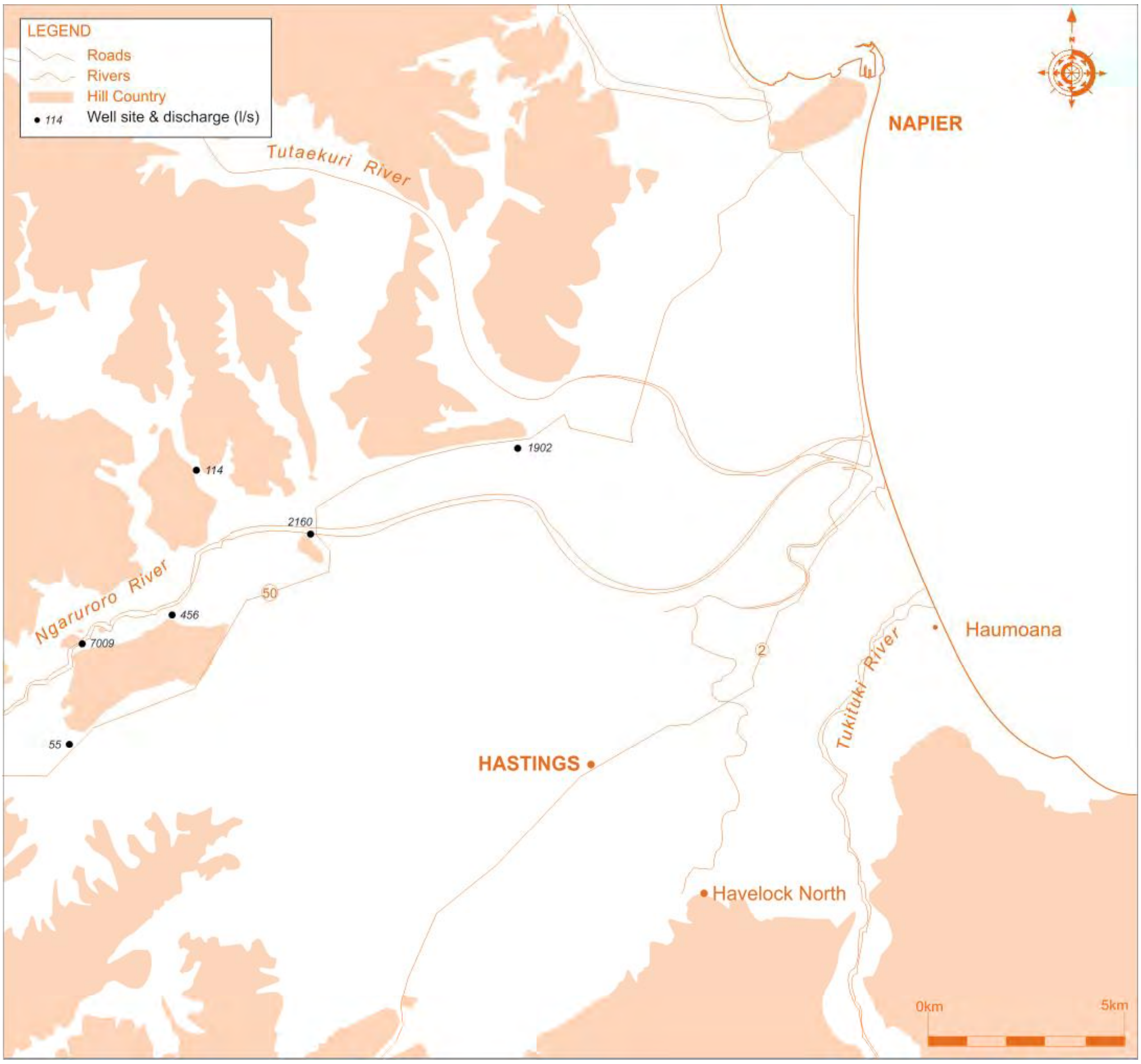


Figure 6.2: Ngaruroro, Tutaekuri and Tukituki river concurrent flow gauging sites together with the results of 8 January 1991 gauging (l/s).

The results of a series of eight low flow measurements by the Ministry of Works (MOW) during 1964 and 1972 undertaken along the Ngaruroro River to determine the decrease of surface flow in the minor recharge reach between Mangatahi (V21/168715) and Ohiti are given in Table 6.3 (Grant 1972).

All this concurrent gauging data suggests that for Ngaruroro River residual flows of up to 35 m³/s, the major recharge reach contributes a relatively constant 4.2 m³/s to the groundwater system, while a further 0.8 m³/s is contributed by the minor recharge reach. For residual flows greater than 35 m³/s, the rate of recharge is likely to be higher but can not be determined as streamflow measurements can not be made at high flow rates. For water balance estimation purposes, a

	m³/	**O m³/**	**r m³/**
13.02.64	9.5	8.3	1.2
18.02.64	11.9	10.4	1.5
27.04.64	8.6	7.4	1.2
29.02.68	9.7	9.2	0.5
06.03.68	8.7	8	0.7
22.01.69	19.9	20.1	0.2
16.02.72	12.0	11.7	0.3
21.02.72	10.5	10.1	0.4
		L	**0.75 m³/**

Table 6.3: MOW Ngaruroro River Minor Recharge Concurrent Gauging Data.

Ngaruroro River contribution to the confined aquifer system of 5 m^3/s (157.7 million cubic metres/year) is adopted.

6.3.1.2 Tutaekuri River

Seven sets of concurrent low flow measurements for the Tutaekuri River between Silverford (V21/329821) and Puketapu undertaken by the MOW (Grant 1970) during 1965 and 1969 are listed in Table 6.4. This data indicates an average flow loss of 0.80 +/- 0.28 m^3/s over the 5 km reach of the Tutaekuri River, to groundwater aquifers underlying the Moteo Valley area.

For the system input / output study the Tutaekuri River contribution to Moteo Valley aquifer is taken as 0.8 m^3/s (25.2 million cubic metres/year).

	S r r **m^3/**	**P** **m^3/**	**L** **m^3/**
09.03.65	4.40	3.40	1.00
26.10.65	8.80	8.10	0.70
02.11.66	8.20	7.30	0.90
11.01.67	11.00	9.80	1.20
01.03.68	5.10	4.50	0.60
07.03.68	4.90	4.00	0.90
22.01.69	7.30	6.90	0.40
			0.80 / 0. 8

Table 6.4: MOW Tutaekuri River concurrent gauging data.

6.3.1.3 Tukituki River

The MOW undertook two sets of river gaugings on the Tukituki River, downstream from Red Bridge during December 1966 and January 1967. The first set (December 1966) of flow measurements suggested a loss of river flow in the order of 2.7m^3/s between Red Bridge and the Black Bridge. The second set (January 1967) of flow measurement was undertaken between Tennants Road and the Red Bridge, and suggested a loss of river flow in the order of 1.3 m^3/s. Three sets of low flow gauging data between Red Bridge and Tennants Road taken at the same time suggested losses in the range of about 0.29 to 0.64 m^3/s. The results of four sets of river gaugings on the Tukituki River between Red Bridge and Black Bridge between December 1990 and January 1991 suggested losses from the river in the range of 0.63 to 1.34 m^3/s.

The variation exhibited by this limited gauging data makes it difficult to estimate accurate flow losses from the Tukituki River. However, geological and hydrogeological evaluation of well log data (see Fig. 5.31) suggest it is possible that the Tukituki River recharges a shallow unconfined to semiconfined aquifer which is perched above the main aquifer system in the area from east of the Karamu Stream to south of Haumoana and Te Awanga (Fig. 5.1). A number of shallow (10 to 25 m depth) wells abstract groundwater from the Tukituki aquifer system for farm and domestic water supply purposes. There is an upward piezometric pressure gradient from the underlying Ngaruroro River recharged aquifer, and the possibility of recharge from the Tukituki River to the main aquifer system is minimal. However during the mid-summer period when there can be a reduction of piezometric pressures in the main aquifer system, some leakage from the Tukituki River to the main aquifer system could occur. Also there is potential for upward vertical leakage from the underlying main aquifer into the Tukituki aquifer system.

Geological cross sections across the Tukituki and the main aquifer systems suggest overlap of gravel aquifers beneath the Thompson Road area (see Fig. 5.31). Well log descriptions of Tukituki River deposited gravels are blue-grey gravels with minimal yellow silt in the matrix compared to red-brown stained gravels and yellow silt and clay of the main aquifer system. This suggests that the Tukituki River derived gravels are fresher and younger than the Ngaruroro River deposits. This is the result of degradation by the Tukituki River in the last few thousand years into the Ngaruroro River floodplain deposits at the eastern edge of the Heretaunga Plains and subsequent aggradation to deposit the fresher younger fluvial gravels. There is an area of aquifer overlap and a groundwater mixing zone beneath the Thompson Road area. The recharge from the Tukituki River to the main system is assumed to be negligible in terms of the total main aquifer storage and is not included in the regional water balance estimation.

6.3.2 Rainfall Input Over the Unconfined Aquifer

The estimation of the quantity of rain seeping through the soil and strata overlying the unconfined aquifer to groundwater, is also a difficult and approximate process because of the wide variation in the water requirements of different crops, the climate before, during and after the rain, the soils and the permeability of the subsurface strata.

The total unconfined aquifer area of the Heretaunga Plains (45 km^2) together with 24 km^2 of unconfined - confined aquifer transition zone east of the unconfined aquifer boundary (Fig. 5.1) was divided into three areas on the basis of nature of soil cover and soil physical and hydraulic properties (Fig. 6.3). A “no soil” area (13 km^2) comprised recent gravel river beds in the Mere and Gimblett road areas with minimal soil moisture storage. An area west of the Ngatarawa Road has soils which are best represented by a type soil in the Takapau area in southern Hawke’s Bay and hence named “Takapau” soils, covers about 29 km^2. The Takapau soil profile was taken as 1 m deep over open gravels. The top soil is moderately permeable, while the subsoil is highly permeable. An area (27 km^2) east of Omahu Road, has soils best described as “Pakowhai” soils where the topsoil is moderately permeable and the upper subsoil moderately slow. The soil is about 2.5 m deep. Other soil physical properties were obtained from an actual profile measured in each type locality (Watt 1995).

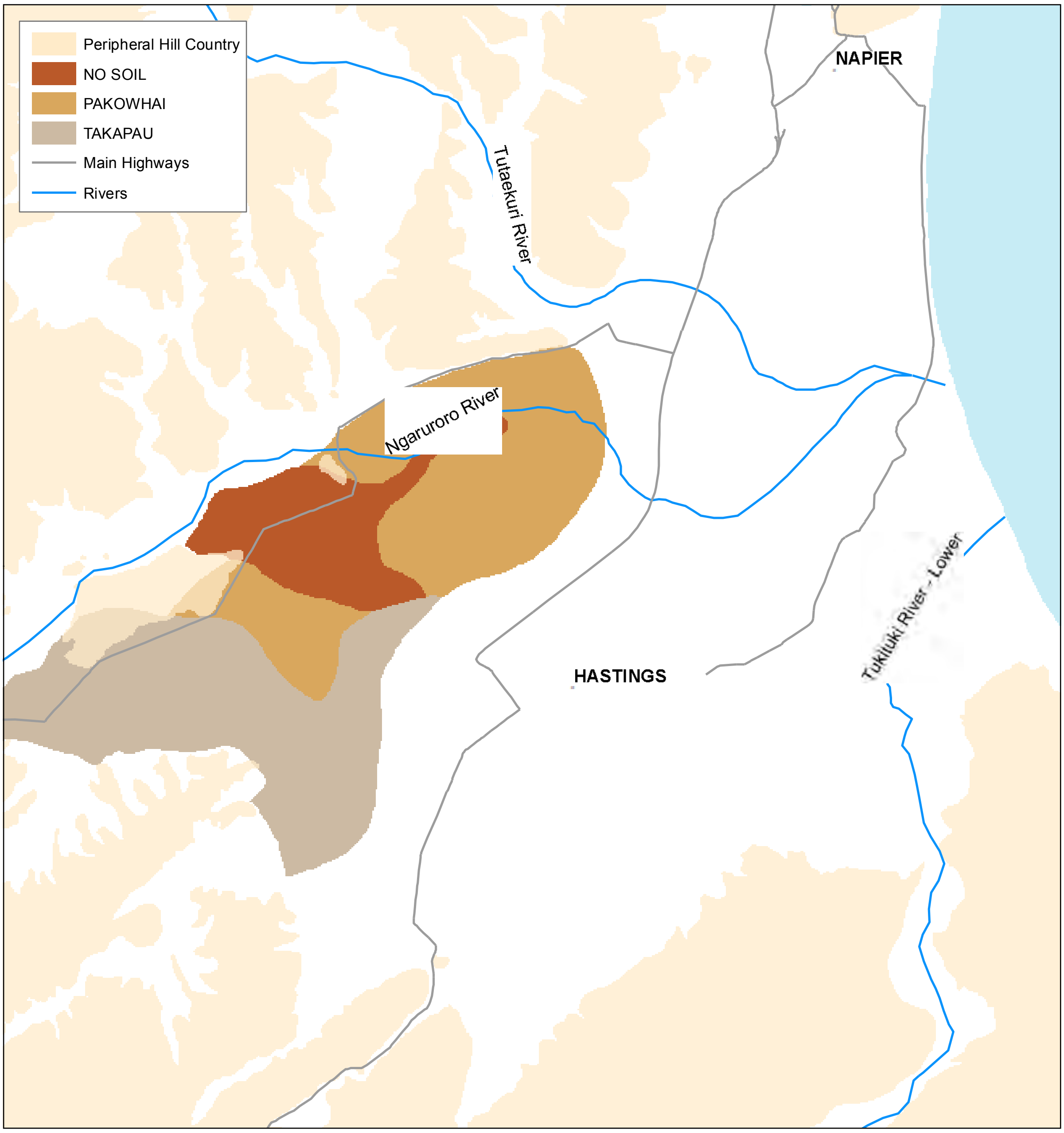


Figure 6.3: Typical soil regions in the Heretaunga Plains unconfined aquifer area based on soil physical and hydraulic properties.

Infiltration and water movement through Takapau and Pakowhai soils of the total unconfined aquifer area was simulated using SWIM (Soil Water Infiltration and Movement, Ross 1990), Model. The unconfined aquifer area devoid of top soil with minimal storage was assumed to allow 100% of the rainfall to infiltrate to groundwater.

SWIM was used to model infiltration and movement of water through the profile on a daily basis. Two consecutive years were selected when the total rainfall for the 24 months was exceptionally high (1975/76, 1976/77), and a further two consecutive years were selected when the total rainfall for the 24 months was exceptionally low (1993/94, 1994/95). The rainfall record commenced in September. Daily rainfall data from Nelson Park, Napier and monthly Penman potential evapotranspiration (PET) data for the same period as the rainfall were obtained from NIWA (Figs. 6.4 to 6.7).

Drainage from the base of the profile, as calculated from the model, is shown on a daily basis for 1974/75, 1975/76, 1993/94 and 1994/95 in Figures 6.4 to 6.7 for the Pakowhai and Takapau soil areas. These results are converted to a volume of rain infiltrating to groundwater by multiplying by the area in each region (Table 6.5).

		1975/7	**197 /77**	**1993/9**	**199 /95**
Rainfall	(Sept-Aug) (mm)	954	1106	535	694
PET	(Sept-Aug) (mm)	951	966	986	1035
"No soil" area: Area = 13 km^2	Drainage (mm)	954	1106	535	694
	Volume (m^3)	12.40x10^6	14.38x10^6	6.955x10^6	9.035x10^6
"Takapau" area: Area = 29 km^2	Drainage (mm)	93	256	13	145
	Volume (m^3)	2.697x10^6	7.424x10^6	0.377x10^6	4.205x10^6
"Pakowhai" area: Area = 27 km^2	Drainage (mm)	4	20	2	1
	Volume (m^3)	0.108x10^6	0.540x10^6	0.054x10^6	0.027x10^6
T m (m^3) x 10 (9 m)		**15.**	**.3**	**7.**	**13.3**

Table 6.5: Drainage depths and volumes for three simplified recharge areas overlying the unconfined aquifer.

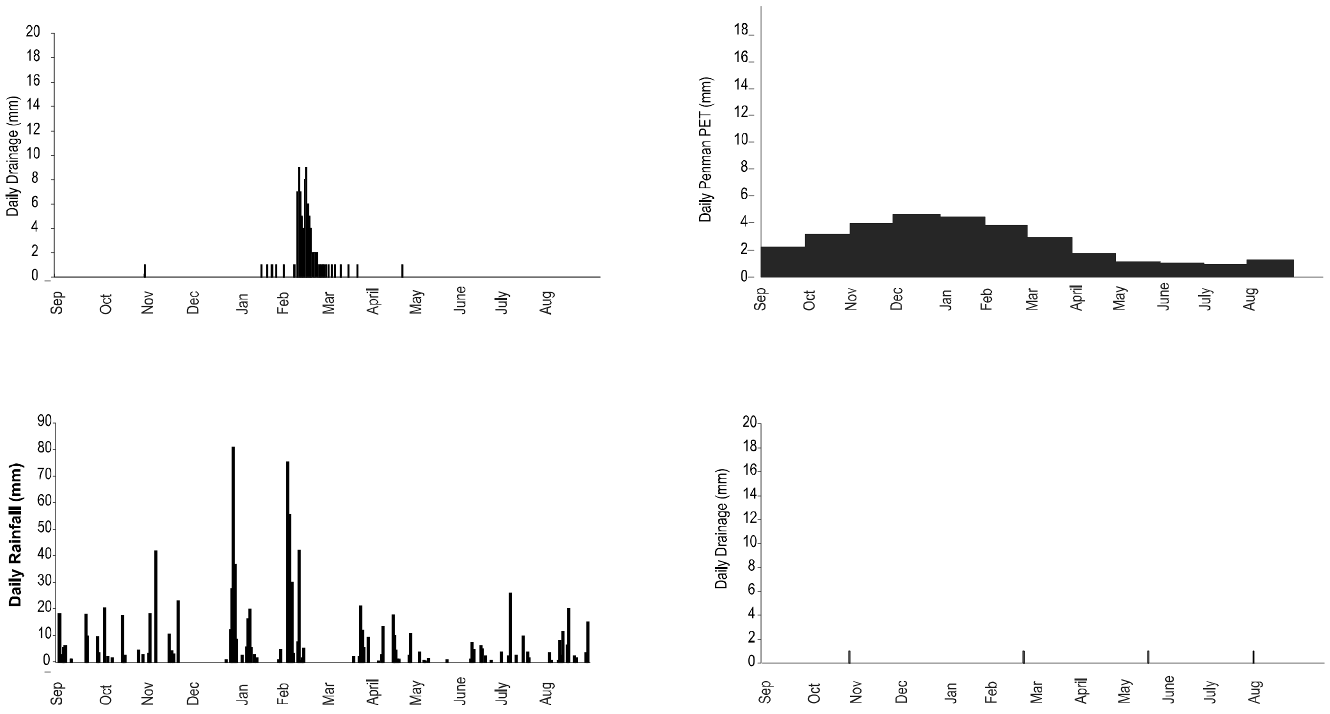


Figure 6.4: Rainfall, PET and drainage data for 1975/76.

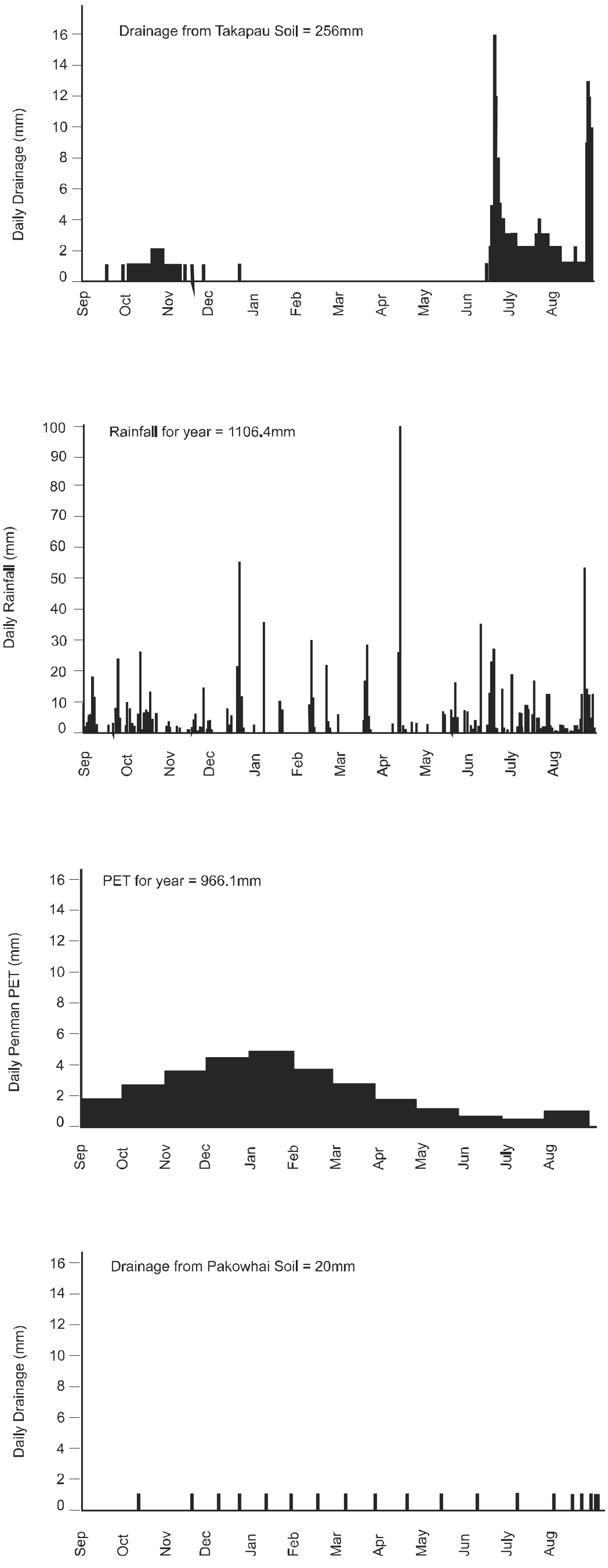


Figure 6.5: Rainfall, PET and drainage data for 1976/77.

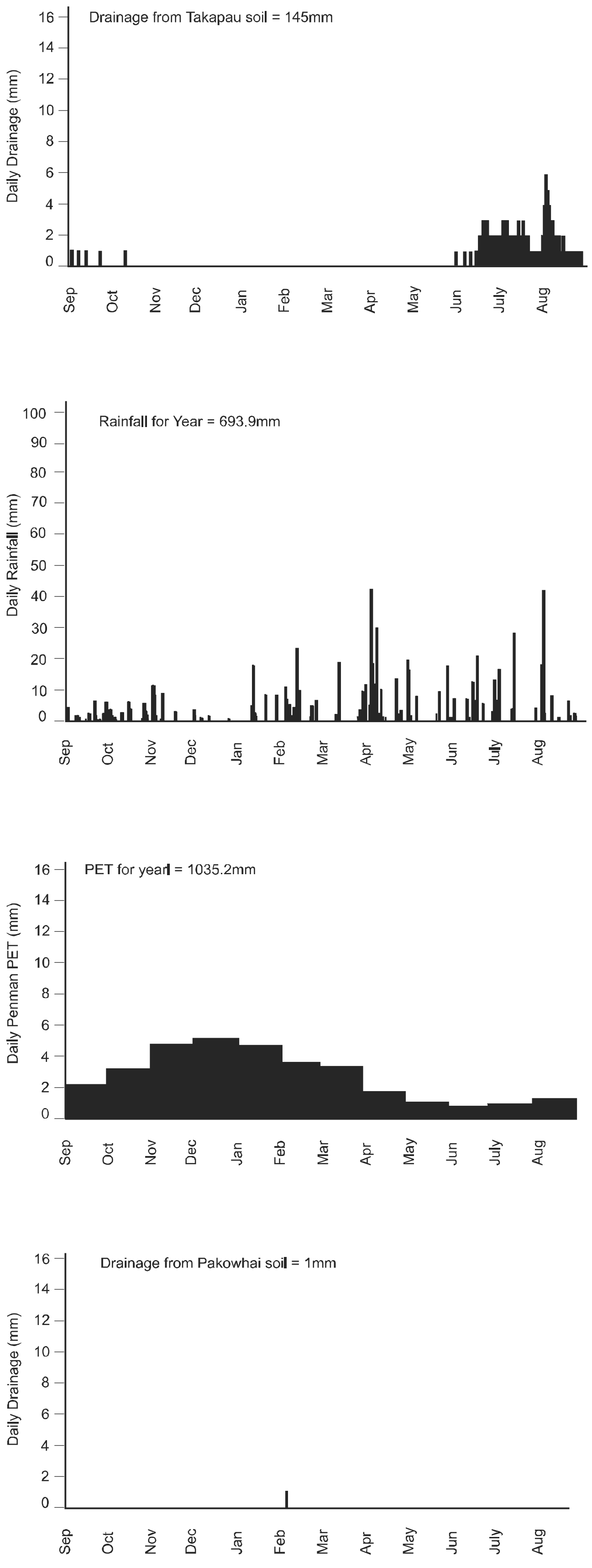


Figure 6.6: Rainfall, PET and drainage data for 1993/94.

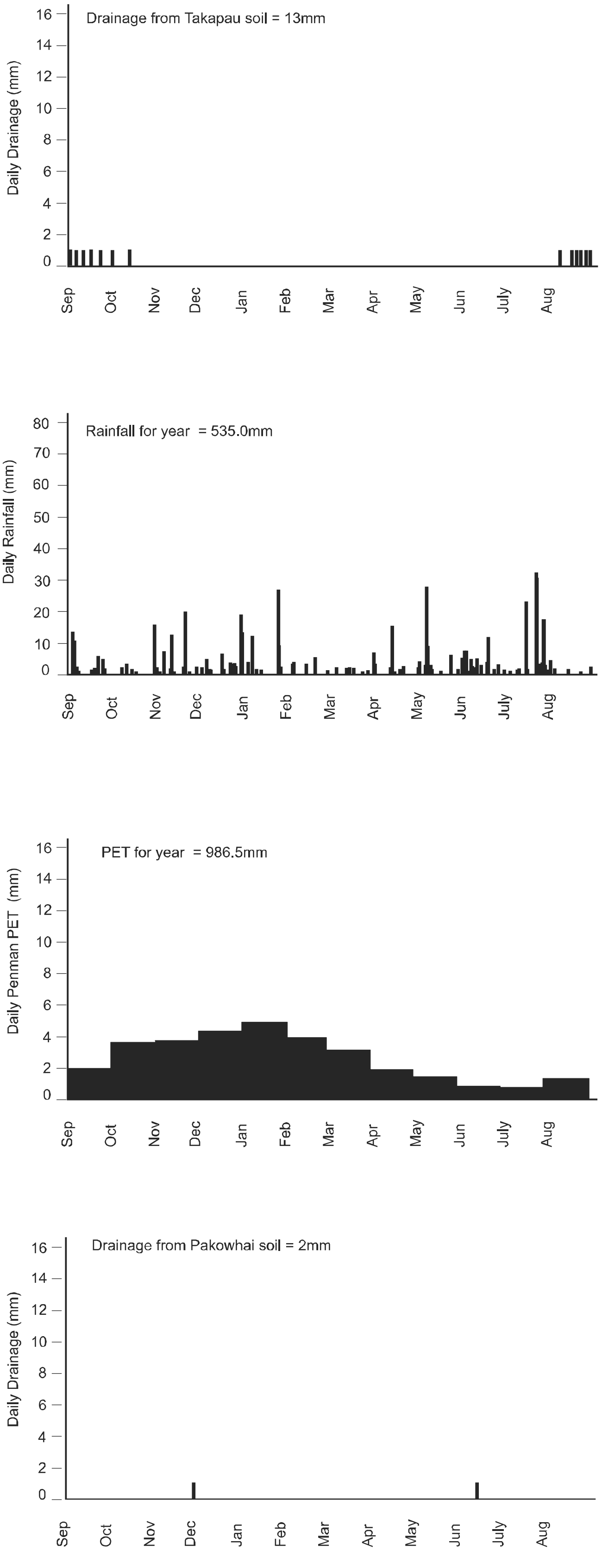


Figure 6.7: Rainfall, PET and drainage data for 1994/95.

The "no soil" area dominates the recharge of the aquifer in all years. The "Takapau" area, as predicted by the model, may yield as much as 250 mm in a wet year and as little as 13 mm in a dry year. In contrast, the deeper and less permeable "Pakowhai" area shows much lower variability, yielding some 20 mm in a wet year, and 1-2 mm as a minimum in the driest years.

Total rainfall input into recharge for the entire unconfined aquifer area is estimated by this study at about 7 million cubic metres in the driest years, and about 22 million cubic metres in very wet years.

To account for the simplification of soil areas and soil hydraulic properties, the computed rainfall recharge for the dry years (7 million cubic metres) has been reduced by a factor of 30% and 5 million cubic metres/year of rainfall input has been adopted for the water balance estimation.

6.3.3 Artificial Recharge

Artificial recharge to the Heretaunga Plains main aquifer system has been undertaken by diverting up to 1 m^3/s water from the Ngaruroro River spread in four 500 m long and 20 m wide and 2 m deep channels. On an average artificial recharge has operated for about 15 days during the driest part of the year. However the efficiency of the recharge system has not been fully determined. Hydrogeological and geological factors suggest that a proportion of recharged water would return back to the river and a part will also resurface in the nearby Raupare and Irongate spring fed streams. The artificial recharge system has not been operational on a continuous basis due to silting problems in the recharge ponds. For water balance purposes the artificial recharge input is considered to be negligible.

6.3.4 Irrigation Seepage

Irrigation water runoff into drains occurs as a result of excessive application of irrigation water over relatively permeable soils. The typical summer pattern of low flow of the Karamu Stream (Fig. 2.31) suggests an unmeasured inflow in the order of 0.68 m^3/s coming into the stream from the drains and tributaries between Havelock North and Floodgate. This gain in flow has entered the Karamu Stream downstream of Havelock North at a time of low flow and low rainfall, and is probably runoff of excess irrigation water from the adjacent plains. For the regional water balance estimation the effect of irrigation seepage is assumed to be negligible.

6.3.5 Leakage Between Aquifers

The potential for leakage between aquifers is indicated by the variation of groundwater level (pressure) as reflected in static water levels from the aquifers at different depths. Apart from the three HBRC exploratory testbores at Flaxmere, Tollemache Orchard and Awatoto, there is not much data available for comparing static water level at different depths for the Heretaunga Plains aquifer system.

In the Flaxmere testbore at the confined - unconfined boundary there was no significant variation of static water level with depth. This supports the concept of an aquifer system with hydraulic connection to all depths down to the total depth of 134 m and no significant impediments to lateral and vertical groundwater flow. Piezometers installed when the casing was withdrawn at 42 - 48, 72 - 78, and 108 - 114 m show a regular synchronized pattern of fluctuating water levels which confirms an interconnected aquifer system.

Water levels in the Tollemache Orchard exploratory testbore also do not show any significant variation with depth (Figs. 4.10 and 5.26). Six flowing artesian aquifers had similar water levels which displayed a regular synchronized pattern of fluctuation suggesting hydraulic connection even though the aquifers appeared to be separated by impermeable aquicludes. Oxygen 18 analyses confirmed a common Ngaruroro River recharge source and the similar water levels a common recharge area.

In contrast in the Awatoto exploratory testbore, aquifers showed increasing piezometric pressures with depth down to 254 m where drilling stopped. These piezometric pressures suggest groundwater flows toward Hawke Bay and upward through “holes or gaps” in the aquicludes and aquitards. The cross sections show variations in the thickness and distribution of the interbedded confining aquicludes, aquitards and the postglacial capping or confining layer that provide a path for the upward flow of groundwater. These “holes or gaps” may have been formed by river degradation or wave erosion at the coast or may be a product of persistent river channel agradation or accumulation of beach gravel deposits that provide permeable connections between aquifers.

The occurrences of higher water levels with depth was noted by Ongley (1937) for wells drilled in the 1930’s at Nelson and McLean parks, Napier. These sites are at the northeast margin or edge of the Heretaunga Plains aquifer system and it is suggested by the well logs that aquicludes are thicker than to the south of Napier, and hydraulic interconnection between aquifers is more difficult than in the central part of the aquifer system where river channel gravels form conduits connecting aquifers. At the Napier or the northeast margin of the Heretaunga Plains, groundwater chemistry suggests (see 7.4.4.4) there is hydraulic connection to the underlying Pleistocene - Pliocene limestone, mudstone and sandstone underlying the late Quaternary Heretaunga Plains sediments, and outcropping in and underlying the area inland from Park Island and Taradale.

6.3.6 Leakage from Water Races

On the Heretaunga Plains there are a number of water races which provide farms with stock water supplies. During the summer the quantity of water in the water races is least due to increased abstraction. Some of the water race flow is lost by evaporation or leakage. The quantity of water race water seeping into the gravel aquifer during the peak summer period is probably small. For the regional water balance estimation the input from stock water races is assumed to be negligable.

6.4 SYSTEM OUTPUTS

Groundwater from the Heretaunga Plains aquifers is used for public and rural water supply, industry and irrigation. Shallow groundwater is also abstracted from 6 pumping stations adjacent to the coast to dewater high water table areas to maintain production of crops on the coastal land. On the Heretaunga Plains there are spring seepage areas, the flows from which combine to form local rivers and streams. The principal outflows or output from the groundwater system are:

- public water supply;
- industrial abstractions;
- irrigation abstractions;
- pumping from the coastal pumping stations for dewatering purposes;
- outflow from inland and offshore springs;
- vertical leakage through aquitards.

6.4.1 Public Water Supply Abstractions

Groundwater from the Heretaunga Plains aquifer system is the source of the reticulated water supplies to Hastings (including Havelock North) and Napier from 26 wells. Locations of these pump stations and bores are shown in Fig. 6.8. These public water supply abstractions are metered and the readings are supplied to HBRC by the Napier City Council and Hastings District Council on a quarterly basis.

The urban water supply abstraction data was compiled for the July 1989-June 1995 period. Estimation of data was undertaken for short periods of missing record. Figure 6.9 illustrates the total monthly municipal abstraction for Hastings, Havelock North and Napier during this six year period.

In a typical year with wet winters and dry summers (see Fig. 2.28) there is maximum water use during the summer period (November to March) with peak water use occurring around January. The monthly public water supply totals are influenced by rain with water use for garden irrigation declining significantly when it rains. In Figure 6.9 the wet summer of 1992-93 has a lower abstraction peak compared with other drier summers. The total public water supply abstractions during July 1994 to June 1995 period is given in Table 6.6.

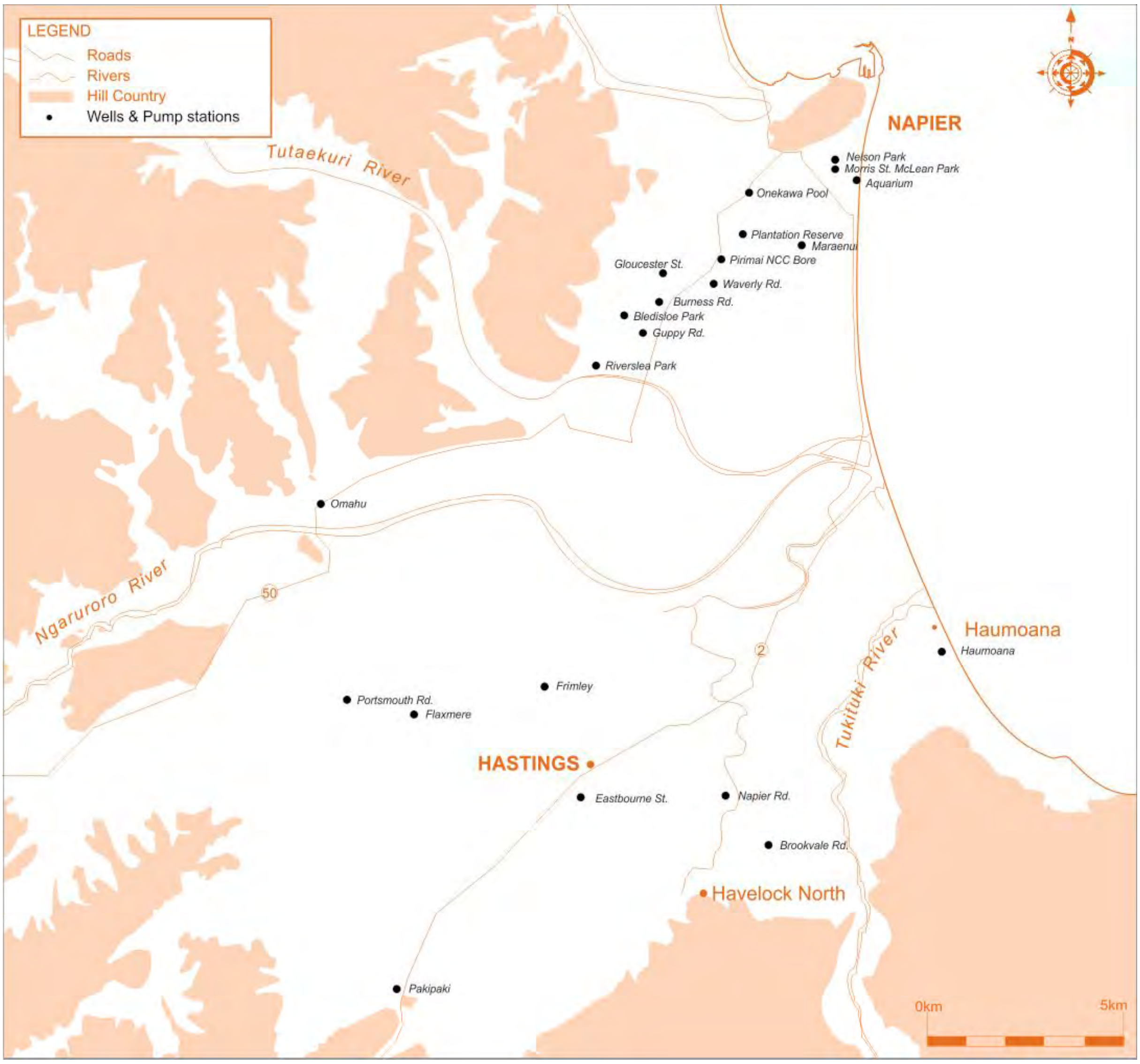


Figure 6.8: Heretaunga Plains public water supply wells and pumping stations.

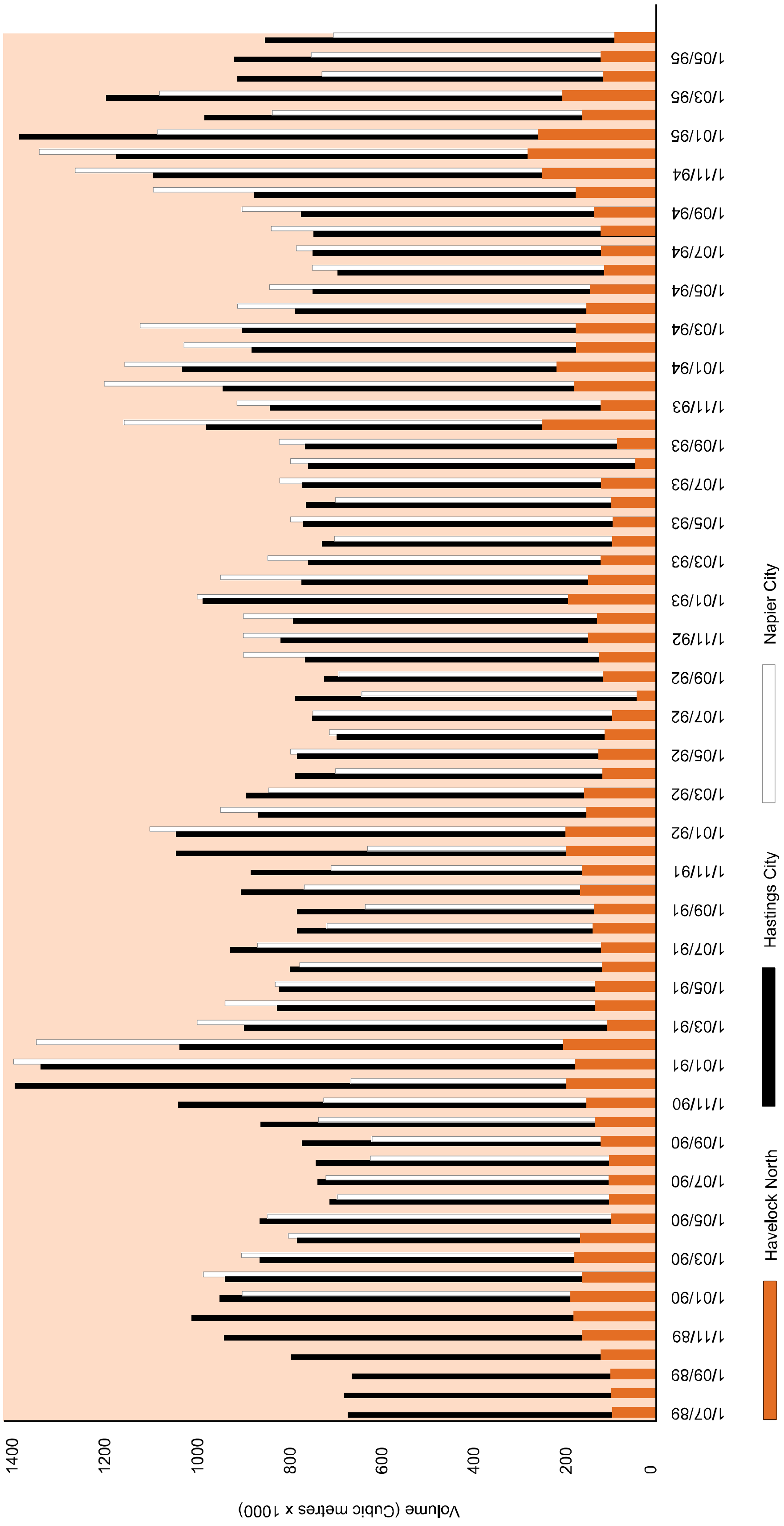


Figure 6.9: Monthly public water supply abstractions during July 1989-June 1995.

Ur Ar	**A Am m3**	**A r y m3**	**A r L r / y/P r**
Napier	11 453 412	31 379	587
Hastings	10 598 619	29 037	495
Havelock North	2 074 324	5 683	611
T	**1 355**		

Table 6.6: Public water supply abstractions during July 1994-June 1995.

During the July 1994-June 1995 period the total quantity of groundwater abstracted for urban water supply was 24.1 million cubic metres. Based on the consent data and earlier water use surveys, about 2 million cubic metres of groundwater would also have been abstracted from about 300 rural wells on the Heretaunga Plains for domestic supply during this period. The higher average per capita public water supply for Havelock North (611 l/day/person) compared with Napier (587 l/day/person) and Hastings (495 l/day/person) is perhaps a result of the greater focus on gardening in the Havelock North urban area compared to Napier and Hastings. Also at Havelock North public water supply is used for rural irrigation of crops on properties adjacent to the town. The total public and domestic water supply abstraction for the period is estimated at 26.1 million cubic metres.

6.4.2 Industrial Abstractions

On the Heretaunga Plains groundwater is abstracted from private wells for water supply to 35 industries. For comparing water use and seasonal water demand trends these industries can be grouped into five groups based on the type of industry - bitumen/gravel, food processing, meat processing, wool industry and general. Abstractions from all industrial groundwater users are metered and HBRC maintains a database of industrial water consumption on a quarterly basis. Water use statistics for the five industrial groups was compiled for the July 1989-June 1995 period (Fig. 6.10). Estimation of data was undertaken for short periods of missing record on the basis of historical water use data and discussion with the specific industries. Figure 6.10 shows the graph of total annual abstraction by industrial groups during the July 1989-June 1995 period.

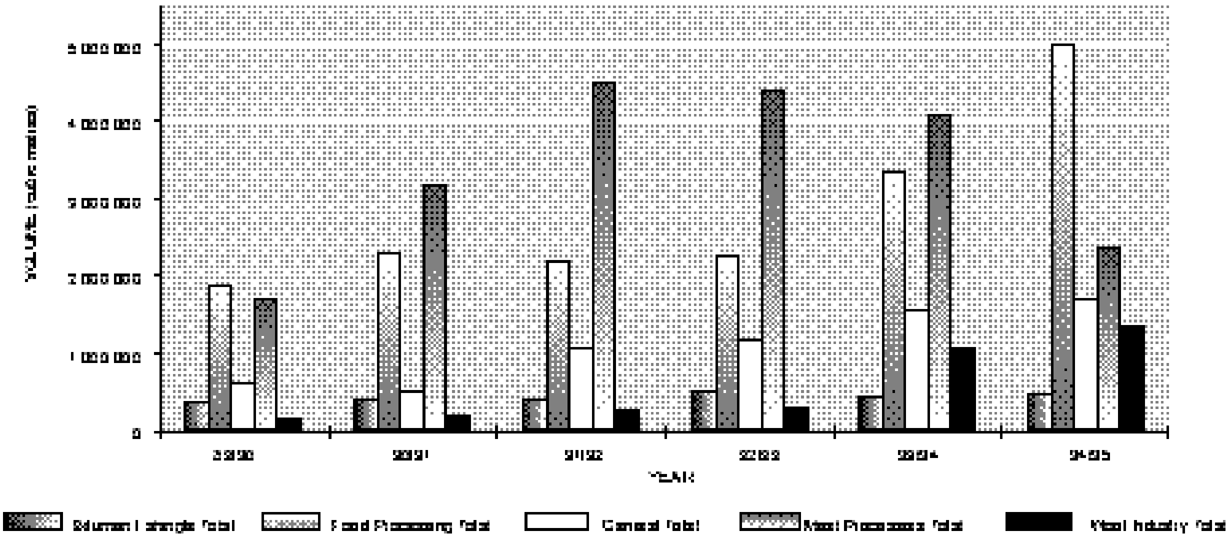


Figure 6.10: Total annual abstraction by industrial groups during July 1989-June 1995.

I r r	**A Am m^3**	**A r y m^3**	**A r y m^3/**	**xm m y m^3/**	**m m y m^3/**
m / r	477 983	1 309.5	0.0151	0.0208	0.0108
Pr	505 9485	13 861.6	0.1604	0.3303	0.0769
r	17 34644	4 752.4	0.0550	0.0797	0.0314
Pr	2 379 501	6 519.0	0.0755	0.1187	0.0398
I ry	1 363 620	3 735.9	0.0432	0.0660	0.0279
T	**11 015 33**	**30 178.**	**0.3 9**	**0. 15**	**0.18 8**

Table 6.7: Industrial water abstraction during July 1994-June 1995.

The predominant trend is the increased demand for groundwater by all industrial groups during the July 1989 to June 1995 period. Water use by the industrial groups from July 1994 to June 1995 is given in Table 6.7.

During July 1994 to June 1995 period the total volume of groundwater abstracted for industrial use was about 11 million cubic metres.

6.4.3 Irrigation Abstraction

Currently there are 2178 groundwater consents for the Heretaunga Plains of which 2004 are for irrigation abstraction (92%). The amount of water used is difficult to assess because only a few irrigation abstractions are metered. During 1994/95 a study was undertaken to estimate the Heretaunga Plains irrigation water use by correlating pump power consumption with pump flow rates (Altoft 1995). The field data collection comprised pump power consumption and flow data from 50 representative irrigators (Fig. 6.11), in terms of soil and crop considerations. The hypothesis of soil - crop specific water need is based on the assumption that the crop water requirements varies with respect to crop and soil hydraulic characteristics. If the hypothesis is correct then it could be used to estimate irrigation water abstractions from landuse data and field soil-specific crop water use surveys. At the time of writing this report a two year (1995-97) field study was in progress in the Pukahu area of the Heretaunga Plains which will provide a comparison of actual quantity of irrigation water applied to allocated volume with the soil-crop-specific irrigation water need.

The 1994/95 Heretaunga Plains landuse is illustrated in Figure 2.32. A crop-specific water use survey was carried out for the entire Heretaunga Plains on the basis of this landuse for the October 1994 to March 1995 irrigation season. A detailed report on crop and soil specific irrigation groundwater use on the Heretaunga Plains is appended in Volume II of this report (Altoft 1995). Table 6.8 summarises the crop-specific water usage data, in terms of monthly averages for the irrigation.

Cr Ty	**Ar**	**r U (m³/ /m)**	**r U mm/ r**	**T Irr r U r S (m³/m) x**
Pipfruit	6783	244	12.2	9930312
Kiwifruit	361	271	13.6	586986
Cropping	329	289	14.4	5699658
Stonefruit	1082	770	38.6	4998840
Nursery	205	713	35.6	876990
Grapes	2161	138	6.9	1789308
T	**10 9 1**			**3 88 09**

Table 6.8: Summary of crop specific irrigation water use data.

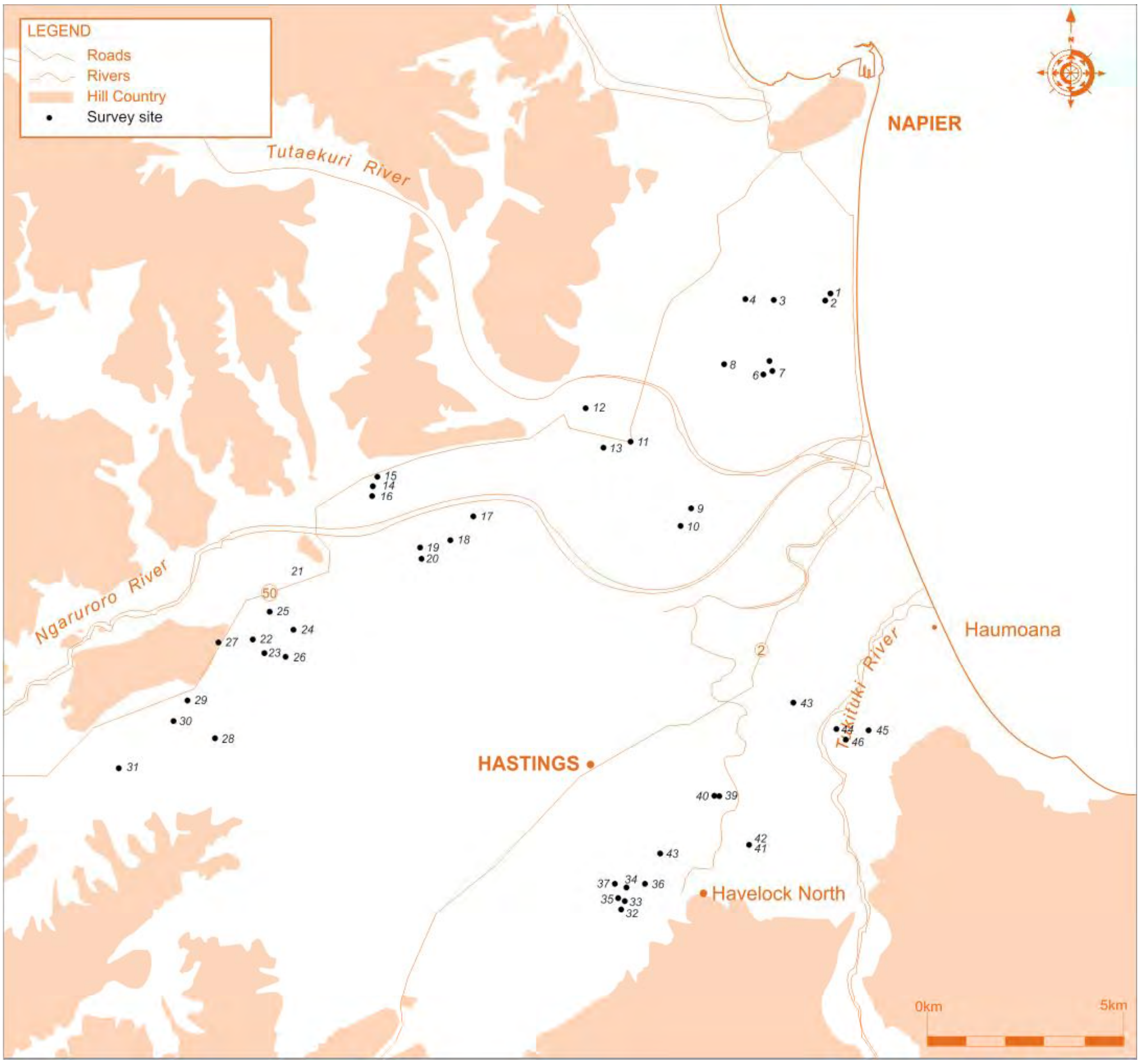


Figure 6.11: Irrigation water use survey sites.

During the July 1994-June 1995 period the total quantity of groundwater abstracted for irrigation purposes was about 23.9 million cubic metres. This assumes that irrigation outside of the six month October 1994 to March 1995 irrigation season for the July 1994 to June 1995 period was insignificant. However abstraction of groundwater during the late winter and spring for spraying in orchards to prevent frost damage to blossom and newly developed fruit on trees is important.

HBRC consent data suggest that a total volume of c. 4 million cubic metres of groundwater was allocated for frost protection during the July 1994-June 1995 period. The actualquantity of groundwater abstracted for frost protection is also difficult to estimate because it depends on the number of frosty days and this can vary from place to place as a result of local microclimate that develop during particular climate patterns. Also there are no flow meters installed on wells pumped for frost protection purposes to provide data on the actual amount of groundwater pumped. Actual use is expected to be considerably less than the consented quantities. During 1994/95 there were relatively few frosty days. For the 1994/95 water balance estimation it is assumed that only about 50% of the allocated volume (2 million cubic metres) was used for frost protection activities.

6.4.4 Abstractions from Dewatering Pumping Stations

On the Heretaunga Plains adjacent to the Hawke Bay coast where the water table is close to ground surface it is necessary to pump groundwater (dewater) to lower the water table to maintain production of crops. Further inland there are also dewatering pumping stations near areas of extensive spring seepage. On the Heretaunga Plains eight coastal and inland dewatering pumping stations (Fig. 6.12) operated by the HBRC, abstract a significant quantity of groundwater from the system. These pumping stations consists of bores which are generally 2 to 4 m in depth.

Adjacent to Flaxmere between York and Irongate roads and south of Portsmouth Road near Montrose, substantial quantities of groundwater are pumped from shallow bores in the unconfined aquifer directly into drains, to reduce the flow of springs and the area of wetlands associated with the spring seepage areas. There is also a considerable proportion of drain water derived from stormwater runoff and runoff of excessive application of irrigation water. It is not possible to estimate the exact proportions derived from stormwater and irrigation drainage, compared to the groundwater component pumped from the aquifers or intercepted from the groundwater sourced spring flows. In order to refine the groundwater component, it was assumed that the inland dewatering bores located on known spring seepage areas pumped 100% groundwater throughout the year. For dewatering bores located at the coast and outside the spring seepage areas, the groundwater component was assumed to be 20%. Based on these crude criteria, the groundwater component of the dewatering abstraction was estimated for each month during the July 1994 to

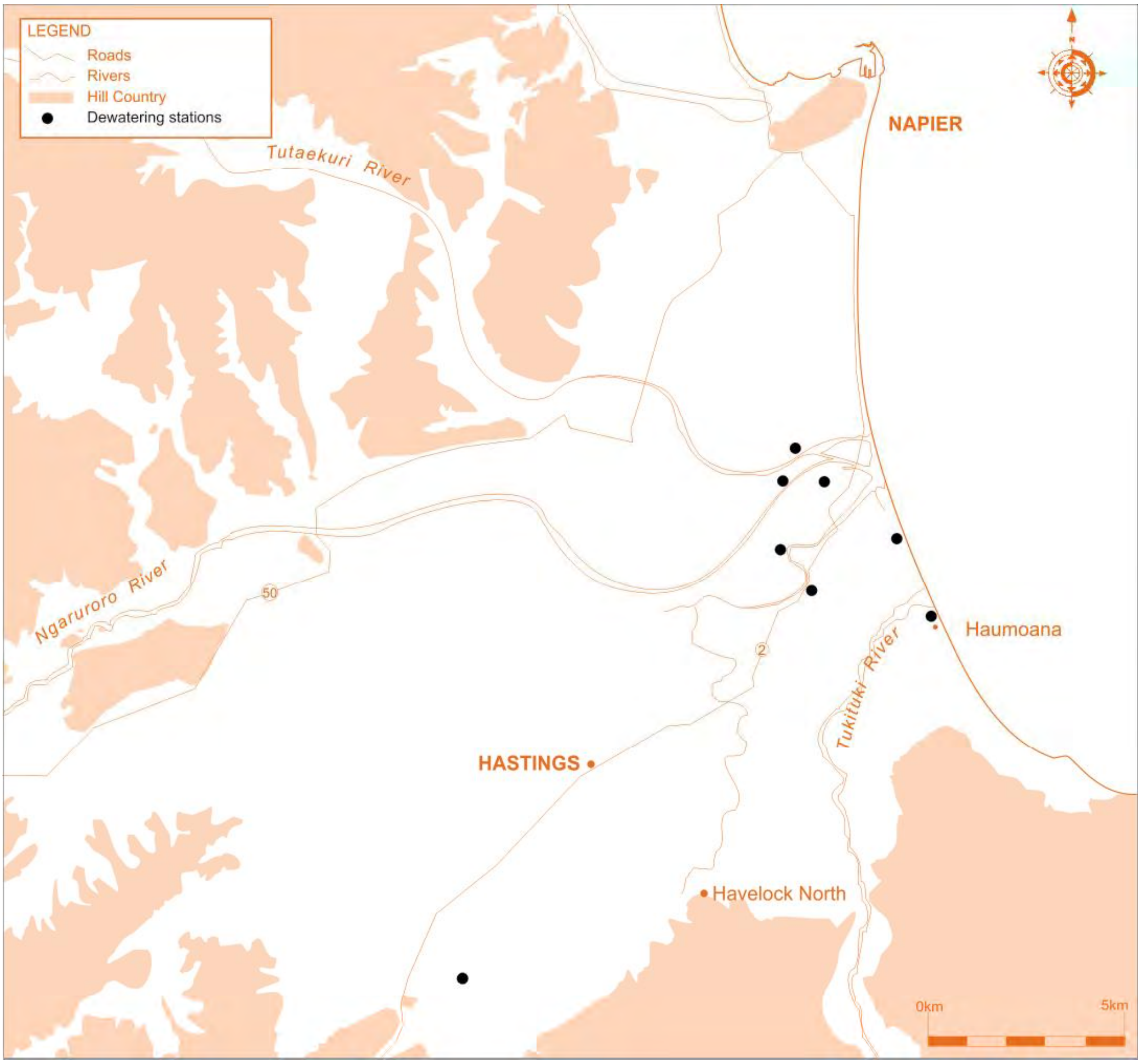


Figure 6.12: Coastal and inland shallow groundwater pumping (dewatering) stations.

June 1995 period (Fig. 6.13). It is estimated that about 3 million cubic metres of groundwater was pumped by the dewatering pumping stations during the study period. Due to difficulties in separating the various components in dewatering abstractions and inaccuracies involved in reading of dewatering pump meters and pump discharge calibrations, the estimated groundwater dewatering abstraction represents only a coarse guess. In the future, regular reading of meters and better understanding of the various components of dewatering abstractions, should allow refinement of this estimate.

6.4.5 Seepage from Springs and Spring-fed Streams

The groundwater flowing through the unconfined sector of the gravel aquifer at relatively shallow depth towards the coast is impeded by the impermeable confining layer at the unconfined - confined aquifer boundary (Fig. 5.1). The groundwater either flows below the impermeable layer into the confined aquifer, or above the layer into the near surface gravel channels to form the springs, the sources of local rivers, streams, creeks and drains. The base flow in the streams is derived from re-surfacing shallow groundwater and is the overflow from the groundwater recharge process for the confined aquifer at the confluence of the unconfined and confined aquifer region. Springs occur along the stream beds and surface flows increase downstream.

Perennial spring-fed rivers, streams, and creeks are an important component of the hydrology of the Heretaunga Plains (Fig. 2.31). In order of magnitude the largest of these streams are:

- Tutaekuri - Waimate Stream
- Karamu Creek
- Raupare Stream
- Irongate Stream
- Mangateretere Stream.

Spring flow and the streamflow data are important indicators of the “state” of the water balance in the confined aquifers. The spring flow is dependant on the groundwater pressure in the confined aquifer and the contributing channel length of the stream beds changes in response to seasonal and longer-term fluctuations in groundwater levels. For example the seasonal decline of groundwater levels during the summer is reflected in a downstream movement of the headwater spring locations and consequently lower stream flows. High and rapid rises of flows of the streams are primarily due to rainfall runoff and stormwater discharges from urban catchments where buildings, roads and paving intercept rain and quickly channel it into stormwater drains flowing into the streams. The surface water and groundwater interaction and the temporal fluctuations are discussed more fully in section 5.3.3.

Karamu Stream flow data is given in Table 6.9. Figure 6.14 presents the locations of these concurrent gauging stations.

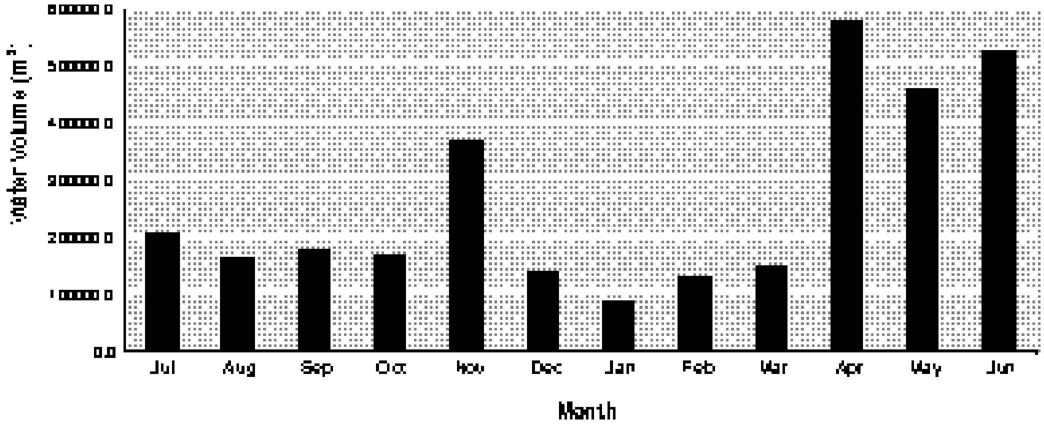


Figure 6.13: Dewatering abstractions during July 1994 to June 1995.

No.	Site No.	River No.	River	Site Name	Map ref.	13 Mar 1968	21 Jan 1969	18 Jun 1970	23 Jul 1970	16 Sep. 1970	6 Nov. 1970	14 Nov 1972	07 Dec. 1972	22 Sep. 1976	08 Dec. 1976	17 Jan. 1977	08 Feb 1979	01 Feb 1980	09 Apr. 1981	25 Nov. 1982	11 Jan 1983	07 Jun 1984	03 Jul. 1984	14 Feb. 1985	15 Sep 1986	08 Jan 1987	03 Feb 1987	17 jan. 1991	15 Dec. 1993	7 Feb 1995
1	23183	231039	Karewarewa	Raukawa Rd.	V21/322661														59.0			70.4	76.0							
2	23135	231039	Karewarewa	Rosser Rd	V21/330635																		83.1							
3	23150/A	231039	Karewarewa	Turamoe Rd	V21/341677														84.0		377.0	108.0	60.0							
4	23136	231039	Awanui	Pakipaki	V21/351609	36.6	57.0						$^{8/12}$ 4.9						110.0	60.9	21.0	110.9	104.5	27.6			23.3			24.4
5	23171/A	231039	Karewarewa	Pakipaki	V21/351610																	118.0	107.0							
6	23105/A	231039	Poukawa	Railway Br.	V21/352607	22.9	94.5												249.4	39.8	20.4	117.1	110.5	17.4			16.4			
7	23148/B	231039	Awanui Stm.	Flume	V21/357613																	300.5	293.7	228.4			186.4	65.0	135.7	
7A	23175/A	231030	Irongate	Farndon Pakowhai Rd	V21/365662							$^{15/11}$ 2170		611.0	$^{9/12}$ 379.0	41.0														
8	23169	231030	Irongate	Clarkes Weir	V21/367666		$^{22/1}$ 96.9										161.6		294.7	157.0			361.7				71.7	47.8	169.5	116.8
8A	23183/A	231038	Sthland Drn.	York Rd.	V21/372669							$^{15/11}$ 2.0																		
8B	23101/A	231030	Irongate	S.H. 2	V21/374642							$^{15/11}$ 215.0	345.0																	
9	23102/A	231030	Irongate	Riverslea Rd.	V21/380635							$^{15/11}$ 233.0		730.0	426.0	409.0		389.0	383.0	439.0	99.0		441.0							
10	23166/A	231030	Karamu	St. Georges Rd	V21/397624																		787.0							
10A	23184	231050	Raupare Drn.	Ormond Rd.	V21/398713	472.9	$^{20/1}$ 506.6	708.3	736.0	700.8	705.0						353.9			414.6	370.6	712.9	$^{2/7}$ 707.6	386.5				341.0	477.6	
11	23182/A	231038	Southland Dr	St. Georges Rd	V21/405640							3.0		$^{23/9}$ 51.0	14.0	18.0		128.0	15.0			12.0	10.0	2.0						
11A	23109/A	231038	Southland Dr.	St. Andrews Rd	V21/409635		3.4						11.0																	
12	23110/A	231037	Louisa Stm	Te Aute Rd	V21/410625		11.8						21.0								60.9		82.8				18.9	33.3		43.8
13	23139	231040	T/kuri W/mate	Chesterhope	V21/416716										2224.0		1693.0						2458.0	1920.0						
13A	23115	231036	Herehere	Lane Rd	V21/421606				14.8	16.7																				
13B	23172/A	231035	Mangarau St.	Te Aute Rd	V21/422633									$^{23/9}$ 63.0		19.0								2.0						
13C	23108/A	231030	Karamu Stm	Hast. H.lock Rd	V21/423637								586.0												924.2	309.7	324.7			
13D	23168/A	231030	Elwood Rd. Dr	Ruahapia Rd	V21/425702							10.0		$^{23/9}$ 105.0	$^{9/12}$ 27.0	9.0		6.0												
14	23138	231030	Karamu Stm.	Floodgates	V21/427708	1141.1	1342.6	2461.6	2382.3	2413.4	1956.3	1341	1450.0	4510	1887	1921.0	1159.0	1506.0	2021.9	1343.4	1005.1	1858.3	1866.4		1954.0		1078.5	916.5	1590.3	$^{8/12}$ 1289.7
15	23122/A	231031	Ruahapia Stm	Ruahapia Rd	V21/429687		$^{20/1}$ 98.1	91.6	103.6	108.7	118.6	87.0	$^{8/12}$ 80.5	$^{23/9}$ 271.0	$^{9/12}$ 136.0	100.0	98.1	137.0						88.9	101.8					
16	23199	231030	Karamu Stm.	Crosses Rd	V21/430643		373.8																990.0							
17	23111/A	231034	Karituwhenua	Napier Rd	V21/432643		7.3						0.5	25.0	5.0	2.0							0.5	3.2	2.7					
18	23114/A	231032	Awahau	St. Georges Rd	V21/432667		19.4					12.0	20.0	57.0	$^{9/12}$ 17.0	20.0							11.5	5.3	24.6					
19	23112/A	231033	Mangateretere	Napier Rd	V21/438659	$^{14/3}$ 145.6	205.2	284.6	298.1	255.4	215.7	167.0	209.0	339.0	195.0	203.0	182.8	189.0					265.1	96.2	265.7	103.9		71.5		101.4

Table 6.9: Summary of concurrent data along Karamu Stream (l/s).

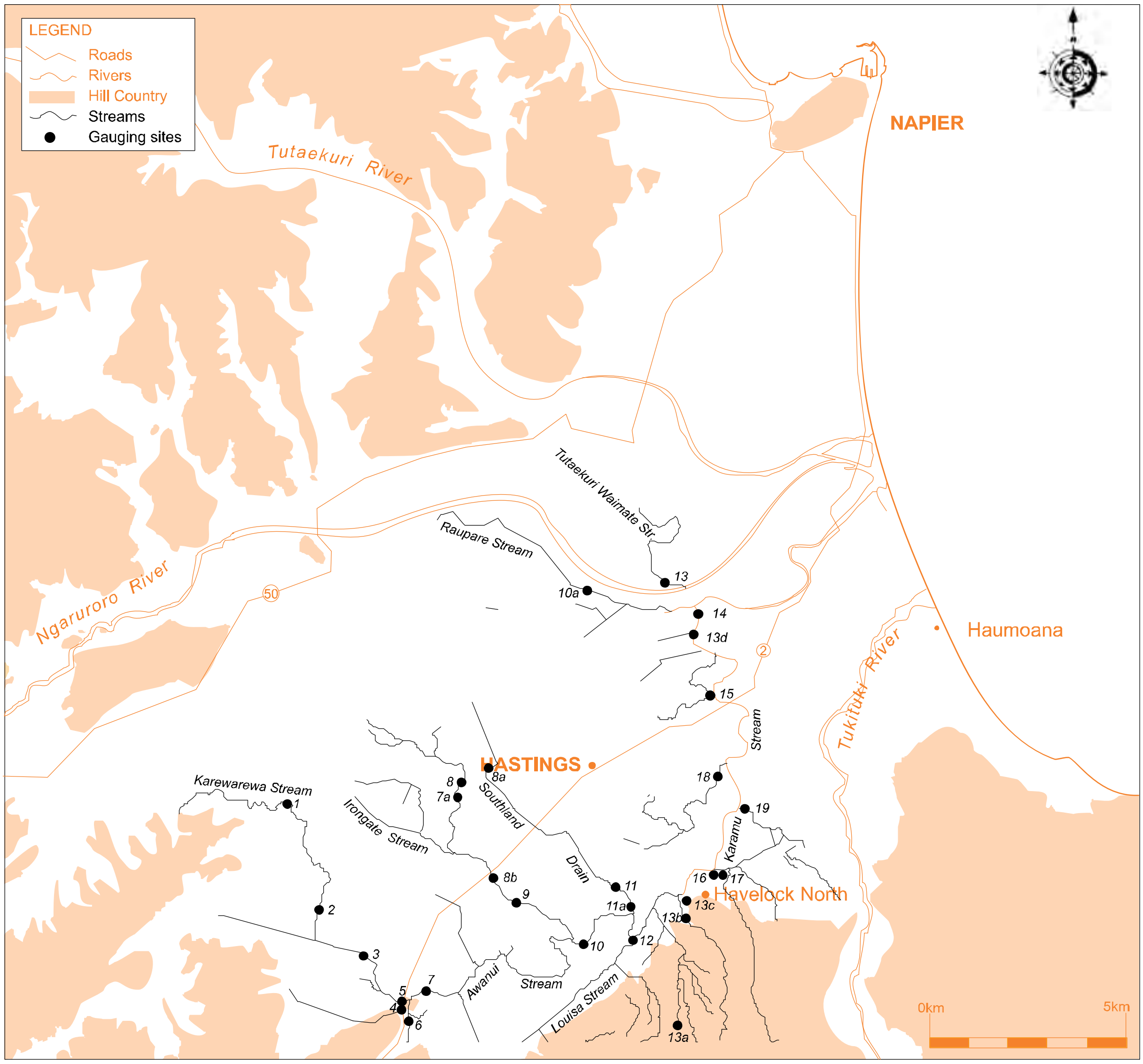


Figure 6.14: Concurrent gauging sites along Karamu Stream.

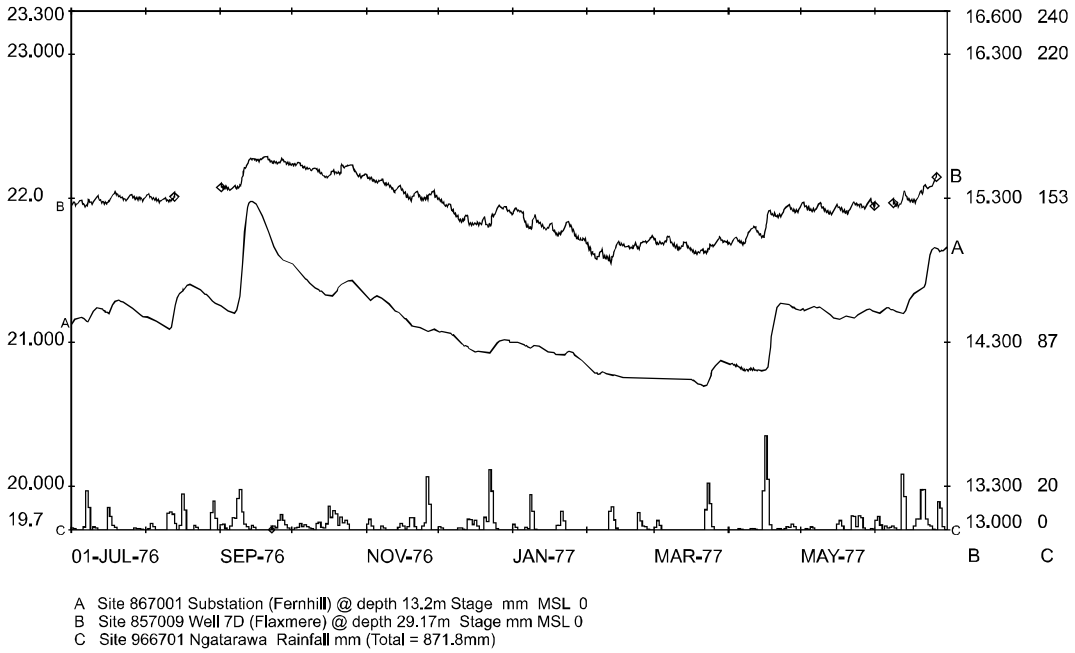


Figure 6.15: Comparison of spring discharges during high water level period (22 September 1976).

Spring flows vary considerably throughout the year. This is demonstrated by the seasonal fluctuations in the flow of the spring-fed rivers, streams, creeks and drains. The limited amount of concurrent gauging undertaken on the Plains is tabulated (Table 6.9). Figures 6.15 and 6.16 are multiplots of groundwater level, and rainfall. They cover the time period when spring flows were high (22 September 1976 - Fig. 6.15) and low (17 January 1991 - Fig. 6.16). On 22 September 1976, the Ngaruroro River flow at Fernhill was approximately 60 m^3/s. Concurrent discharge measured along Karamu Stream at Floodgate was 4.5 m^3/s (Table 6.9). On 17 January 1991, the Ngaruroro River flow at Fernhill was 2.390 m^3/s and the Karamu at Floodgate discharge was 0.916 m^3/s (Table 6.9).

Based on the limited stream flow gauging data collected from January 1969 to February 1995, a typical summer surface flow pattern for the spring-fed rivers, streams, and creeks of the Heretaunga Plains was derived. This together with the recharge coming from the river seepage zones is shown in Fig. 2.31. Despite the seasonal variation in the spring-fed stream flows with variation in river stage and its complex relationship with groundwater storage and abstraction, the summer pattern of surface flows given in Fig. 2.31 provides a reasonable basis to estimate the groundwater outflow (spring flow) component for the aquifer water balance.

6.4.5.1 The Tutaekuri-Waimate Stream

The Tutaekuri-Waimate Stream derives water from both the Ngaruroro and the Tutaekuri rivers. Of particular significance is the observation that in the absence of local rain, the Tutaekuri - Waimate Stream flow increases when the Ngaruroro River rises (Grant 1974). The available information suggests that the Ngaruroro River is the main source of water to the Tutaekuri - Waimate Stream. It is estimated that about 1.2 m^3/s of the Tutaekuri - Waimate Stream flow is derived from the Ngaruroro River upstream of Fernhill (see 2.8 and Fig. 2.31). As there has not been a significant loss of surface flow measured along the Tutaekuri River downstream of Waiohiki to coast, the only contribution the Tutaekuri River makes to the Tutaekuri - Waimate Stream, is the 0.8 m^3/s (see Table 6.4) flow loss measured in the reach of the river between Puketapu and Waiohiki.

6.4.5.2 The Raupare Stream

As with the Tutaekuri - Waimate Stream, Grant (1974) identified that the Raupare Stream flow increased when a fresh occurred in the Ngaruroro River resulting in an increase in the flow of the springs which form its principal source. This suggests that most of water in the Raupare Stream is sourced from the Ngaruroro River. The Ngaruroro River recharged groundwater contributes a mean summer flow of 0.4 m^3/s to the Raupare Stream (see 2.8 and Fig. 2.31).

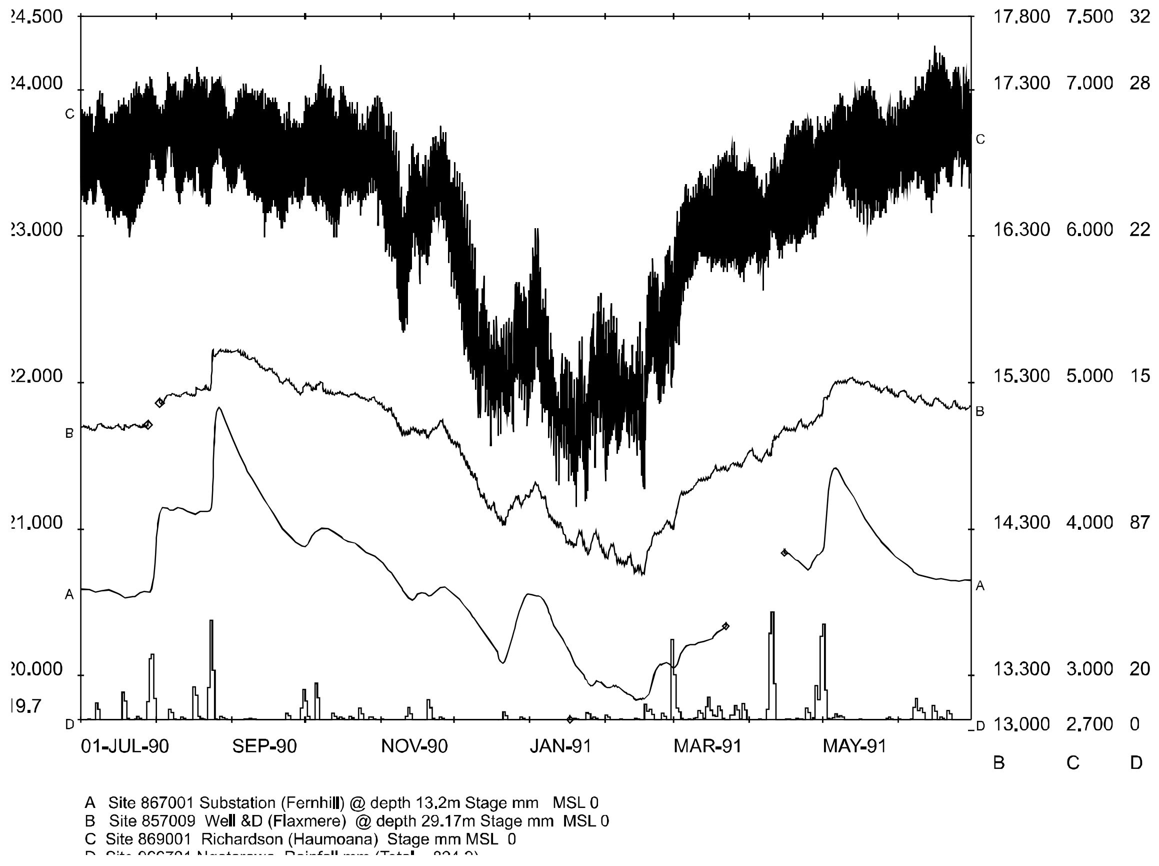


Figure 6.16: Comparison of spring discharges during low water level period (17 January 1991).

6.4.5.3 The Mangateretere Stream

The summer low flow gauging data suggests that the Mangateretere Stream discharges about 0.2 m^3/s to the Karamu Creek. The Mangateretere Stream originates from a series of spring seeps adjacent to Brookvale and Thompson roads along the Tukituki River, which would suggest that river as the primary source. However, the Mangateretere spring seepage area is perched above and hydraulically interconnected to the main aquifer system recharged by the Ngaruroro River (6.3.1.3). The possibility of upward leakage of the Ngaruroro River sourced water into the Mangateretere Stream cannot be discounted. The summer low flow Mangateretere Stream gauging of 0.2 m^3/s would occur when piezometric pressures in the main Heretaunga Plains aquifer system would be at the seasonal low and upward leakage to the overlying Tukituki River recharged gravel aquifers would be minimal. In contrast the winter high flow Mangateretere Stream gauging of up to 0.35 m^3/s on 22 September 1976 (see Table 6.9) would include groundwater derived from both the Ngaruroro River sourced Heretaunga Plains aquifers and the Tukituki River.

6.4.5.4 The Irongate Stream

Irongate Stream follows the pre-1867 course of the Ngaruroro River which extended to the south of Hastings into what is now Karamu Stream (Fig. 2.31). The summer low flow of the Irongate Stream at the intersection of Maraekakaho Road is 0.1 m^3/s. Most of this flow would be derived from springs fed from Ngaruroro River recharged groundwater.

6.4.5.5 The Karamu Stream

At its outlet to the Ngaruroro River near Floodgate the summer low flow of the Karamu Stream is 1.4 m^3/s (Fig. 2.31). The Karamu Stream near Havelock North has a summer flow of 0.4m^3/s. The inflows coming into the Karamu Creek from the tributaries between Havelock North and Floodgate are 0.32 m^3/s. This when added to the flow of the Karamu Stream at Havelock North (0.4 m^3/s), gives a flow of 0.72 m^3/s and not 1.4 m^3/s. A high proportion of the unmeasured increment of 0.68 m^3/s is probably runoff of excess irrigation water from the adjacent plains which has entered Karamu Stream downstream of Havelock North at a time of low flow and low rainfall.

6.4.5.6 Collective Spring Outflows

The seasonal variation in the surface spring flow (overflow) from summer to winter is a direct response to the changes in the volume of groundwater abstraction from the confined aquifer and to the maintenance of through flow of groundwater in the confined aquifer to the offshore springs. If abstraction constantly exceeds recharge there would be a permanent decline of groundwater levels during the summer and a downstream movement of the headwater spring locations and consequently permanent lower stream flows in the spring-fed streams and drains. This is not observed so it seems that the maintenance of groundwater flow to recharge the Heretaunga Plains confined aquifer is the preferential hydraulic flow path across the unconfined - confined aquifer boundary. In a typical summer, it is estimated that the Ngaruroro River recharge to the confined aquifer is about 1.2 m^3/s whereas the spring flow (overflow) component is about 3.8 m^3/s.

The collective outflows of springs forming the five spring sourced streams and creeks of the Heretaunga Plains are listed in Table 6.10. Total outflow from springs for the water balance is 119.8 m^3/year.

INPUT (m^3/yr x 1000000)		**OUTPUT (m^3/yr x 1000000)**	
SOURCE	**INPUT**	**SOURCE**	**INPUT**
Ngaruroro River	157.7	Public Water Supply	24.1
Tutaekuri River	25.2	Rural Domestic	2
Rainfall	5	Industries	11
		Irrigation	23.9
		Frost Protection	2
		Drainage Dewatering	3
		Total Pumped	***66.00***
		Spring Leakage	119.8
		Submarine Outflow	unknown
		Total natural	***119.8***
TOTAL	**187.9**	**TOTAL**	**185.8**

Table 6.10: Heretaunga Plains July 1994 - June 1995 groundwater balance

6.4.6 Offshore Springs

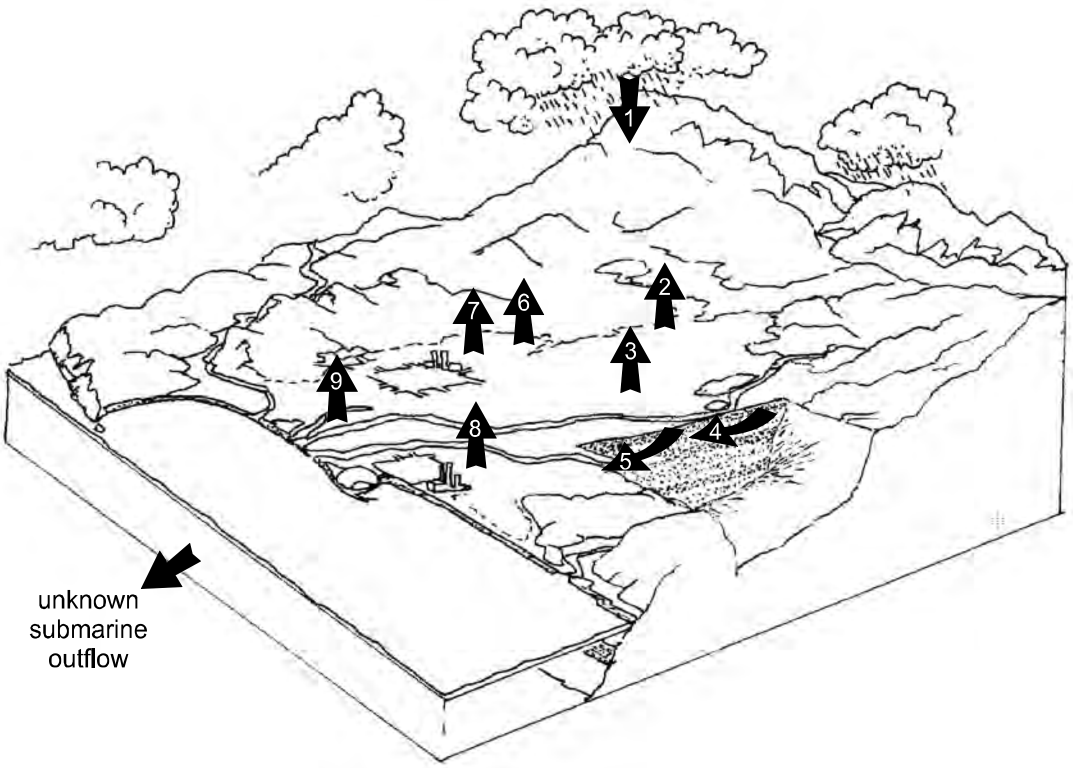
The navigation chart of the area (NZ56, Royal Navy Hydrographic Branch) shows a number of submarine freshwater springs located between 20 and 30 km east of Napier in Hawke Bay. These locations were transposed onto map MOW 19 (Grant 1974) and are indicated on Fig. 2.25. Salinity measurements undertaken by Ridgway & Stranton (May 1969) on four stations on the sea floor in the charted positions of these springs did not detect reduced salinities. The failure of searches since the discovery of the springs in 1954 to relocate them suggests that outflow may vary in response to factors such as groundwater abstraction and that the offshore springs may thus be a transient feature. Offshore spring outflow is not considered for the water balance.

Various unsubstantiated reports of other freshwater springs in Hawke Bay have been made by fisherman. Location details are vague except for reports of springs at Pania Rock which is about 4 km northeast of Napier Harbour. Pania Rock is shown on several charts including Pantin & Gibb (1968) where it is mapped (charted) as rock of unknown age. Pania Rock should not be confused with Pania Reef (Kingma 1971 - p.147) which is below low tide level at the beach immediately east of Bluff Hill.

6.5 The Groundwater Balance

Figure 6.17 graphically illustrates the Heretaunga Plains July 1994 - June 1995 groundwater balance. The aquifer inputs and outputs for this period are given in Table 6.10.

The water balance equation states that the difference between inputs and the outputs is equal to the change in storage. Although there is seasonal change in groundwater storage there is no evidence for long-term change in groundwater storage. As there is generally little or no rain during the summer period of increased groundwater use, typical summer outputs will always be greater than inputs and as a consequence summer groundwater levels will decline depending on the amount of groundwater abstracted from the confined aquifer system.



LEGEND

1. Rainfall recharge 5 Mm^3 ***2.*** Rural domestic 2 Mm^3 ***3.*** Leakages 123Mm^3 ***4.*** Ngaruroro River recharge 157Mm^3
5. Tutaekuri River recharge 25Mm^3 ***6.*** Irrigation abstraction 11Mm^3 ***7.*** Frost protection abstraction 2Mm^3 ***8.*** Industrial abstraction 11Mm^3
9. Drainage dewatering 3Mm^3

⬇ 1 Recharge (Input)

⬆ 2 Abstraction (Output)

Figure 6.17: Heretaunga Plains July 1994 - June 1995 groundwater balance *(drawing: Bruce Churchhouse, HBRC)*

Figure 6.18: Well 7D (well no. 3737), Flaxmere showing housing for a continuous water level recorder. *(photo: Lloyd Homer, IGNS CN 34 51)*

CHAPTER 7

GROUNDWATER AND ISOTOPE CHEMISTRY

Neale Hudson

7.1 INTRODUCTION

The chemical quality of groundwater determines its suitability for industrial, irrigation and domestic water supply purposes. During the past twenty years groundwater quality considerations have also influenced local and regional development. A review of investigations into groundwater quality on the Heretaunga Plains shows how various issues emerged and how they were dealt with. Consideration of historical issues and responses also provides guidance as to how the currently emerging issues might be addressed in the future.

The chemical quality of groundwater is determined by the presence of a large number of variables including dissolved chemical constituents with particular reference to toxic substances, and physical characteristics such as temperature, turbidity, colour, taste, odour and total salinity. The chemical and isotope content of groundwater is the result of all processes and reactions that have occurred since water vapour condensed in the atmosphere and fell on the land as rain, snow and dew, infiltrated through the soil and subsurface deposits to the aquifer, and finally emerged as groundwater in springs and water wells penetrating aquifers. Chemical and isotopic constituents of groundwater can often be used to determine the recharge source of a particular groundwater, the flow path through the strata, the rate of groundwater flow, the age of the groundwater and the interaction of groundwaters derived from different sources and affected by different processes (e.g. connate groundwater and geothermal water).

Besides hydrological and hydrogeological processes, groundwater quality is also influenced by human activities such as intensive horticulture, agriculture, industrial and urban developments and flood control. The Heretaunga Plains are typical of a New Zealand region where water has always been readily available since settlement 120 years ago. Only in the last twenty years have groundwater quality considerations become important. The tempo of development and changes of landuse activities and crop production on the Heretaunga Plains is now increasing in response to changing overseas market requirements. As development continues and new crops are grown groundwater quality considerations will become more important and new issues will continue to emerge.

This Chapter is divided in three parts: the first part reviews groundwater quality issues and responses and summarises the results of sporadic and site specific groundwater quality investigations undertaken by the MOW, HBCB and HBRC until 1993. The second part assesses and interprets recent comprehensive groundwater and isotope quality data collected since 1993 and discusses groundwater quality for distinct aquifer areas. The third part relates groundwater and isotope quality to lithology, hydrogeology of aquifers and provides recommendations for future monitoring in the context of emerging groundwater quality issues.

7.2 WATER QUALITY INITIATIVES, ISSUES AND RESPONSES

7.2.1 Pre-1974 Water Quality Investigations

The pre-1974 groundwater investigations undertaken by the HBCB and MOW reflected the growing awareness of the relationship between landuse and groundwater quality. The principal objectives of the investigations were to determine the boundaries of the unconfined aquifer, to evaluate susceptibility to contamination and advise on landuse in the area of the unconfined aquifer. About 67 wells were drilled and logged in the unconfined aquifer area. Groundwater samples were collected at monthly intervals for chemical analysis from these wells in the unconfined aquifer area together with additional wells in the confined aquifer area. Surface water quality sampling was also undertaken on the Ngaruroro River at the Fernhill Bridge during 1973 to establish the quality of the recharge water. The analyses programme confirmed that the river and groundwater were of high quality with almost no seasonal variation in seasonal composition.

The effect of various landuses on groundwater quality was investigated by site-specific monitoring and analysis. These included assessments of the impact of:

- leachate from silage pits;
- leachate from the Roys Hill landfill site;
- septic tank effluent from residential properties;
- piggery operations.

The report discovered a number of fundamental conceptual problems, relating to such things as the definition of terms such as pollution, unconfined aquifer and safe landuse. The discussion also indicated the need for further investigation because of lack of knowledge about the extent and zone of groundwater mixing and the possible presence of preferential flow paths. The potential for contamination of groundwater through landuse was acknowledged, although the impact was considered to be limited on the Heretaunga Plains. Despite the absence of evidence for more than localised impact of landuse on water quality in the Heretaunga Plains aquifer, the report recommended that a primarily precautionary approach be followed with respect to future development.

It was further recommended that:

- The rural landuses should be restricted to those uses which are related to the capability of the existing soil mantle to support agricultural or free-range pastoral farming.
- The urban uses should be limited to the confined aquifer area.
- Any expansion of urban uses should be fully reticulated with sewage, stormwater disposal and water supply systems.
- The storage of selected products (e.g. agrichemicals, petroleum products) which pose a high degree of hazard to the quality of the groundwater should be prohibited from the unconfined aquifer area.

Other specific problems identified included the requirement that expansion of Hastings City to the west be preceded by a plan, with specific consideration for the provision of services. Subdivision of land in the unconfined area of the Plains was recommended as being restricted to self-supporting units based on the capability of the soils. The increased use of septic tanks that would result from this subdivision was proposed as being a subject for specific approval by the HBRWB.

There were a number of problems associated with reviewing the pre-1974 water quality investigations:

- The precise location of sampling sites was not easy to verify.
- The raw data derived from the analyses could not be found.
- The reports themselves were incomplete, without maps and appendices.
- Interim reports or partially completed reports were not dated or given version numbers, making identification of the timing and sequence of completion of the reports difficult to ascertain.

7.2.2 1974 to 1978 Water Quality Investigations

After the release of a report by the MOW in 1974, the Hastings City Council advised an intention to extend the western boundary of the city over the unconfined aquifer. To assist the formulation of guidelines and investigations a Heretaunga Plains Groundwater Contamination Technical Committee was established. The terms of reference included:

- Quantifying processes governing the movement of potential contaminants into and through the Heretaunga Plains groundwater system.
- Assessing the impact on groundwater quality of two major proposed landuse changes -urban expansion of Hastings City over the unconfined aquifer and border-dyke irrigation of pasture land in the Ngatarawa Valley.

The investigation was designed with three broad tasks:

- Geological, hydrogeological and water quality information were collated, and the pattern of landuse were examined in terms of impact on groundwater quality and future threats.
- Processes governing the movement of potential contaminants into and through the unconfined aquifer were examined and the data collected used to provide input to a groundwater flow simulation model.
- Processes controlling the leaching of nitrate from grazed pasture in the Ngatarawa Valley were studied.

The results were directed to the three areas of the Heretaunga Plains where the findings and their application were considered significant for planning to maintain the high quality of surface water and groundwater.

7.2.2.1 Flaxmere Unconfined Aquifer Area

Groundwater in the unconfined aquifer area was oxygenated and characterised by low concentrations of total dissolved salts (TDS) (90 - 115 mg/l), low hardness (50 - 80 mg/l) and low nitrate concentrations. Groundwater of this quality was regarded as reflecting that of the Ngaruroro River itself.

The major conclusions reached that were pertinent to this area were -

- Groundwater quality was good with only minor contamination associated with the Roys Hill landfill and septic tanks.
- Groundwater quality could not be protected from transport of contaminants from the soil surface, while the contaminant could be rapidly transported once it entered the groundwater.
- Possible adverse effects on the deeper confined groundwater through diffuse pollution from the unconfined region was deemed unlikely. Release of concentrated contaminants was however regarded as a potential threat to the confined aquifer.

7.2.2.2 Ngatarawa - Bridge Pa Semiconfined Aquifer Area

In this area pertinent conclusions were -

- High groundwater nitrate levels occur from landuse practice, and seepage of groundwater from the peripheral limestone hills results in high levels of hardness in groundwater.
- Future water quality was predicted to deteriorate further due to the increase in border-dyke irrigation practice, and it was recommended that alternate domestic water supply schemes to the area be considered.
- The predicted deterioration in water quality was not considered to pose a threat to the Hastings City water supply.

7.2.2.3 Confined Aquifer Area

Groundwater quality issues in the confined aquifer area were:

- Groundwater quality in the confined aquifer was similar to that of the unconfined aquifer and adequately protected from direct contamination from the land surface.
- Changes in groundwater quality with distance from the recharge area were related to an increasingly reducing environment, with conversion of nitrate to ammonia and sulphate to hydrogen sulphide.
- Future reduction in groundwater level through increased abstraction was viewed as a potential threat to groundwater quality as a result of increased concentration of dissolved chemical constituents in groundwater due to seasonal reduction in groundwater storage.
- The most likely immediate threat to confined aquifer water quality was the entry of contaminated water from the unconfined aquifer area.

A number of other factors pertinent to groundwater investigations and the relevance of developing a predictive flow model of the Heretaunga Plains aquifer system can also be attributed to these reports. Difficulties were experienced with determining groundwater flow velocities and with model development due to the heterogeneous nature of the aquifer materials. Deviation of measured flow directions from those predicted were also attributed to heterogeneous aquifer materials, specifically those occurring in buried river channels. As a result the task of developing a groundwater flow simulation model was abandoned.

7.2.3 1979 - 1991 Water Quality Investigations

Groundwater quality investigations by the HBCB focused mainly on those issues which had led to the investigations by the MOW. A major survey of industrial and landuse development that had occurred on the unconfined aquifer area was undertaken during 1979. The survey included an aerial survey, and documented both the specific nature of the developments and the pollution potential that each development posed to groundwater environment. In particular the nature and volumes of chemicals used for agriculture and industrial operations as well as means of storage were documented for the unconfined aquifer area.

Among the problems identified were those associated with:

- Storage and handling of hazardous and toxic chemicals.
- The dumping and stockpiling of sawdust and faecally contaminated topsoil.
- Discharges from septic tanks.
- Leaching of pesticide and fertiliser residues.
- Leakage of potentially contaminated storm water into the groundwater.

In order to protect the quality of groundwater in the Heretaunga Plains aquifer system, the report made specific recommendations to the local authorities concerned. Among the recommendations made to Hastings City Council were:

- Restrictions on the quantity of nitrogen that should be allowed for disposal to land.

- Prevention of storm water discharges to groundwater.
- Closure of the Roys Hill landfill.
- The establishment of a well network and the undertaking of a monitoring programme up and down gradient of the Roys Hill landfill site by HBCB.

It was recommended that the Hawke's Bay County Council:

- Identify the unconfined aquifer area as an area for water quality control.
- Carefully consider all applications for septic tanks under the 1967 Water and Soil Conservation Act.
- Require that all dangerous goods be stored in an approved fashion, including a requirement for reinforced concrete bunding for both above and below ground storage facilities.
- Restrict future industrial expansion to "inert, non-polluting industries".
- Implement a stock density policy to limit the discharge of nitrogenous material to the surface of the unconfined aquifer.

Specific investigations including sampling and analyses were also undertaken to assess the status of nitrate contamination of domestic wells in the Ngatarawa Valley. This work followed on from that of the MOW and aimed at more accurately assessing the exposure of consumers to elevated nitrate concentrations. The results confirmed that nitrate concentrations in 50% of wells sampled were in excess of the World Health Organisation standard of 10 mg/l. It was proposed by the HBCB that groundwater containing up to 23 mg/l be acceptable for consumption providing that specific precautions were followed. Recommendations were also made that collaborative monitoring of water supply wells in the Ngatarawa Valley be undertaken by the HBCB and Health Department.

A network of wells for groundwater quality sampling was established for the Heretaunga Plains and monitoring was carried out for the period 1974 - 1993. Some of this monitoring was focused on specific point sources of pollution (or potential sources of pollution), such as the Roys Hill landfill or timber treatment operations. Other monitoring was undertaken to discern the quality of groundwater across the Heretaunga Plains and included the "flow-line" wells, and a transect of coastal wells between Napier and the Tutaekuri River mouth. The "flow-line" wells were a set of 4 groups of wells located along flow lines at 90^0 to the piezometric contours. It was intended to follow the probable direction of groundwater movement to determine changes in groundwater quality as water flowed from the Ngaruroro River recharge to the coast. Changes such as reduction in sulphate concentration and increases in sulphide concentration were observed. A similar trend was noted for nitrate and ammonia respectively. Specific surveys were also undertaken in localised areas of the main aquifer system, such as around Pakipaki, in the coastal area around Bay View and Whirinaki and in the Moteo Valley to monitor nitrate levels in groundwater.

7.2.4 Limitations of Water Quality Data

A summary of this historical water quality data and the interpretation of the results is limited by the uncertainties of the data quality, completeness and site locations. This can not be correlated without a comprehensive review of original data records that is beyond the scope and resources of this study. This review has been included as part of the current groundwater quality investigations (7.3.2).

Despite the limitations, the data and information have been used to highlight existing and potential problems. Issues were identified and solutions proposed. Unfortunately, not all of the recommendations made by the investigating and regulatory authorities of the time were always followed through. As a result, many of the issues remain unresolved. The historical data has also been used in a limited fashion to assess trends in groundwater quality and draw attention to policy and planning requirements.

7.3 RECENT WATER QUALITY INVESTIGATIONS

7.3.1 HBRC 1991 to 1994 Water Quality Investigations

Groundwater quality investigations initiated in the early days of the HBRC were undertaken as a series of short projects. Reports were produced for the closed Roys Hill landfill site (Dravid 1991a) (V21/319715) and the Omaranui landfill site (Dravid 1991b) (V21/365795). The report on groundwater quality in the vicinity of the Roys Hill site drew attention to the impact of leachate from the landfill on groundwater quality. This impact was typified by elevated concentrations of conservative variables such as chloride and sodium and concentrations of ammonia observed down gradient of the site. The report concluded with the following

recommendations:
- That monitoring continue for a number of years to assess seasonal variation.
- A monthly sampling regime be followed.
- An adequate number of variables be used to assess groundwater quality.
- Additional bores at greater distance down gradient from the landfill be monitored to assess the spatial extent of impact.
- Samples be analysed to determine the presence of toxic substances which could be present at low concentration.

Following the breach of the impermeable blanket underlying the Omaranui landfill site, three additional monitoring bores were installed and water quality samples analysed (Dravid 1991b). The results of these samples formed the basis for establishing background groundwater quality in the vicinity of the site. Proposals were also made regarding ongoing monitoring requirements.

These recommendations were adopted and have been integrated into the HBRC current groundwater quality investigations.

7.3.2 Current (June 1994 to present) Groundwater Quality Investigations

In June 1994 the HBRC began monitoring programmes based on a systematic, structured plan, with specific goals and objectives to obtain baseline information on the quality of surface and groundwater resources of the Heretaunga Plains. Wells were selected for monitoring only if the well depth was known and a well log was available. The programme was expanded in 1995 to provide information appropriate to groundwater quality issues on the southern fringes of the Heretaunga Plains.

It was recognised that many of the groundwater quality issues that were perceived at the time of establishing the regional monitoring network had in fact existed for decades. Much attention had been given to these issues in the past. It was considered necessary to review this historical data, which would provide an historical framework within which the current and future data would be examined and interpreted.

The following process for dealing with both historical and current data evolved over the period January - September 1995:
- situation analysis;
- database development;
- data capture;
- interpretation.

7.3.3 Other Groundwater Quality Investigations

Other issues with potential to impact on Heretaunga Plains groundwater quality have been investigated. These have included landuse activities outside of the Heretaunga Plains area. One of these was a test drilling and groundwater quality sampling programme to monitor the effect of a sheep feedlot at Maraekakaho adjacent to the Ngaruroro River inland from the Heretaunga Plains. The feedlot holds up to 80 000 sheep at a time for about a ten day period before shipping them live to overseas markets. The concentration of a large number of sheep in a small area (approximately 1km^2) has the potential for elevating the concentration of nutrients (specifically nitrate and ammonia) in the groundwater in the feedlot area. In 1993, a collaborative research programme by IGNS and HBRC began to determine the processes related to nitrate migration and groundwater flow directions in the aquifer beneath the feedlot. The results show a pattern of elevated nitrate - nitrogen concentrations at the feedlot. Groundwater flow and nitrate plume directions are towards the Ngaruroro River northwest of the town of Maraekakaho. This may increase the nitrogen load to the river by an unknown amount (Rosen and McNeill 1996). The feedlot while producing high localised nitrate levels in groundwater which exceed the maximum acceptable by the Drinking Water Standards of New Zealand (1995) is not likely to have any impact on groundwater quality of the Heretaunga Plains as no direct flow paths to strata or aquifers could be identified. Dilution and dispersion in the Ngaruroro River even at low flows would preclude elevated nitrate river water recharging the aquifer system.

7.4 ASSESSMENT OF SURFACE WATER AND GROUNDWATER QUALITY

As the Ngaruroro River is the primary source of groundwater recharge to the main aquifer system underlying most of the Heretaunga Plains and the Tukituki River recharges a relatively shallow and localised, interbedded aquifer system in the eastern parts of the Plains, the surface water quality of these two rivers has been analysed to establish base water quality control parameters.

7.4.1 Assessment of Ngaruroro and Tukituki river water quality

Water quality monitoring of the Ngaruroro River has been undertaken by the MOW, HBCB and since 1990, the HBRC, and a variety of regulatory and governmental agencies over the last 25 - 30 years. Historically the sampling and analysis of samples from rivers has been subject to the same constraints as that of groundwater - a lack of a comprehensive strategy with clearly defined objectives and changes in the sampling sites, frequencies and variables of concern. Despite these problems, a water quality record is available for all rivers for the period 1978 to present. There is a gap in data for the period March 1982 - February 1984. For certain variables, this gap is more extensive, covering almost five years. Since July 1994, sites in the vicinity of the recharge zones have been sampled as part of a longer-term monitoring strategy, and the quality of the data record should be maintained over the next 10 years. Summary statistics for selected water quality variables are given in Table 7.1.

Specific water quality features shown by these statistics include:

- Turbidity and suspended solids concentrations are higher in the Ngaruroro River than the Tukituki River - this can be ascribed mainly to the different geology and geography of the catchments and courses.
- Higher concentrations of suspended solids in the Ngaruroro River are probably responsible for the high concentrations of total organic carbon in this river.
- The impact of the point sources of pollution and the more intensive landuse is indicated by nitrate concentrations - water in the Tukituki River is consistently enriched relative to the Ngaruroro River.
- Alkaline earth metal concentration (magnesium and calcium) are elevated in the Tukituki River relative to the Ngaruroro River, in part causing the elevated values for pH, alkalinity and conductivity - this can be related to the geological and hydrogeological differences between the catchments, as well as the

VARIABLE	SITE					
	N r r r R r C r r			T R r r		
			R			R
Turbidity (NTU)	14.42	4.00	180.00	6.15	2.00	170.00
Temperature (°C)	14.17	14.50	20.50	15.49	16.00	20.00
pH (units)	7.92	7.90	2.21	8.42	8.38	3.42
Electrical conductivity (µS/cm)	143.18	140.00	240.00	199.71	195.00	185.00
Alkalinity	52.64	49.00	123.00	70.35	70.00	92.00
Chloride	8.17	8.00	24.00	11.62	11.00	14.00
Sulphate	9.84	9.50	21.00	11.05	10.00	19.00
Magnesium	2.39	2.30	4.30	3.13	3.00	9.00
Sodium	8.94	8.00	13.20	11.78	11.00	21.50
Calcium	18.01	17.00	36.80	25.49	25.00	60.50
Potassium	1.33	1.10	6.00	1.59	1.80	2.60
Total phosphorus	0.04	0.02	0.32	0.03	0.02	0.15
Total soluble phosphorus	0.01	0.01	0.03	0.01	0.01	0.02
Soluble reactive phosphate	0.02	0.01	0.11	0.02	0.01	0.06
Nitrate	0.13	0.10	0.46	0.69	0.53	2.34
Ammonia	0.02	0.00	0.20	0.03	0.01	1.16
Suspended solids	50.43	5.50	440.70	9.05	2.00	69.50
Total organic carbon	1.37	1.10	1.60	1.00	1.00	0.20
ll al es in m l nless other ise stated						

Table 7.1: Summary statistics for Ngaruroro and Tukituki river water quality

greater number of point source pollution discharges in the Tukituki River system.

- Concentrations of sodium, potassium, chloride and sulphate are all elevated in the Tukituki River relative to the Ngaruroro River - again this can be related to the geological and hydrogeological differences between the catchments, as well as the greater number of point source pollution discharges in the Tukituki River system.

Comparison of the Ngaruroro and Tukituki rivers water quality data with data for other New Zealand rivers indicates that these river waters contain a relatively high proportion of dissolved minerals. Based on less than three year's monitoring, (Smith & Maasdam 1994) included the Ngaruroro River and Tukituki River in water quality clusters 3 and 4 respectively, indicative of the degree of mineralisation. Data from longer term monitoring indicates that these rivers do not fit into these groups very well, mainly because of the higher concentrations of chloride, sulphate, sodium and in particular, calcium. When compared with river water quality on a global scale, the quality of water in both rivers can be regarded as excellent (Smith & Maasdam 1994).

As the major source of groundwater recharge to the Heretaunga Plains main aquifer system, the Ngaruroro River water can be described as being of low electrical conductivity, with low concentrations of all ionic species. The dominant cation is calcium, with chloride and sulphate being of almost equal importance as anions.

7.4.2 Assessment of Groundwater Quality

The Heretaunga Plains groundwater quality interpretation has been limited by the restricted variables which were analysed historically. These tended to be for selected physical and inorganic variables with very limited organic micropollutants and metals. Wherever possible physical variables, i.e. electrical conductivity and pH and chemical variables, i.e. alkalinity, sodium, magnesium, potassium, calcium, iron, manganese, chloride, nitrate, sulphate and ammonia are included in the data set.

In order to perform a spatial analysis of groundwater quality, the Heretaunga Plains study area was divided into 52 grid blocks (referred to as 'map sheet'), each covering an area of 9 km^2 (Fig. 7.1).

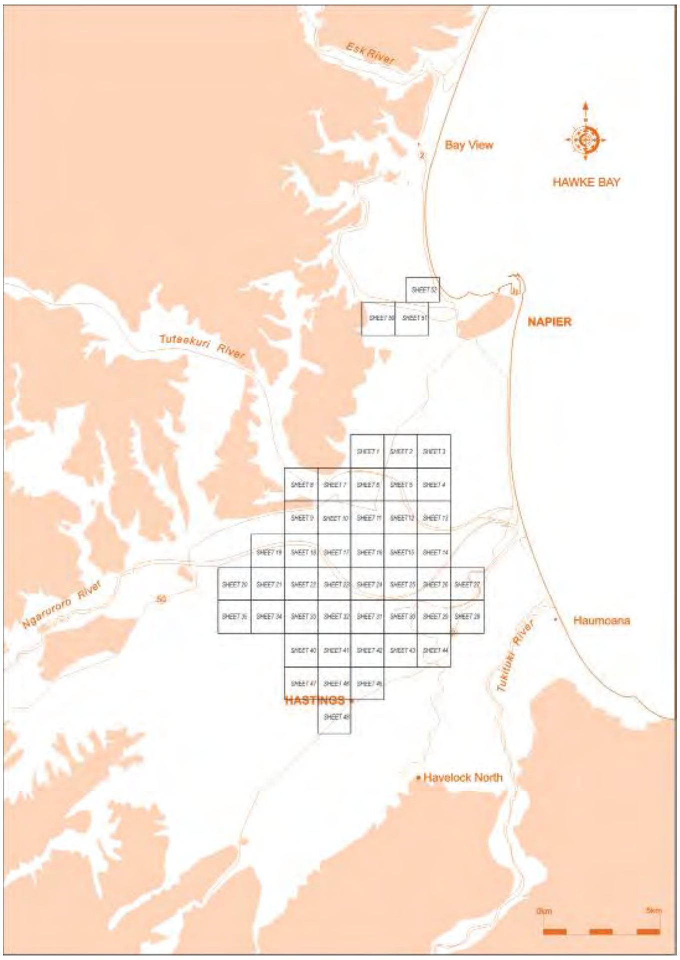


Figure 7.1: Division of the Heretaunga Plains area into 52 grid blocks.

Groundwater quality data for each variable for all wells within each grid area were condensed into a series of summary statistics. The number of wells sampled within each grid area varied as a result of the patchy manner in which historical sampling had been undertaken. Relatively few wells were found for which an adequate record could be identified. Despite this these summary statistics were considered representative of the groundwater quality in that specific area, and were used in further analysis. Direct representation of spatial water quality differences was achieved by plotting the summary statistics for each variable as a bar or column using GIS. The mean value for each variable from each grid block was used for spatial analysis. This value has been presented on a base map as a bar; the relative height of the bar is proportional to the concentration of the variable. The bar is located at the centre of each of the 9 km^2 grids. The spatial distribution of concentration of major variables is presented in a series of four maps (Figs. 7.2 to 7.5).

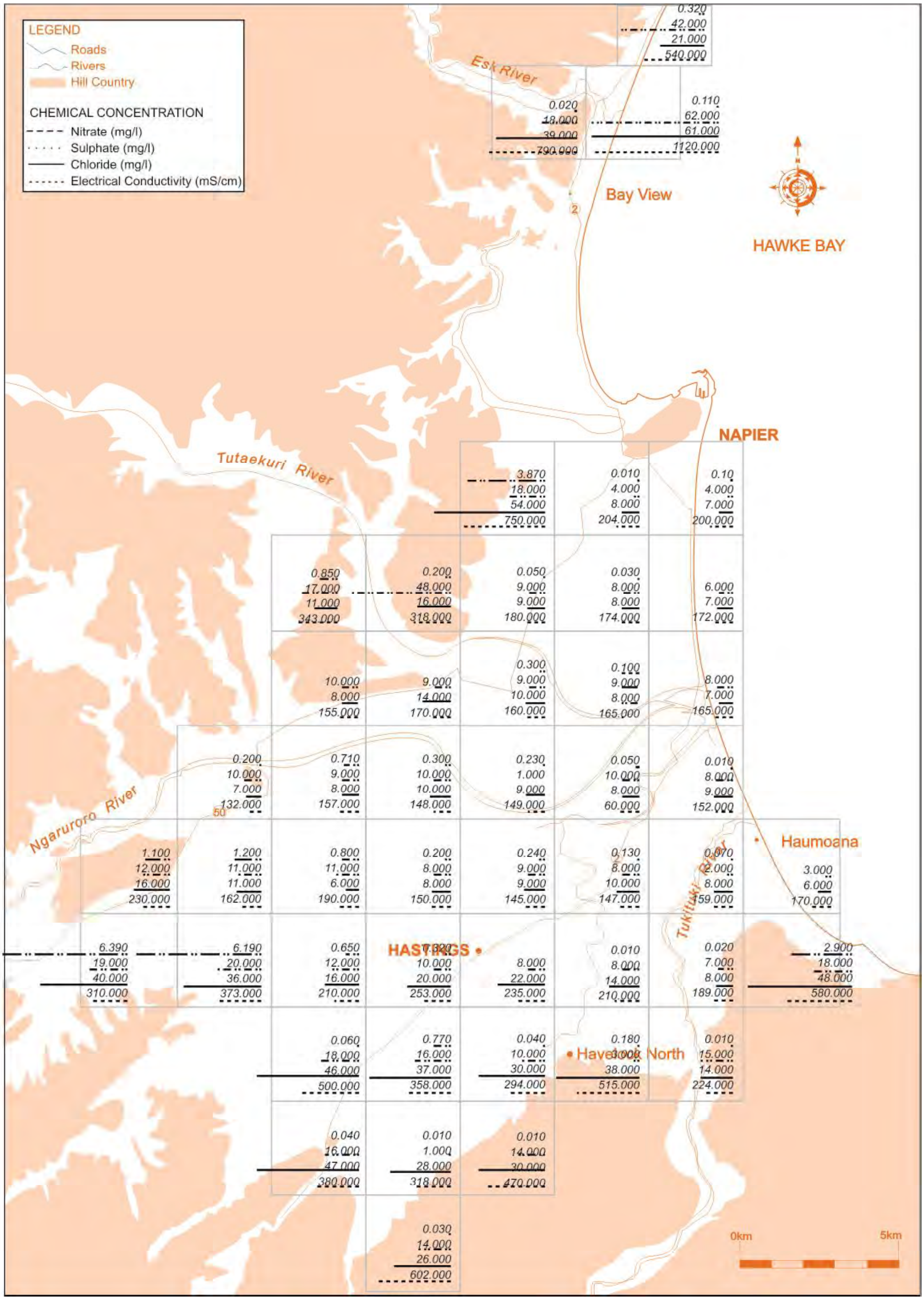


Figure 7.2: Concentration of chloride, electrical conductivity, nitrate, and sulphate in the Heretaunga Plains groundwater.

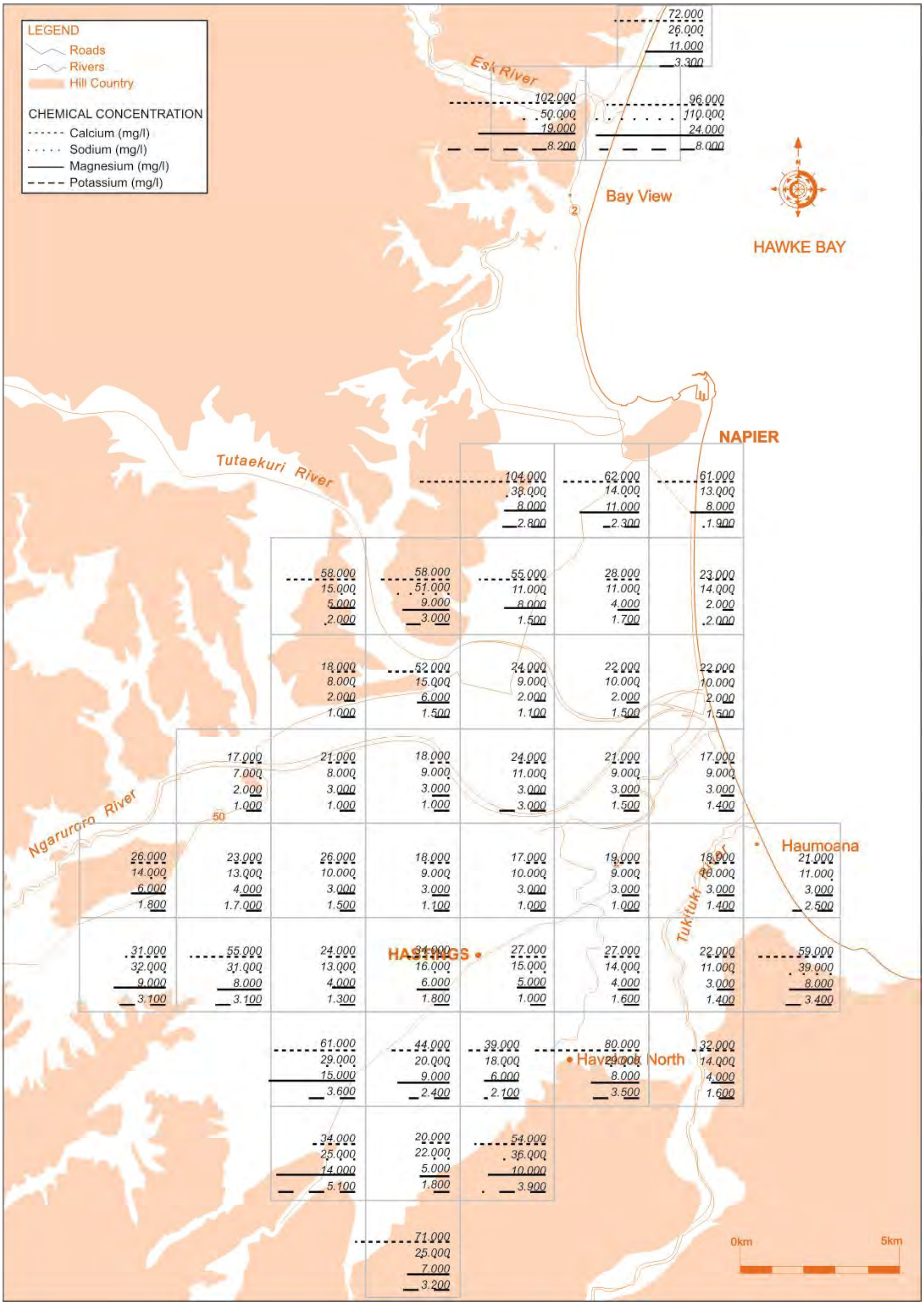


Figure 7.3: Concentration of in the calcium, magnesium, potassium and sodium in the Heretaunga Plains groundwater.

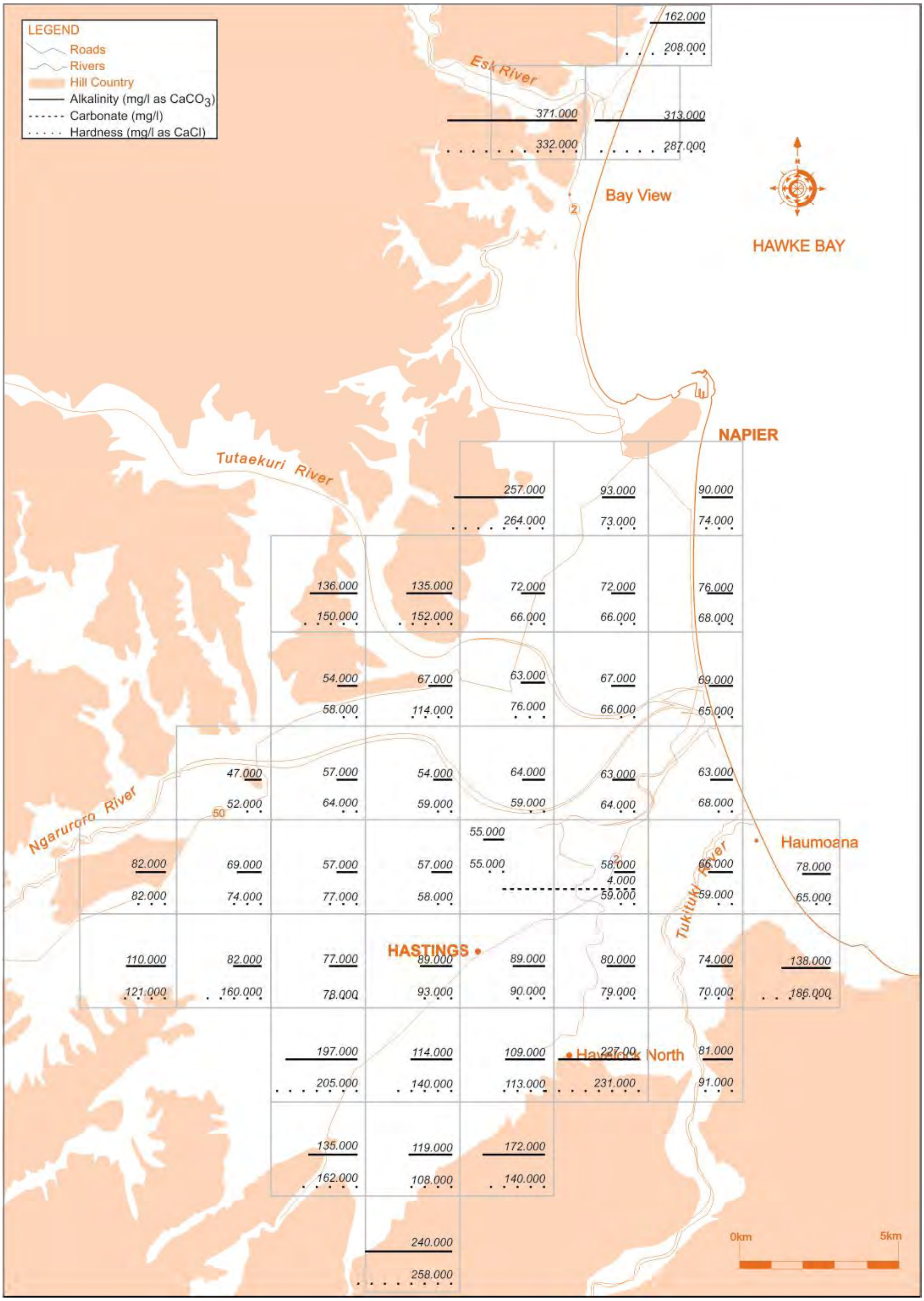


Figure 7.4: Concentration of alkalinity, carbonate and hardness in the Heretaunga Plains groundwater.

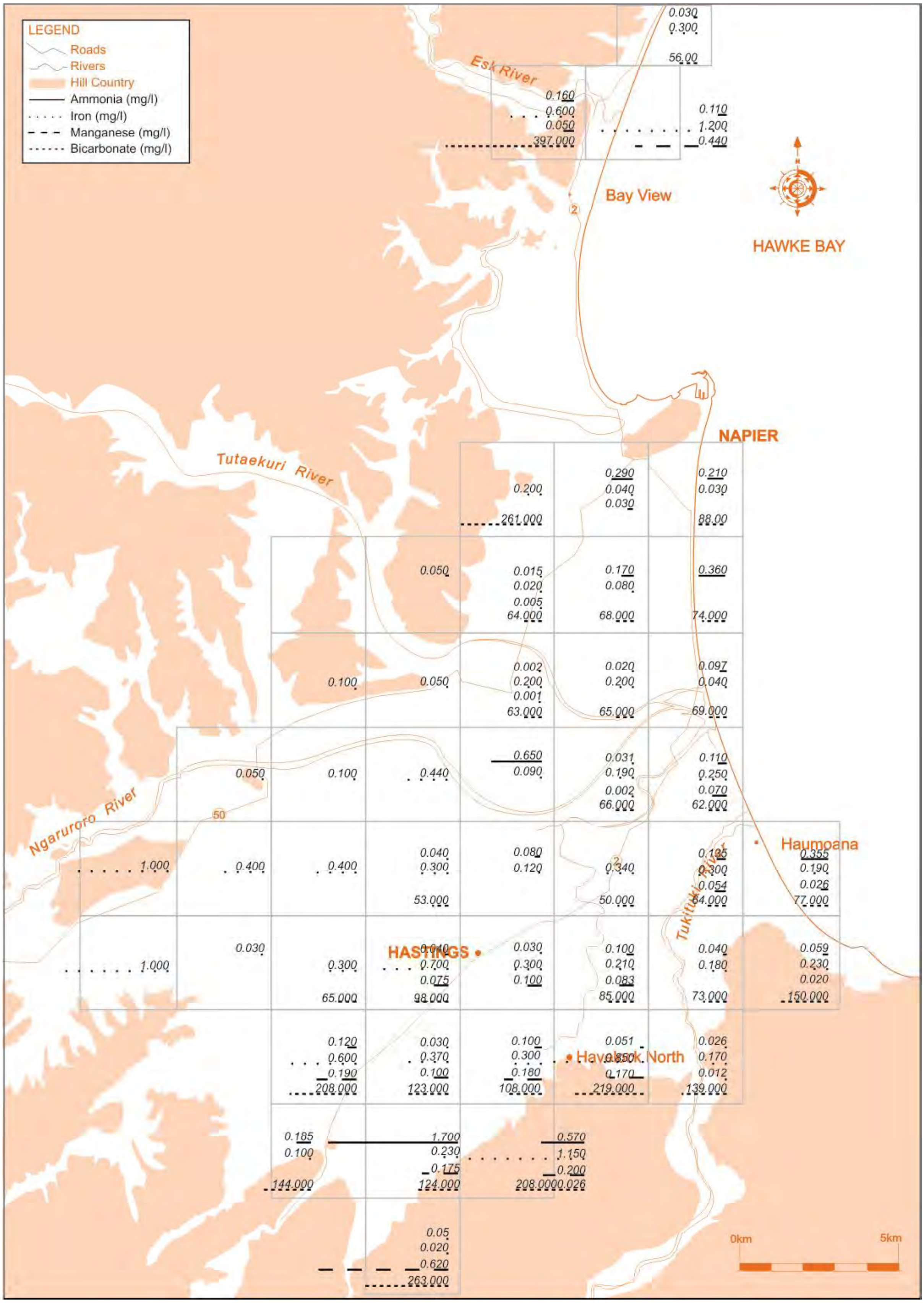


Figure 7.5: Concentration of ammonia, bicarbonate, iron and manganese in the Heretaunga Plains groundwater.

Figures 7.2 to 7.5 allow comparison of spatial differences in groundwater quality variables in terms of relative concentrations of major variables - chloride, electrical conductivity, nitrate, sulphate, (Fig. 7.2); calcium, magnesium, potassium and sodium (Fig. 7.3); alkalinity, carbonate and hardness (Fig. 7.4); iron, manganese, ammonia and bicarbonate (Fig. 7.5) in the Heretaunga Plains groundwater.

Water quality data for the period July 1994 - December 1995 were used to generate water quality contour lines for the Heretaunga Plains for specific variables (Figs. 7.6 to 7.14) - electrical conductivity (Fig. 7.6); calcium (Fig. 7.7); magnesium (Fig. 7.8); hardness (Fig. 7.9); chloride (Fig. 7.10); sodium (Fig. 7.11); sulphate (Fig. 7.12); iron (Fig. 7.13) and nitrate (Fig. 7.14). Data for individual wells were used to produce a computer generated contour map for each variable, which were subsequently smoothed for clarity and reproduction purposes.

Also attempts were made to relate water quality to the stratigraphy and location of wells (Figs. 4.15 to 4.19, Tables 7.6 to 7.8) . This was an important requirement to identify discrete areas of recharge, and establish the fate of water inflows to the aquifer systems. It was also hoped to identify aquifer areas where water from different recharge sources mixed through leakage from different aquifer units.

7.4.3 Heretaunga Plains Groundwater Quality

7.4.3.1 Electrical Conductivity

As a variable related to the physical properties of water, electrical conductivity is a useful non-specific indicator. Electrical conductivity (EC) values are related to the concentrations of dissolved salts (similar to dissolved solids) and the activity of the specific dissolved materials, and is a useful non-specific indicator of the degree of mineralisation. Differing salts also vary in their ability to conduct electrical current. Electrical conductivity values are therefore determined by both the absolute concentrations and the identity of the mixture of dissolved materials. Electrical conductivity is measured in µS/cm which is microsiemens per centimetre.

Figure 7.6 is a contour map of electrical conductivity of groundwater on the Heretaunga Plains. In the central area of the Heretaunga Plains, groundwater electrical conductivity levels range from approximately 150 to 300 µS/cm. Elevated levels occurred at the margins of the Plains adjacent to the peripheral limestone aquifer systems in Poraiti, Havelock North, Pukahu, Pakipaki and southwest of Bridge Pa. Elevated levels also occurred near the coast between Haumoana and Te Awanga, Lagoon Farm and at Whirinaki. Electrical conductivity levels were approximately 600 to 700 µS/cm adjacent to the peripheral limestone aquifers. Levels were higher at the coast, with 900 µS/cm in the Te Awanga - Haumoana area, 1600 µS/cm at Lagoon Farm and 18,000 µS/cm in groundwater sampled at Whirinaki.

Lowest values for electrical conductivity were associated with groundwater in the centre of the Plains in an area extending from the Ngaruroro River at Fernhill through the Twyford area to the Awatoto coast. This sector forms the most transmissive part of the aquifer (see Fig. 5.4), with shortest residence period of water in the groundwater system and least opportunity for mineralisation through interaction with the aquifer material.

Electrical conductivity values increase both north and south toward the margins of the Plains. This increase was due to intermixing with groundwater derived from aquifers in the limestone and mudstone of the peripheral hills. The groundwater derived from these aquifers has a high concentration of ionic material. The effect is particularly noticeable in the Pakipaki, Pukahu and Havelock North areas and along the Ngatarawa Road. In an area to the east of the Ngatarawa Valley where the electrical conductivity increased considerably, it is suggested that this is partly due to the landuse practices, with pollutants entering the groundwater from the soil surface and partly a result of low transmissivity with slower groundwater flow and pollutant dilution and dispersion.

North of the Tutaekuri River there was an increase in electrical conductivity from south to north, and from east to west. This trend coincided with the direction of groundwater flow at the northern edge of the Heretaunga Plains main aquifer system (Figs. 5.5 and 5.6). There did not appear to be much influence from the limestone Poraiti hills. Increases in conductivity appear to be more related to increased residence time of groundwater in the aquifer system and the resulting mineralisation rather than water derived from the limestone aquifers.

Further north, the groundwater quality in the Esk River valley is characterised by generally higher electrical conductivity. It is suggested that this is a result of a combination of intermixing of groundwater derived

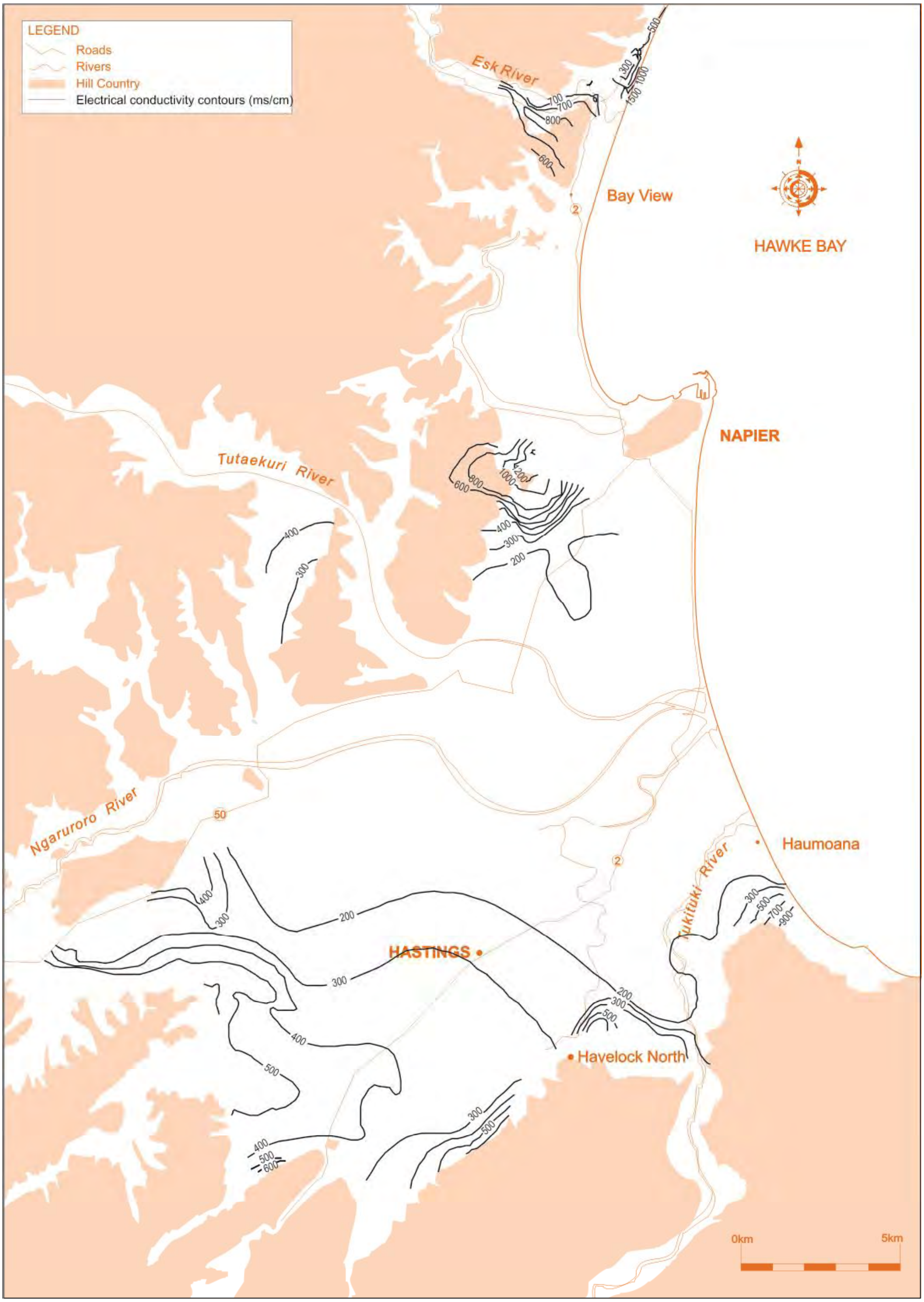


Figure 7.6: Electrical conductivity contour map of the Heretaunga Plains groundwater.

from limestone aquifers, limited recharge and longer residence time within the groundwater system. On the coastal margins of the Esk River valley, there is also the possibility that high electrical conductivity is related to sea water intrusion.

Electrical conductivity values appear elevated in the vicinity of Flaxmere. Earlier work by the MOW indicated this area to be down gradient of any leachate that might originate from the Roys Hill landfill, and from potential contamination from the industrial area along Omahu Road. Additional, specific sampling needs to be undertaken to determine the cause of this rise in measured electrical conductivity.

7.4.3.2 Calcium, Magnesium and Hardness

Figures 7.7, 7.8 and 7.9 are the contour maps of concentration of calcium, magnesium and hardness in Heretaunga Plains groundwater.

Figure 7.7: Contour map of calcium concentration in the Heretaunga Plains groundwater.
Calcium levels in the groundwater in the central area of the Heretaunga Plains range from approximately 20 mg/l to 40 mg/l. Calcium levels increase towards the margins of the Plains with 100 mg/l in the Havelock North and Poraiti areas and 60 to 80 mg/l in the Pakipaki and Bridge Pa area. High calcium levels also occur near the coast with levels of up to 400 mg/l sampled at Whirinaki.

Figure 7.8: Contour map of magnesium concentration in the Heretaunga Plains groundwater.
Magnesium levels in the central Plains groundwater are approximately 2 to 6 mg/l. Levels increase towards the southern margins of the Plains and in the Ngatarawa Valley, with a maximum of 28 mg/l occurring west of Pakipaki.

Figure 7.9: Contour map of hardness in the Heretaunga Plains groundwater.
Groundwater hardness in the central Heretaunga Plains range from approximately 60 to 100 mg/l. Hardness increases to 200 to300 mg/l towards the peripheral limestone hills south of Havelock North, Pakipaki and Bridge Pa, and west of Poraiti. In the Bay View area, hardness of 280 to 340 mg/l occurs at the base of the limestone hills, while at the coast levels as high as 3600 were recorded. At Te Awanga, hardness is approximately 80 to 100 mg/l at the base of the hills and increases to 280 mg/l towards the coast as the salinity of the groundwater rises.

A similar spatial pattern applied for all of these variables. Over most of the Heretaunga Plains area, calcium concentrations were in the range of 17 to 30 mg/l (Figs. 7.3 and 7.7). As for electrical conductivity, the area of low calcium concentrations was the area of the Heretaunga Plains where groundwater transmissivity was highest (Fig. 5.4) and approximately followed the current course of the Raupare Stream. Observed magnesium concentrations were lowest slightly north of this area, suggesting a zone of maximum transmissivity passing through Awatoto (Fig. 7.8). Hardness values also suggested a more northerly zone of maximum transmissivity (Figs. 7.4 and 7.9).

The influence of the intermixing of groundwaters at the margins of the Heretaunga Plains aquifer system was particularly noticeable for these variables, with mean calcium concentrations exceeding 50 mg/l south of Pakipaki and Pukahu, near Havelock North and at Poraiti (Figs. 7.3 and 7.7). Increases in calcium concentration in the Taradale, Onekawa and Napier areas can be ascribed to the increasing effect of the presence of a shallowing limestone aquifer which trends in a north-east direction toward Napier Hill. An increase in calcium concentrations in an easterly direction along Ngatarawa Road is also evident. This again confirms the poor transmisivity in this part of the aquifer (Fig. 5.4), as well as seepage from the peripheral limestone aquifers. The influence of this limestone basement is more evident from magnesium concentrations. The groundwater resources in the Esk River valley appear to be typically enriched with calcium and magnesium, probably related once more to groundwater derived from limestone.

7.4.3.3 Alkalinity

Alkalinity of the Heretaunga Plains groundwater has not been plotted separately as a contour map. Alkalinity provides an estimate of the capacity of a solution to neutralise acid, amd is an indication of the concentrations of a range of solute species. In most natural waters, alkalinity is a product of dissolved carbonate and bicarbonate ions. Measurement of alkalinity at a series of pH values allows concentrations of carbonate and bicarbonate to be estimated. Heretaunga Plains groundwater quality data is available for total alkalinity, which represents the sum of the carbonate and bicarbonate ions expressed as $CaCO_3$. From this data it is not possible to estimate the individual concentrations of carbonate and bicarbonate ions which are required for the dissolution processes occurring within the groundwater of the Heretaunga Plains. Future monitoring activities should provide this information which will assist in understanding localised groundwater quality issues.

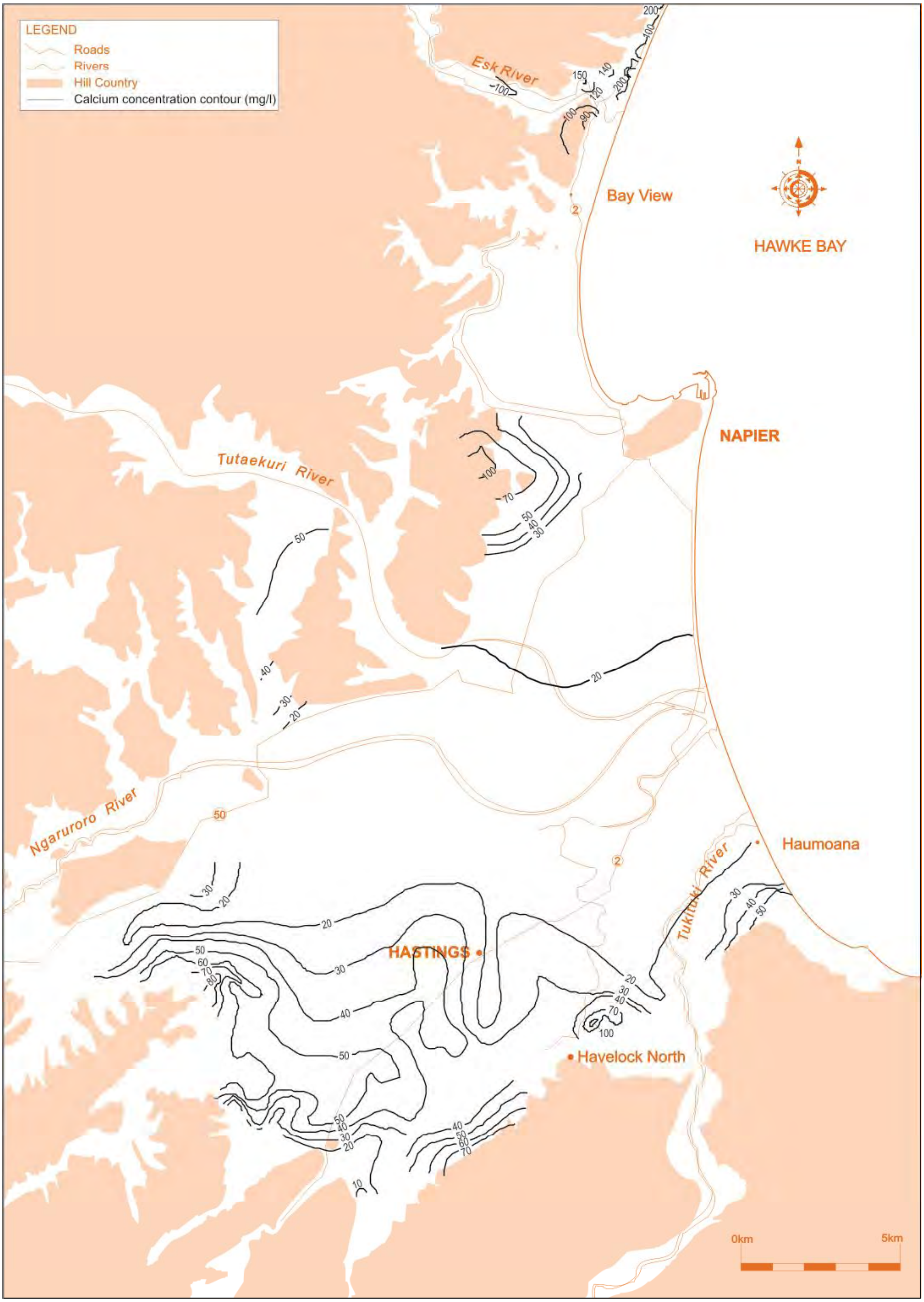


Figure 7.7: Contour map of calcium concentration in the Heretaunga Plains groundwater.

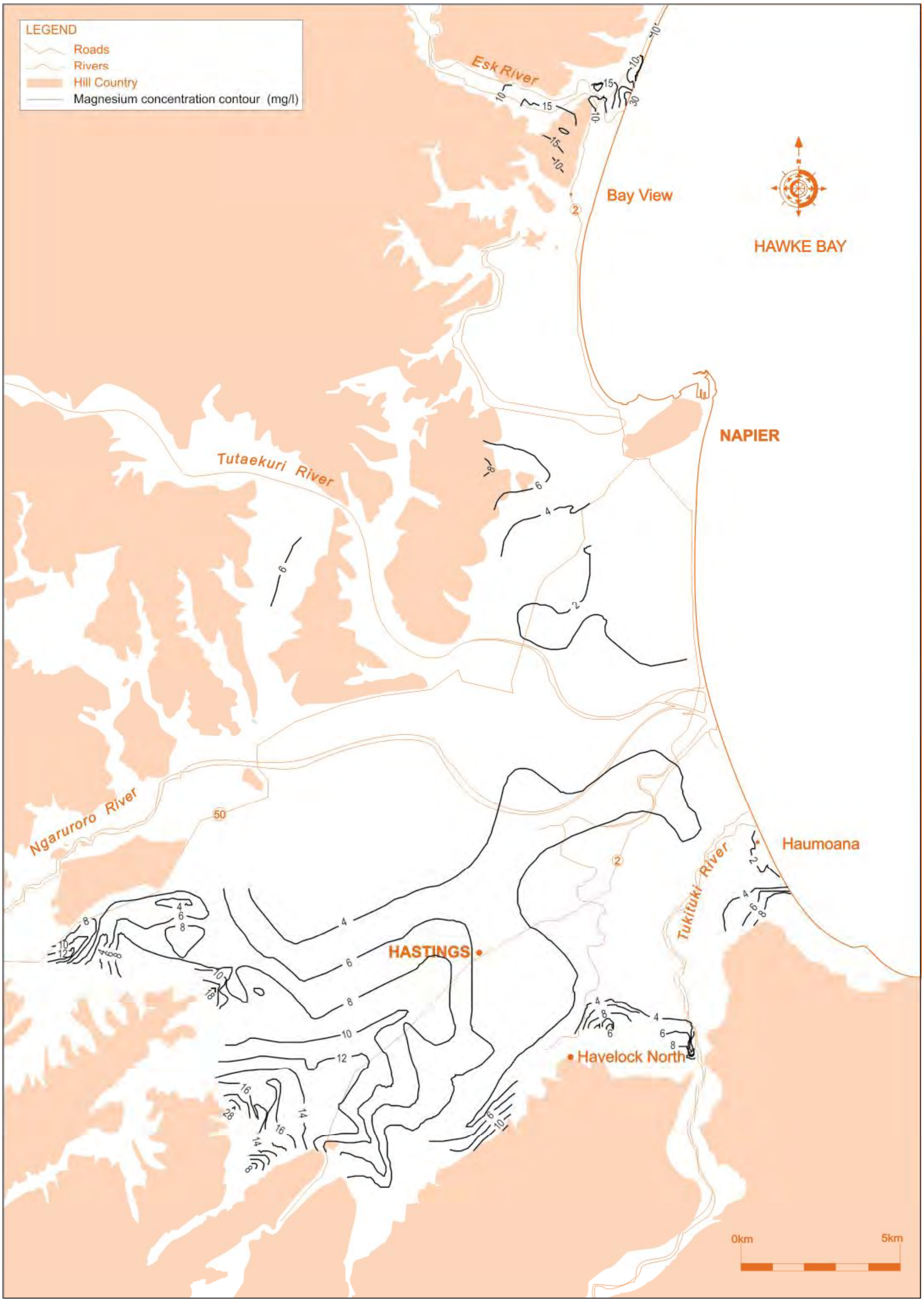


Figure 7.8: Contour map of magnesium concentration in the Heretaunga Plains groundwater.

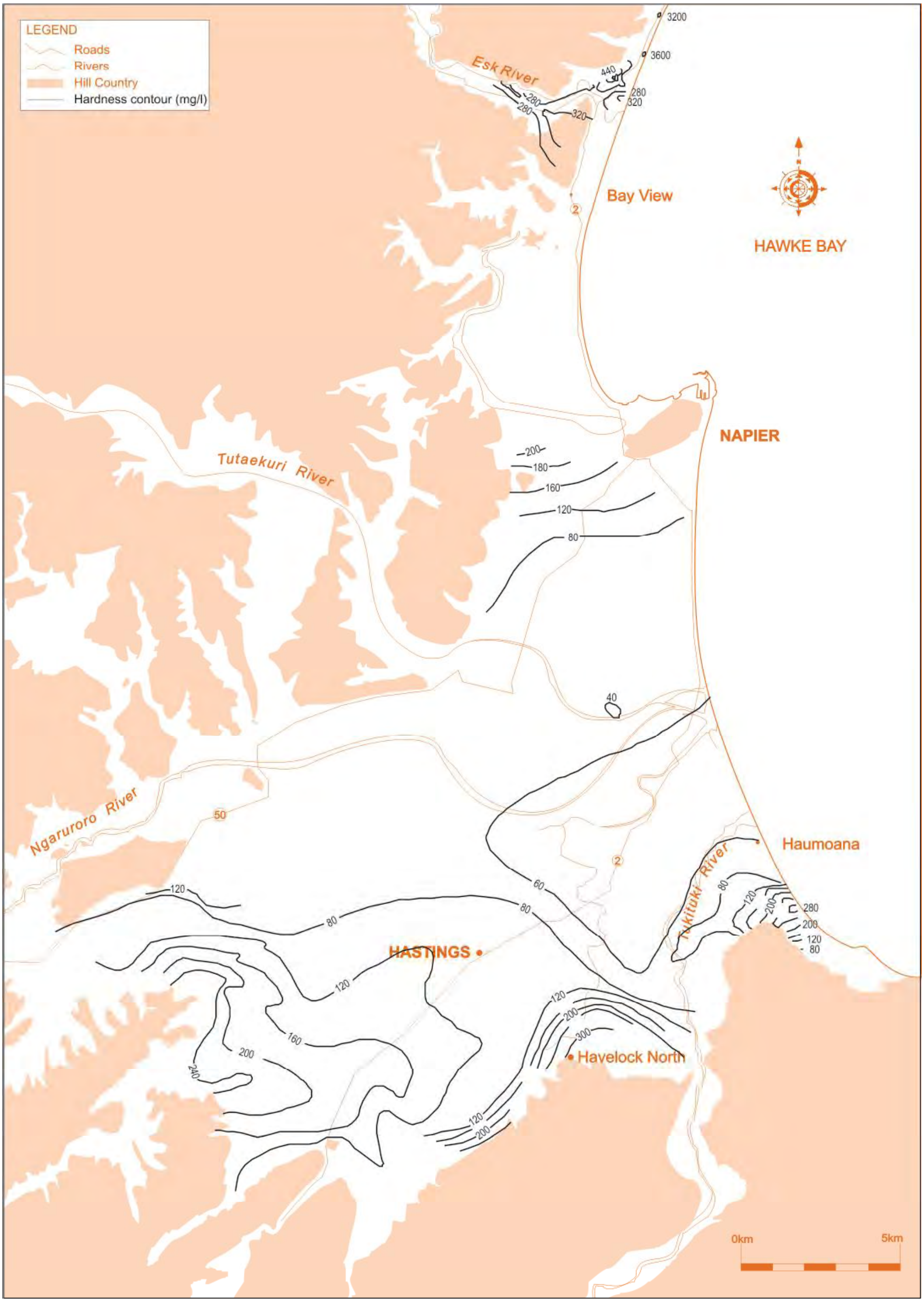


Figure 7.9: Contour map of hardness in the Heretaunga Plains groundwater.

7.4.3.4 Chloride and Sodium

Figures 7.10 and 7.11 are contour maps of concentrations of chloride and sodium in Heretaunga Plains groundwater. Chloride and sodium can generally be regarded as conservative variables; substances moving as fast as the water in a groundwater system and not subject to attenuation beyond that caused by dispersion or diffusion.

Figure 7.10: Contour map of chloride concentration in the Heretaunga Plains groundwater.

Chloride concentrations in the central Heretaunga Plains groundwater range from approximately 10 to 20 mg/l. Levels rise towards the peripheral limestone hills reaching 300 mg/l west of Pakipaki, 60 mg/l in the Havelock North area, and 40 to 50 mg/l in the Poraiti area. In Bay View levels rise to approximately 200 mg/l towards the hills and to in excess of 250 mg/l in bores sampled at the coast. Chloride levels in Te Awanga range from 20 mg/l at the base of the hills to 150 mg/l in bores located near the coast. In the Napier area, elevated levels occur at Park Island and Lagoon Farm bores.

Figure 7.11: Contour map of sodium concentration in the Heretaunga Plains groundwater.

Sodium levels in the central Heretaunga Plains range from approximately 10 to 20 mg/l. Levels increase towards the margins of the Plains adjacent to the peripheral limestone hills with up to 50 mg/l recorded in the Havelock North area, 70 mg/l southwest of Pakipaki, and 40 mg/l in the Poraiti area. Slightly saline water in the Lagoon Farm area northwest of Napier returned a sodium concentration of 250 mg/l. A slight increase in groundwater sodium concentration appears to occur in the Clive area. In the Te Awanga coastal area groundwater sodium appears to be highest inland below the coastal hills and decreasing to approximately 20 to 70 mg/l at the coast. In the Bay View - Whirinaki area, contours show a similar pattern to the chloride contour with sodium levels increasing towards the hills and the coast, with 250 mg/l recorded in bores at the base of the hills and in excess of 280 mg/l in some coastal bores.

Chloride and sodium concentrations tend to be lowest in the centre of the Plains, consistent with the area of highest transmissivity. Concentration of chloride in groundwater increase to the south in the Havelock North, Pukahu and Pakipaki area. Increases are also apparent in an easterly direction along Ngatarawa Road. Sodium concentrations are higher in the west and south of the Plains, between Pakipaki and Ngatarawa Road. High concentrations are also observed on the western side of the western hills, along the Tutaekuri River valley. These results suggest a relationship between the quality of groundwater and the geology in the fringe areas, with geology being the dominant factor.

No increase in mean chloride concentration is observed in wells north of the Tutaekuri River toward Napier, in contrast to what is observed for calcium and magnesium concentrations and electrical conductivity values. Sodium concentrations tend to increase marginally toward the north. It is proposed that slight enrichment of groundwater in the Napier area with respect to chloride and sodium, occurs as a result of the increased residence period and the sandy nature of the aquifer material.

Sodium and chloride concentrations in groundwater in the Esk River valley increase toward the west and south. The influence of a component of saline intrusion in the coastal aquifers of the Esk River valley is possible.

7.4.3.5 Sulphate

Figure 7.12 is a contour map of concentration of sulphate in Heretaunga Plains groundwater.

Groundwater sulphate concentration in the Heretaunga Plains ranges from approximately 10 to 20 mg/l. As with other variables sulphate levels increase towards the southern limestone hills reaching 60 mg/l in the Mangateretere and River roads area east of Havelock North and 30 mg/l in the Poraiti area. High concentrations are also found in bores located at the coast at Te Awanga and Whirinaki. In the coastal areas, concentrations decrease inland.

As with other variables sulphate concentrations are influenced by the geology of the sediments at the margins of the Heretaunga Plains and the transmissivity of the aquifer. Highest concentrations appear to be associated with the hills fringing the main Heretaunga Plains system, particularly in the west and south. This again indicates a localised influence of minor sources of recharge on the Plains groundwater. Adjacent to the coast elevated sulphate levels may indicate a mixing with saline water.

Concentrations within the main Plains aquifer system however tend to decrease north and south of the zone of maximum transmissivity. The concentrations observed are consistent with increasingly reducing conditions within the Heretaunga Plains groundwater system from west to east. Under these conditions, sulphate (in the presence of a suitable food or energy supply)

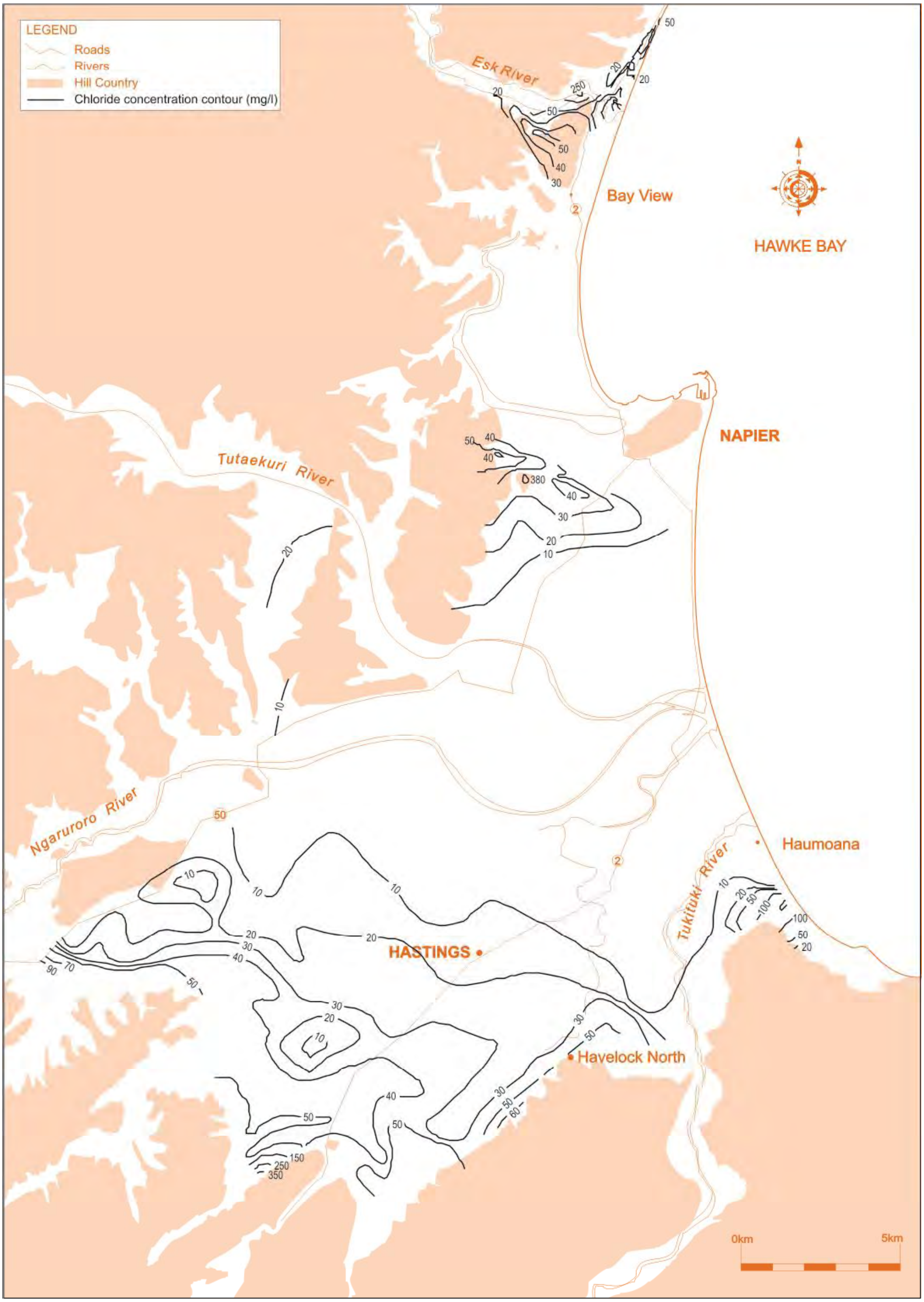


Figure 7.10: Contour map of chloride concentration in the Heretaunga Plains groundwater.

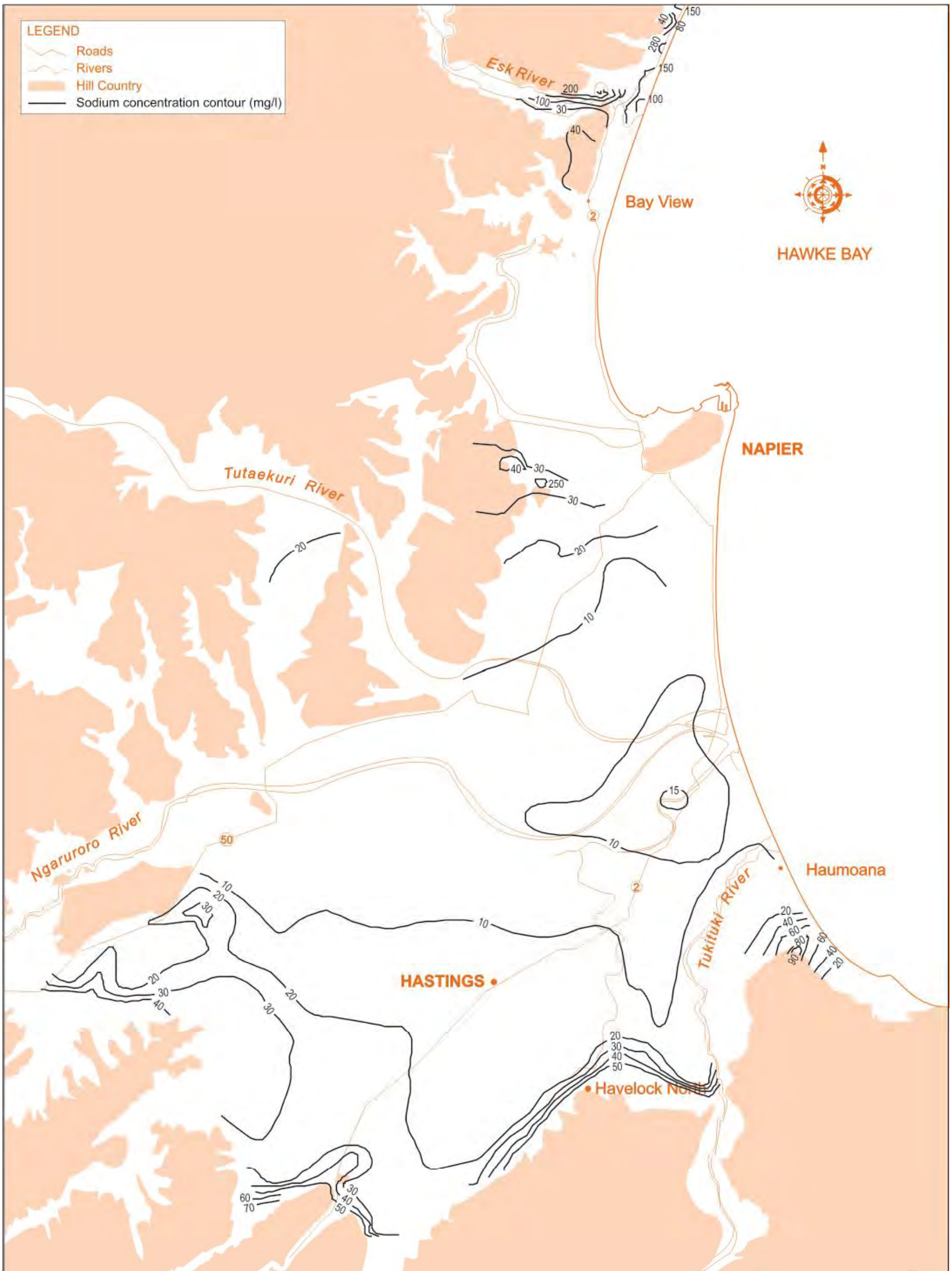


Figure 7.11: Contour map of sodium concentration in the Heretaunga Plains groundwater.

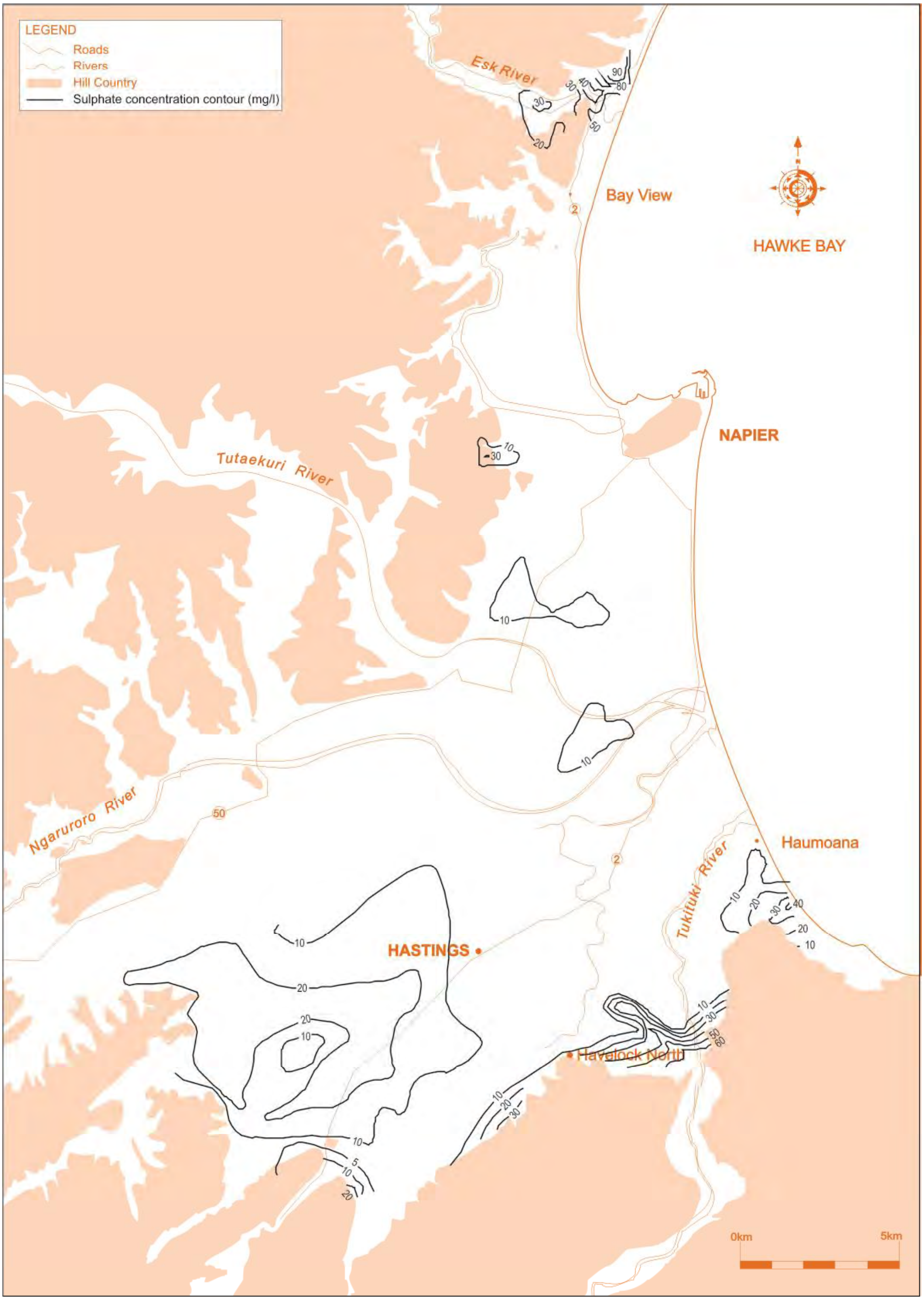


Figure 7.12: Contour map of sulphate concentration in the Heretaunga Plains groundwater.

can be utilised by anaerobic bacteria as an oxygen supply. The widespread occurrence of methane (see Tollemache Orchard and Awatoto exploratory well reports in Volume 2 of this report) in deeper wells across the entire Plains system indicates that such an energy source does exist. Decreases in sulphate concentration from the main Ngaruroro River recharge zone (mean sulphate concentration in the Ngaruroro River is about 10 mg/l) are observed in a northeast and southwest direction (Figs. 7.2 and 7.12). Sulphate concentrations in groundwater in the Napier area are about 4 mg/l, while those in the Lawn Road / Haumoana area on the southeastern fringes of the Plains are less than 3 mg/l. The elevated sulphate concentration observed in the Puketapu / Springfield Road area appears to be well correlated with sodium concentrations and could be related to the local geology.

In the Esk River valley, sulphate concentrations are elevated and appear to increase toward the coast. The elevated concentrations along the coast could again be associated with saline intrusion.

7.4.3.6 Iron and Manganese

Limited data are available for both these variables, particularly manganese probably because of prolonged residence time of groundwater in the aquifer. Figure 7.13 is a contour map of concentrations of iron in Heretaunga Plains groundwater.

From the central Plains area, iron concentration increases towards the peripheral limestone hills with concentrations of between 5 and 7 mg/l occurring in the Havelock North area and up to 6 mg/l at Poraiti. In the Haumoana - Te Awanga area, several bores located on the coast had iron concentrations of between 6 to 10 mg/l, but away from the coast concentrations decrease to less than 1 mg/l. At Whirinaki - Bay View iron concentration increases away from the hills and is typically 1 mg/l to 3 mg/l at the coast.

Data for iron suggest that high concentrations are associated with the western and southern fringes of the main Heretaunga Plains system. High concentrations are also observed in groundwater in the Esk River valley (Figs. 7.5 and 7.13). The data tends to confirm anecdotal evidence from well drillers regarding iron concentrations. High concentrations of iron have been reported from wells in the Ngatarawa and Maraekakaho road areas. The iron appears to be in a soluble reduced state (ferrous form), oxidising rapidly to produce considerable quantities of iron in the insoluble ferric state. In groundwater systems, iron solubility tends to be a function of pH and dissolved bicarbonate and an investigation of iron species within Heretaunga Plains groundwater requires accurate data.

Manganese data are restricted mainly to the southern area of the Heretaunga Plains (Fig. 7.5). Elevated manganese concentrations occur in groundwater in the aquifer in proximity to the hills fringing the Plains. Elevated manganese concentrations do not appear to present problems or restrict use of the groundwater.

7.4.3.7 Nitrate

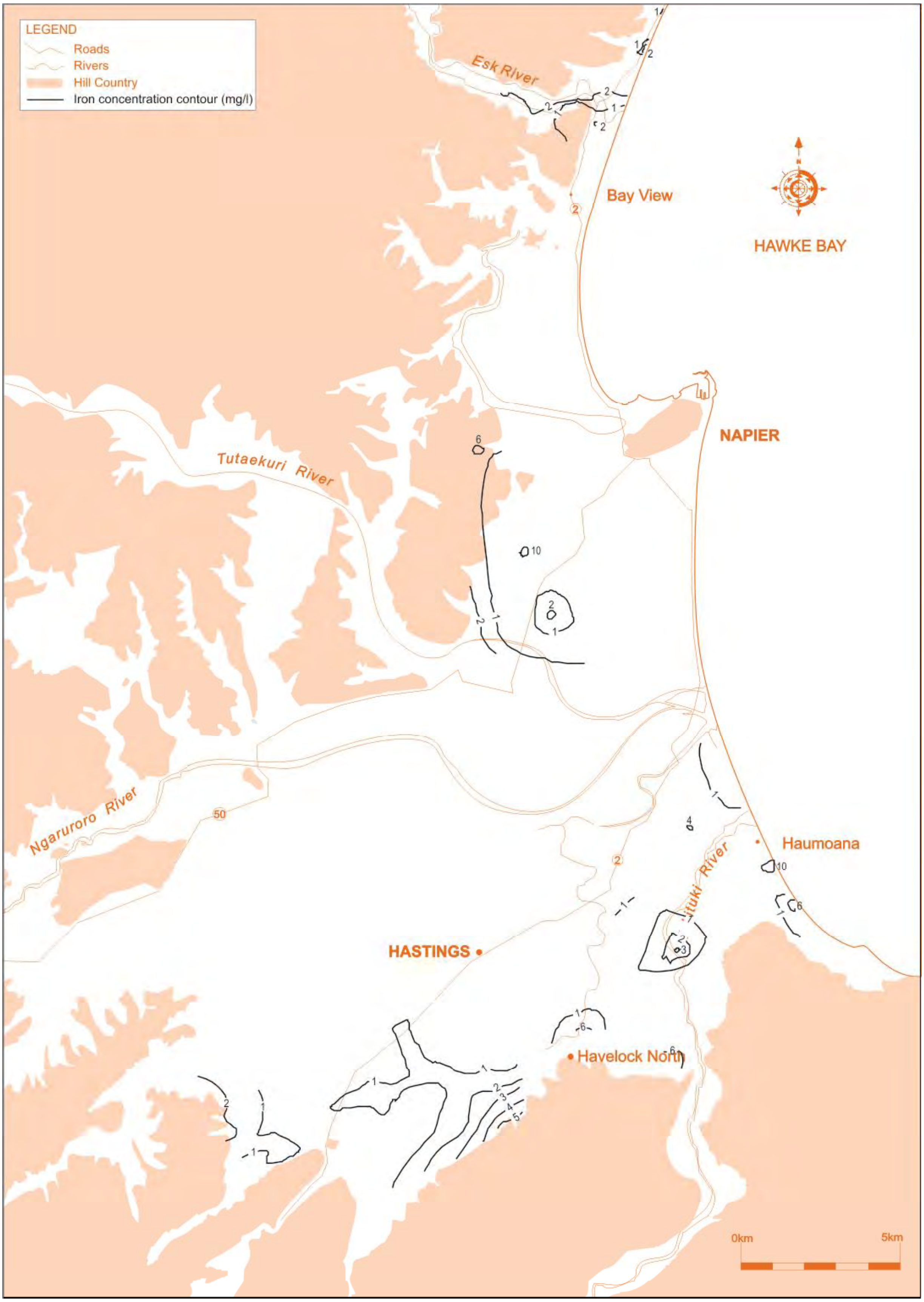
Figure 7.14 is a contour map of concentration of nitrate in Heretaunga Plains groundwater.

Concentrations of nitrate in the groundwater of the Heretaunga Plains have been the subject of concern and investigation over the previous 20 years. Much of the focus of these investigations has been on the quality of water in the unconfined aquifer, specifically in the Ngatarawa Valley and along Maraekakaho Road.

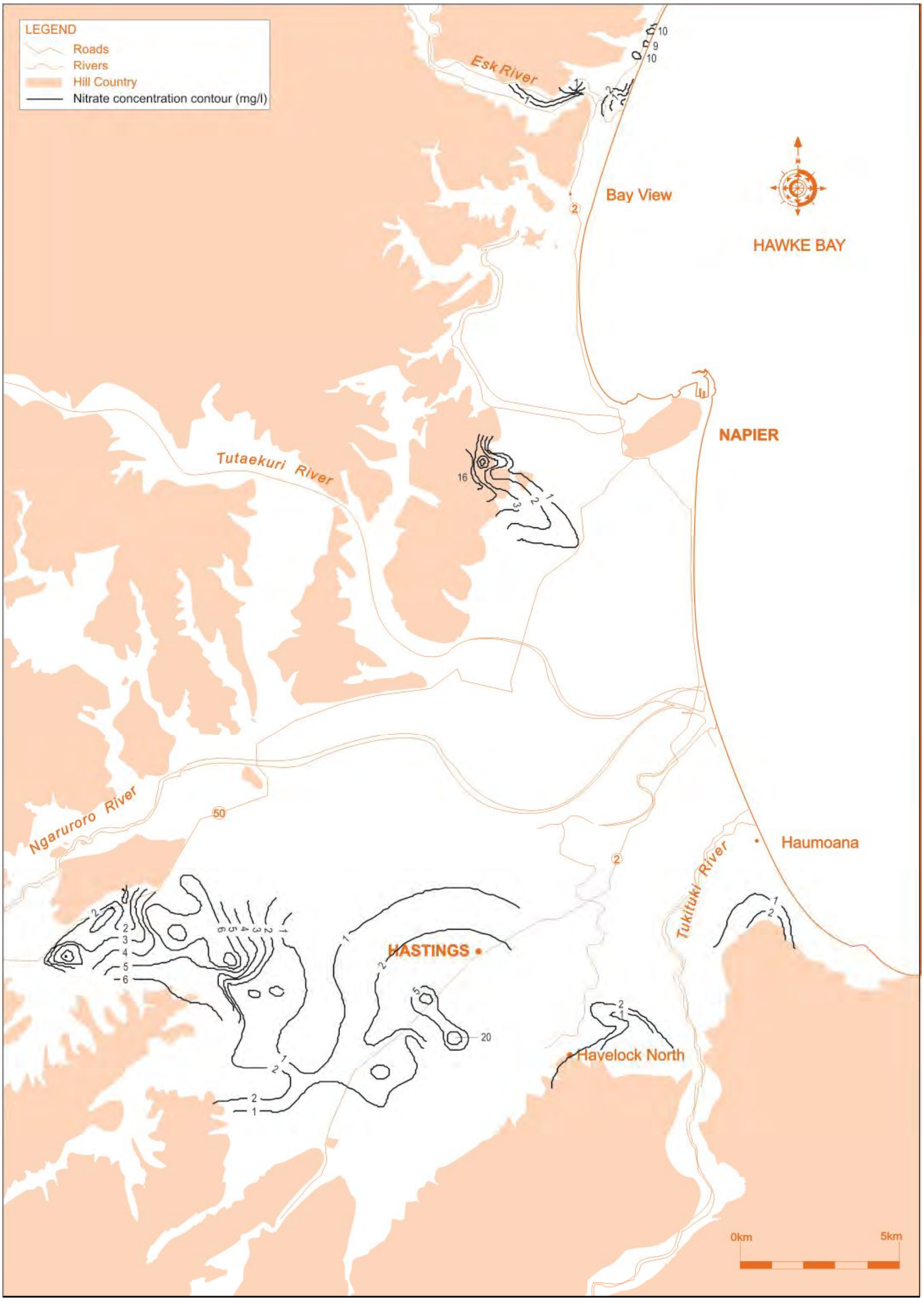
Contour data indicates that nitrate levels in the Heretaunga Plains groundwater are from point source contamination on the Plains and mineralisation from the peripheral limestone aquifers at the margins of the Plains. In the Ngatarawa - Bridge Pa area, several isolated high levels of nitrate occur, with 6 mg/l recorded at the western end of the minor recharge area and 7-8 mg/l in the Bridge Pa township area. Towards Hastings, nitrate concentration appears to decrease to 1-2 mg/l, and then increases markedly to 5-20 mg/l in the Tollemache Road area. In the Poraiti area, nitrate levels range from 14 mg/l in the fringing hills, decreasing to 1-2 mg/l on the plain in the Taradale area. Concentrations of 2 to 10 mg/l occur in the coastal bores in the Whirinaki area, with the elevated levels thought to be caused by septic tank contamination. Away from the coast levels decrease temporarily to approximately 1 mg/l then rise again near the base of the limestone hills behind Bay View.

Elevated concentrations of nitrate appear to be localised and associated with proximity of the groundwater to the fringes of the Heretaunga Plains main aquifer system (Figs. 7.2 and 7.14). Relatively high concentrations are found in three specific areas:

- along Maraekakaho Road in the Ngatarawa Valley;
- in the vicinity of Haumoana;
- in western hills adjacent to Poraiti area.



Figures 7.13: Contour map of iron concentration in the Heretaunga Plains groundwater.



Figures 7.14: Contour map of nitrate concentration in the Heretaunga Plains groundwater.

Landuse practice, in particular intensive and extensive pastoral farming and flood irrigation, has long been associated with elevated nitrate concentration in groundwater in the Ngatarawa Valley. These factors, as well as the presence of a shallow pan structure (Griffiths 1975), were cited as the causes for generally elevated nitrate concentrations in groundwater in the Ngatarawa Valley by Burden (1980). Results obtained by the HBCB in the early 1980's confirmed these elevated concentrations. Samples taken since July 1994, although from different wells to those previously sampled, have confirmed the status of nitrate concentrations in groundwater in the area. Data for the periods 1979-1984 and 1994-1995 are summarised in Table 7.2.

SU AR STATISTICS	O r 1979 m r 198	S m r 199 r 1995
Mean	4.00	4.21
Median	3.41	3.91
Range of concentrations	8.62	11.00
Minimum	0.38	< 0.01
Maximum	9.00	11.00
Number of samples (n)	35	56

Table 7.2: Summary statistics for Nitrate concentrations in the Ngatarawa Valley, 1979 - 1995 (mg/l).

Nitrate concentrations do not appear to have altered appreciably over the time period (16 years) covered. It is difficult to relate the more recent data to that of the Burden (1980) or the HBCB (1984) because different wells have been sampled and the hydrological conditions at the time of sampling are unknown. Landuse in the area has altered considerably since the original samples were taken in 1978. Pastoral farming has been considerably replaced by horticultural and cropping activity. Nitrogen loading could possibly have decreased as a result of this change in landuse.

Nitrate concentrations for the Heretaunga Plains aquifer system generally comply with the New Zealand Drinking water standard of 11 mg/l. The maximum value measured recently (December 1995) at Maraekakaho has been 11 mg/l. Additional monitoring and investigation involving demographic and landuse data should be undertaken to ensure that no public health risks situations exist. Such monitoring should be undertaken on a site or area specific basis, taking into account special risk factors such as the presence of schools and communities where a greater number of at-risk vectors might exist.

7.4.4 Temporal Trends in Groundwater Quality

Time series data are essential for the management of groundwater quality. Analysis of data according to time allows changes and trends in concentrations of water quality variables to be identified. It also provides an insight into shorter term fluctuations in water quality, such as may occur on an annual or seasonal basis. The identification of temporal trends in the water quality needs to be considered in conjunction with analysis of landuse demographic data, so that the complex relationships between landuse planning and development, hydrogeology and groundwater quality, can be identified and effectiveness of policies assessed and modified if required.

In this study, water quality records for all wells within each of the 52 grid block areas (Fig. 7.1) were assessed for appropriateness for time series analysis. Factors such as the completeness of the data record for individual variables were important. Relatively few wells were found with an adequate record for time series analysis. For those areas or blocks where adequate data was available, the assumption that all wells within relatively discrete areas provided water of similar quality was made, so that spatial and temporal comparisons could be made. At the edges of the main system, the validity of this assumption could be questioned.

Examples are identified in the following sections for a few aquifer sectors beneath the Heretaunga Plains:

- unconfined aquifer area adjacent to Flaxmere;
- semiconfined aquifer area underlying Ngatarawa Valley;
- confined aquifer area underlying Hastings;
- confined aquifer area underlying central and south Napier;
- confined aquifer area underlying Pakipaki.

7.4.4.1 Unconfined Aquifer Adjacent to Flaxmere

For all variables, the data was obtained from two periods of monitoring - for about two years around 1981 and continuously post-1990. Groundwater quality in the major groundwater recharge area closely reflects that of the quality of water in the Ngaruroro River. The range of values for most variables is smaller for the groundwater than for the river, reflecting the smaller impact of transient events on the groundwater quality. The limited, discontinuous nature of the data makes detection of trends difficult. No trend is evident from time-series graphs (Fig. 7.15). A similar absence of trend is evident from the river water quality data. These data indicate that no change in the quality of recharge water can be discerned from the groundwater quality data that is available.

7.4.4.2 Semiconfined Aquifer Underlying the Ngatarawa Valley

Groundwater quality from wells in the Ngatarawa Valley area exhibits increases in electrical conductivity, hardness, chloride and sulphate concentrations over the last 15 years. It is difficult to assess whether nitrate concentrations have also altered over this time due to the variability of the data available (Fig. 7.16). A few results indicate nitrate concentrations in excess of those reported in the 1982-1984 period. The majority of post-1984 results however are similar to or less than those previously reported. The increased mineralisation of the groundwater in the Ngatarawa Valley suggests reduced recharge from the Ngaruroro River sourced major recharge area to the north and increased or induced recharge from the minor recharge area, and an increasing component of the recharge from the limestone hills to the south and west of the Plains. Similar temporal trends in the Pakipaki area are suggested by the limited long-term groundwater quality data available from that area (7.4.4.5).

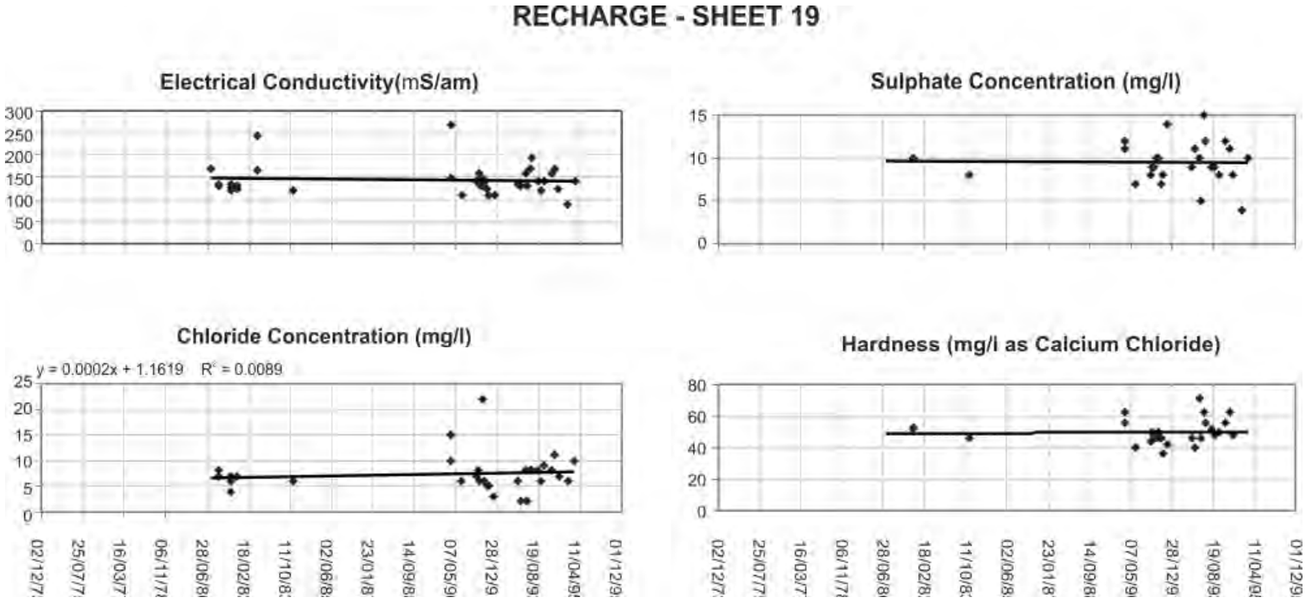


Figure 7.15: Temporal trends in groundwater quality in the unconfined aquifer underlying Flaxmere area.

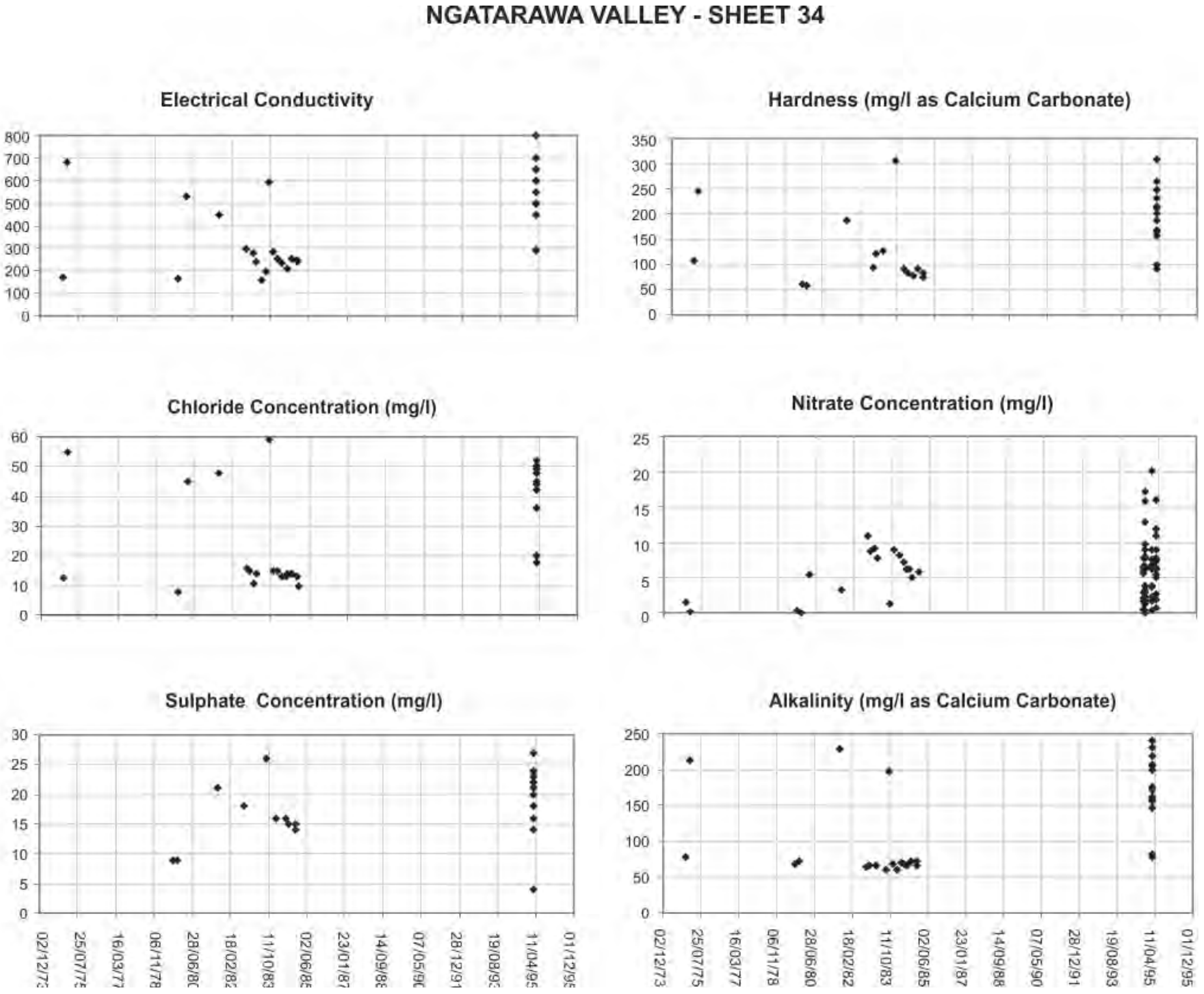


Figure 7.16: Temporal trends in groundwater quality in the semiconfined aquifer underlying Ngatarawa Valley.

7.4.4.3 Confined Aquifer Underlying Hastings

Very patchy and discontinuous data are all that is available for this part of the Heretaunga Plains aquifer. The data for selected variables are presented in Fig. 7.17. Variability within the data sets and the discontinuous distribution of the data do not allow more than a visual assessment for trend. Significant trend appears absent apart from the observation that the data does appear to indicate variability with time of the period covered. More regular monitoring is necessary to establish the patterns the groundwater quality data might be exhibiting.

7.4.4.4 Confined Aquifer Underlying Central and South Napier

Data for these areas are also discontinuous and patchy. Electrical conductivity data for areas 3 and 5 (Fig. 7.1) does show some indication of increasing trend (Fig. 7.18). The slope of the least-squares fit trend line was low for both areas, while the low R^2 value indicates poor reliability in forecasting trend in future water quality ($R^2 = 0.0065$). Data for sodium concentrations for both areas show an apparent trend toward decreasing concentrations of sodium. No simple explanation can be offered for the observed behaviour. Factors such as increasing abstraction from the groundwater system in the Napier area (Fig. 1.13) and possible induced recharge from beach gravel and limestone aquifers interbedded with and underlying the Heretaunga Plains confined aquifers (Fig. 4.16) is a possibility.

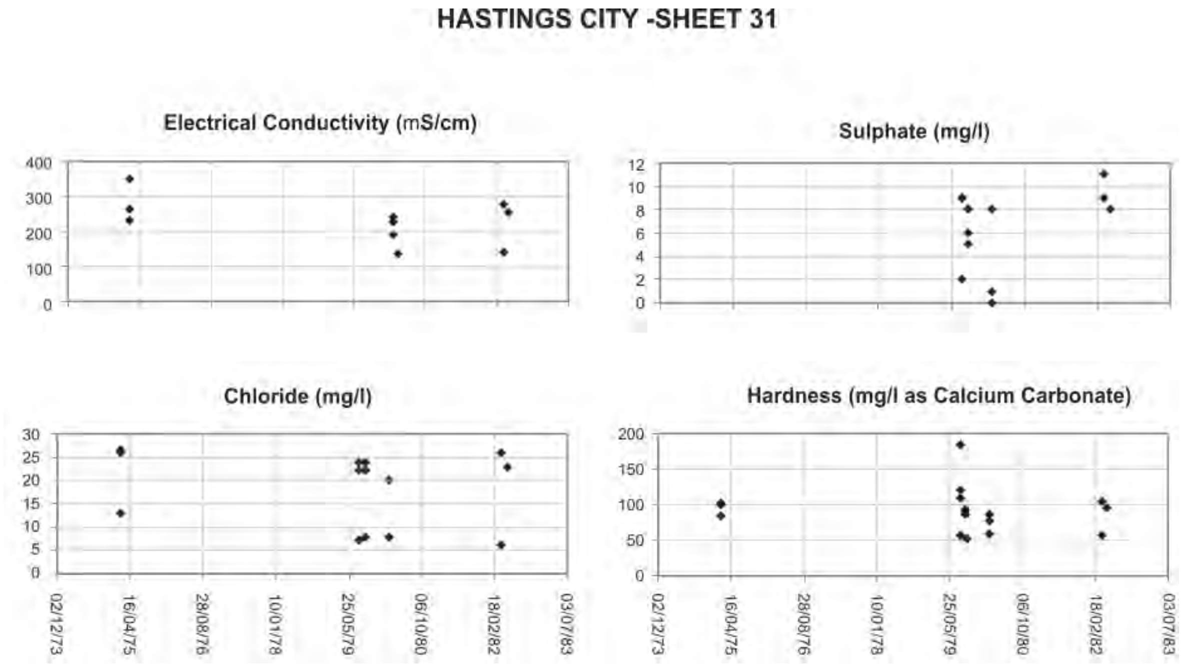


Figure 7.17: Temporal trends in groundwater quality in the confined aquifer underlying Hastings.

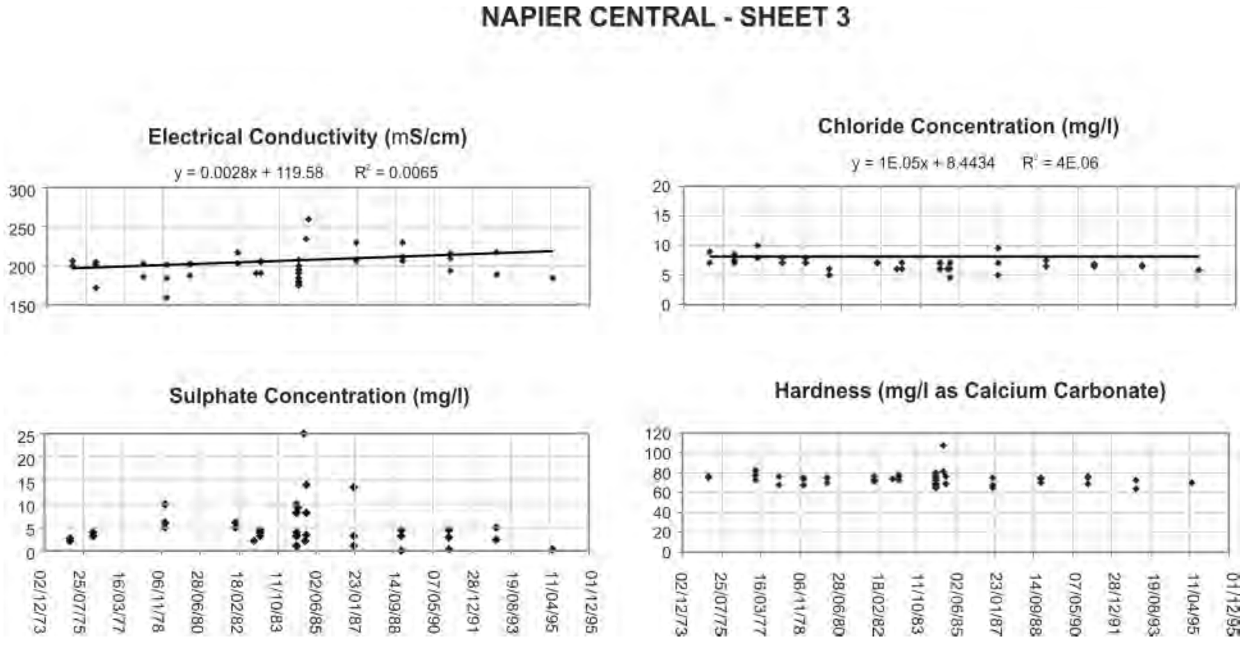


Figure 7.18: Temporal trends in groundwater quality in the confined aquifer underlying central and south Napier.

7.4.4.5 Semiconfined to Confined Aquifer Underlying Pakipaki

In the vicinity of Pakipaki water quality data is from three specific periods - 1974, 1983-1985 and post July 1994. Data obtained during the middle period (1983-1985) appeared quite homogeneous, with little variation over time (Fig. 7.19). In contrast, data for both the earlier and more recent periods show considerable variability. For most variables, there is a distinct difference in water quality between the two periods. Electrical conductivity appears to have increased from a mean value of about 350 µS/cm to 450 µS/cm. Hardness and in particular sulphate concentrations show similar increases in concentration with time. In contrast, concentrations of nitrate in groundwater appear to have decreased over the period for which data are available.

The variation in water quality with time is related to groundwater abstraction. Groundwater quality in the Pakipaki area is determined by the quality of water in the main aquifer system, which mixes with that entering the system from the minor recharge area, along with groundwater derived from the hills forming the southern and western boundaries of the Plains. The change in concentrations of these three variables is in response to effects related to landuse and induced flow due to increased groundwater abstraction.

The Pakipaki area could be a critical area for monitoring the Heretaunga Plains aquifer system. The Pakipaki area is at the southern extremity of the Heretaunga Plains aquifer system at the unconfined - confined aquifer boundary (Fig. 5.1), and would be the area where stress

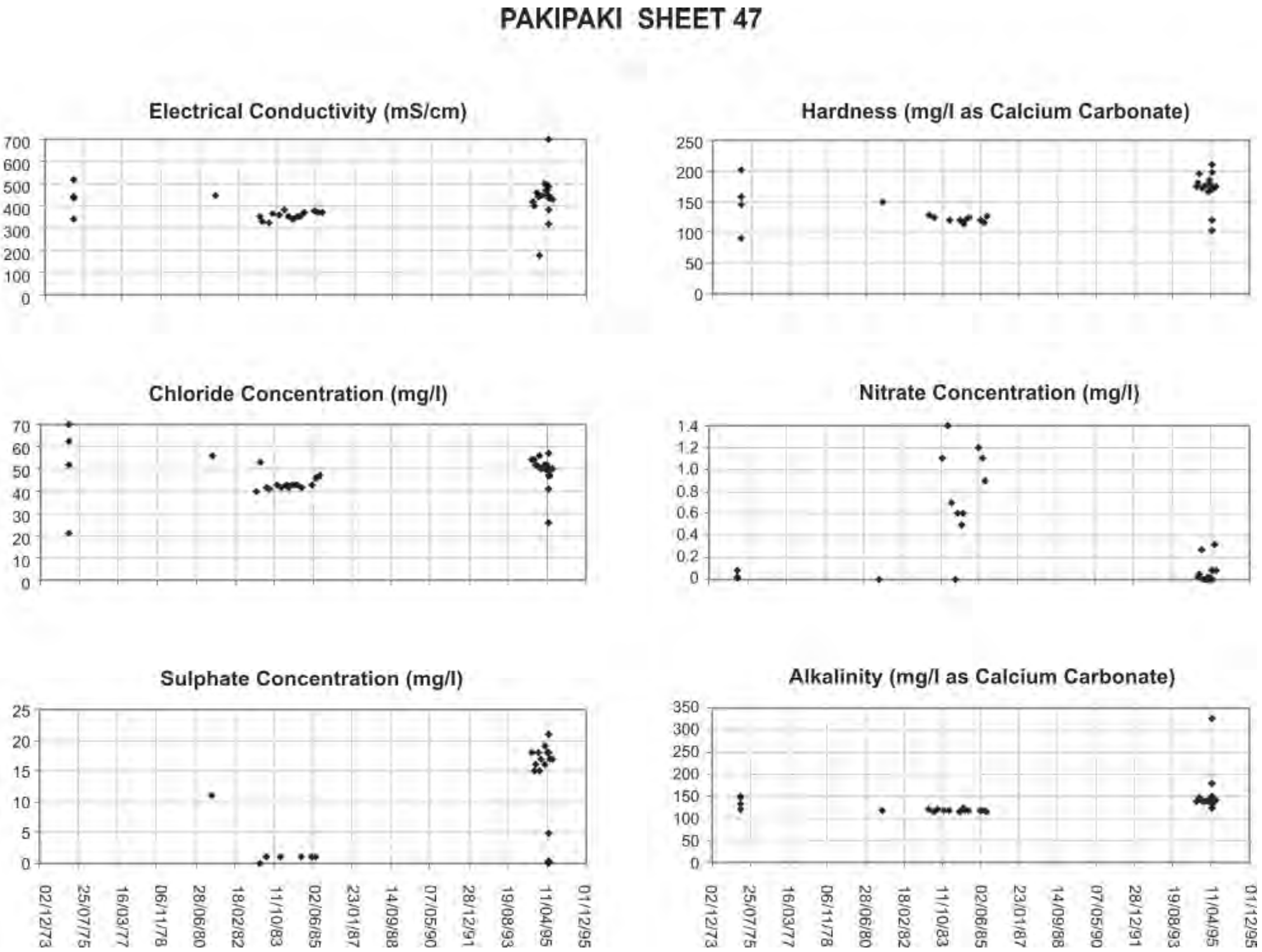


Figure 7.19: Temporal trends in groundwater quality in the semiconfined to confined aquifer underlying Pakipaki.

related to over withdrawal from the system is first likely to be apparent. It is anticipated that this stress would be apparent in two forms - declining water levels in wells and fluctuating groundwater quality. Fluctuating groundwater quality occurred at Pakipaki in 1974 and 1994 to present. The climate for the three periods for which time series groundwater quality data is available is characterised by moderate drought for 1974, severe drought for 1983-85, and severe drought followed by average winter for 1994 to present. Perhaps more significantly landuse at Pakipaki has changed from predominantly pastoral farming in 1974 to horticulture in 1994. This has been accompanied by a steep increase in the number of wells drilled to provide water for irrigating the crops. Thus a combination of stress to the groundwater system imposed by additional groundwater abstraction from the Heretaunga Plains aquifer system and stress imposed by the increase in local groundwater abstraction at Pakipaki, is manifesting in local variation in groundwater quality. In 1974 fluctuations of groundwater quality at Pakipaki were a result of regional stress on the Heretaunga Plains aquifer system, whereas in 1983 - 85 there was no stress at all, and from 1994 the stress is mainly locally applied by intense groundwater abstraction.

7.4.4.6 Semiconfined to Unconfined Esk (Whirinaki - Bay View) Aquifer

Water quality problems in the northern coastal area have persisted for many years. These problems relate primarily to saline intrusion into the shallow unconfined aquifers that occur along the coastal fringe. Salinity problems led to the development of a water supply scheme for the Bay View area by the Napier City Council in the 1980's with water pumped from Napier through a former fuel oil pipeline. Residential development north of Bay View is resulting in more wells being drilled and problems with the intrusion of saline waters into the water table and unconfined - confined aquifer in the area adjacent to the coast at Whirinaki. (see 5.4.4.)

Figure 7.2 indicates spatial variation of electrical conductivity. There is an influence of the limestone and other Tertiary age sediments on water quality. Water is generally more highly mineralised in the Esk River valley compared with the main Heretaunga Plains aquifer system. Concentrations of calcium, sodium, magnesium, chloride and sulphate are all elevated relative to the Heretaunga Plains system and confirm that saline intrusion is a contributor to the elevated electrical conductivity values. However the quality of the groundwater in most of the Esk River valley meets the international standards for most domestic and agricultural uses.

A survey of water quality in the Whirinaki beach area was undertaken by the HBRC during July 1994, with results reported in September 1994 (Hudson 1994). Specific water quality issues were identified along the narrow coastal strip between State Highway 2 and the shoreline. Electrical conductivity provides a good perspective of the spatial extent of the salinity problem over the stretch of the coast between the southern end of Northshore Road and the northern end of Whirinaki Beach Road. A clear spatial trend with elevated electrical conductivity to the south and particularly to the north of Northshore Road was observed. The values generally decrease toward the centre of this coastal strip.

The elevated electrical conductivity values are explained by the hydrogeology of the area. The coastal aquifer is formed by an interconnected stratum of marine and fluvial gravels (Fig. 5.34) deposited along the coastal strip. Recharge is from the Esk River and to a lesser extent, surface and groundwater derived from the hills inland of the coastal plain. The fluvial gravels extend into the coastal deposits of beach gravel and sand and there is an interface between the fresh groundwater and saline water entering from the sea. Water levels show tidal induced fluctuations (Fig. 5.35).

7.4.4.7 Summary of Temporal Trends in Groundwater Quality

Groundwater quality for the Heretaunga Plains aquifer is excellent and is generally suitable for most typical uses without treatment. Specific water quality requirements may need to be assessed for suitability on an individual basis and may need to consider both temporal and aerial variations. The establishment of temporal relationships in groundwater quality has been restricted due to limited data available. Apparent temporal trends of changing water quality have been observed over much of the Heretaunga Plains area. These apparent changes with time are almost imperceptible in the centre of the Plains area, but increase both to the north and particularly to the south and west. At present the magnitude of change in water quality does not indicate that groundwater quality will limit the current uses. However, the observed apparent changes should be noted and management strategies modified to address the implications for the future. The most important management strategy which needs to be addressed is that of monitoring. Future monitoring must be undertaken to ensure that the trends are detected accurately, and the causes of changes in water quality with time are understood. Where landuse practices, leaks and accidental spillages cause deterioration of groundwater quality remedial

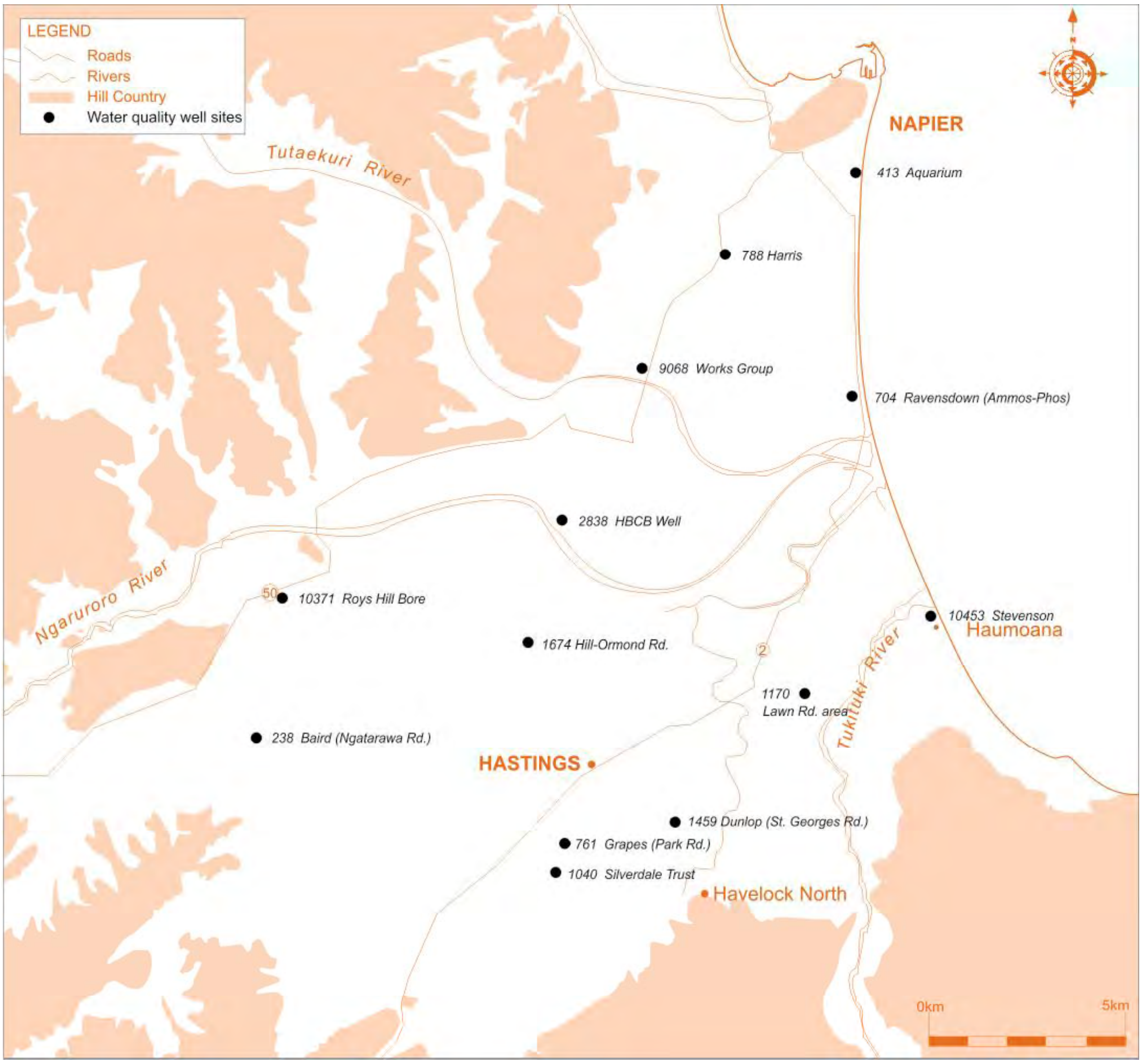


Figure 7.20: Map showing the locations of water quality wells along geological cross-sections.

measures should be designed and applied immediately a problem is detected or notified.

7.5 WATER QUALITY VARIATION ALONG MAJOR GEOLOGICAL CROSS SECTIONS

If landuse and point sources of pollution are disregarded or absent the groundwater quality observed in an aquifer system is the result of a complex series of chemical and physical interactions between the water and the aquifer materials. These interactions are reflected in groundwater chemistry and therefore provide important clues in understanding the geology, hydrogeology, and path and rate of groundwater flow.

The lithologic variation along five geological cross sections through the Heretaunga Plains is discussed in Chapter 4 (see 4.5.1 to 4.5.5). This section describes groundwater quality variation along four of these geological cross sections in the Heretaunga Plains and for the geological cross section in the Whirinaki - Bay View coastal area (Fig. 5.34).

7.5.1 Napier - Haumoana Geological Cross Section

Summary statistics for selected groundwater variables are provided in Table 7.3. The data are from the Napier City Council water supply well adjacent to the Aquarium on the Marine Parade (well no. 413 / V21/469818), one of the water supply wells used by Ravensdown

	E r C .	r	A y	C m	C r	Ir	m		N r	P	m S	m S
o. 1												
	211.33	75.00	87.27	57.58	6.88	0.00	16.33	0.03	0.00	1.59	11.75	6.18
	203.50	75.50	94.00	65.00	7.00	0.01	10.50	0.04	-0.02	1.90	13.00	4.50
	200.00	75.00	97.00	66.00	7.00	0.02	11.00	0.04	-0.02	1.90	13.00	6.00
R	60.00	13.00	90.50	56.00	4.43	0.10	87.00	0.06	0.38	2.23	13.10	12.00
m m	200.00	65.00	6.50	10.00	4.57	-0.05	2.00	0.00	-0.20	-0.03	1.90	2.00
x m m	260.00	78.00	97.00	66.00	9.00	0.05	89.00	0.06	0.18	2.20	15.00	14.00
C	12.00	12.00	13.00	12.00	13.00	13.00	12.00	10.00	11.00	12.00	12.00	10.00
o. 0												
	168.64	65.18	70.18	22.86	6.44	0.08	2.14	0.03	0.02	1.50	9.86	4.72
	165.00	64.00	71.00	22.20	6.00	0.08	2.10	0.03	0.01	1.50	10.00	5.00
	160.00	64.00	71.00	22.20	8.00		2.10		-0.01	1.60	10.00	7.00
R	50.00	18.00	10.00	6.90	5.10	0.02	0.60	0.01	0.21	0.50	8.30	13.00
m m	160.00	60.00	65.00	21.10	2.90	0.07	1.80	0.02	-0.01	1.20	4.70	-1.00
x m m	210.00	78.00	75.00	28.00	8.00	0.09	2.40	0.04	0.20	1.70	13.00	12.00
C	11.00	11.00	11.00	11.00	11.00	2.00	11.00	2.00	11.00	11.00	11.00	11.00
T 0 . o. 10												
	155.75	64.50	68.00	21.67	7.40	0.24	2.00	0.00	0.05	0.00	9.00	8.00
	150.00	66.50	64.00	21.00	7.00	0.00	2.00	0.00	0.00	0.00	9.00	8.00
					7.00	0.00	2.00		0.00			8.00
R	81.00	21.00	33.00	8.00	3.00	0.94	0.00	0.00	0.32	0.00	0.00	0.00
m m	121.00	52.00	56.00	18.00	6.00	0.00	2.00	0.00	0.00	0.00	9.00	8.00
x m m	202.00	73.00	89.00	26.00	9.00	0.94	2.00	0.00	0.32	0.00	9.00	8.00
C	4.00	4.00	5.00	3.00	5.00	4.00	3.00	1.00	6.00	1.00	1.00	3.00

Table 7.3: Summary groundwater quality statistics for selected wells along Napier - Haumoana geological cross section.

Fertilisers well (well no. 704 / V21/467760), Waitangi Road, Awatoto, and Stevensons well (well no. 10453 / V21/478716), Haumoana.

The interaction and intermixing of groundwater recharged by the Ngaruroro River with groundwater from the Scinde Island limestone dipping to the south-east from Park Island and Napier Hill is evident in groundwater at the Aquarium well, Napier. Concentrations of a number of variables are enriched relative to those from the southern wells along the cross-section. The mean concentration of calcium at Napier is double that of groundwater from the other wells, while magnesium is present in a six-fold excess. Sodium concentrations are slightly elevated in the north but the reasons for this are unclear.

Groundwater in the aquifers at the southern end of the cross section appears to have elevated iron concentrations. This is possibly related to the brown or red gravels suggesting iron oxide staining frequently identified in well logs south of Clive, and a product of increased residence of time of groundwater in the aquifer. Slightly elevated sulphate concentrations observed in the wells south of Haumoana suggest the Tukituki River is a recharge source in this area.

7.5.2 Napier - Ngatarawa Geological Cross Section

Four wells were selected for water quality data for this cross section. While the individual wells may not be those used to develop the geological cross section, they are regarded as being sufficiently typical for the purpose of comparison. Summary statistics for selected groundwater variables are provided in Table 7.4.

The water quality data for the selected four wells indicates the influence of geology on local water quality. The Ngatarawa Valley is underlain by a series of hard pans (Griffiths 1975) (see 7.4.3.7). Transmissivity is relatively low (Fig. 5.4) and the groundwater quality is influenced locally by intermixing with groundwater that has infiltrated from the siltstone and limestone hills to the southwest. This influence is evident in elevated concentrations of calcium and magnesium, and in particular, sodium, potassium and sulphate. The water is relatively highly mineralised, with the highest electrical conductivity values for all of the wells in the cross section.

	E r C .	r	A	y C	m C r	Ir	m		N r	P	m S	m S
T o. 8												
	240.58	93.22	66.92	24.63	13.58	0.02	7.89	0.04	7.66	2.13	19.00	15.67
	244.00	90.00	67.00	23.00	14.00	0.00	8.00	0.00	7.90	2.00	19.50	15.50
			66.00	24.00	15.00	0.00	8.00	0.00	6.20	2.00	21.00	16.00
R	141.00	51.00	12.00	19.00	6.00	0.20	2.00	0.40	6.00	2.00	7.00	4.00
m m	155.00	75.00	60.00	18.00	10.00	0.00	7.00	0.00	5.00	1.00	14.00	14.00
x m m	296.00	126.00	72.00	37.00	16.00	0.20	9.00	0.40	11.00	3.00	21.00	18.00
C	12.00	9.00	12.00	8.00	12.00	13.00	9.00	13.00	11.00	8.00	8.00	6.00
o. 6												
	144.00	50.30	47.09	16.39	7.68		2.19		0.27	1.66	8.43	9.52
	140.00	48.00	47.00	16.00	7.00		2.10		0.25	1.10	8.00	9.00
	140.00	46.00	49.00	16.00	6.00		2.00		0.40	0.90	8.00	9.00
R	180.00	35.00	24.00	12.00	20.00		1.30		0.68	13.20	8.00	11.00
m m	90.00	36.00	36.00	12.00	2.00		1.60		0.02	0.80	7.00	4.00
x m m	270.00	71.00	60.00	24.00	22.00		2.90		0.70	14.00	15.00	15.00
C	25.00	23.00	23.00	23.00	25.00		23.00		12.00	23.00	23.00	25.00
P o. 9068												
	163.00	67.00	62.50	23.85	6.45	0.17	2.00	0.00	0.13	1.05	9.45	8.70
	163.00	67.00	62.50	23.85	6.45	0.17	2.00	0.00	0.13	1.05	9.45	8.70
							2.00					
R	6.00	6.00	1.00	2.30	1.10	0.06	0.00	0.00	0.00	0.10	0.90	1.40
m m	160.00	64.00	62.00	22.70	5.90	0.14	2.00	0.00	0.13	1.00	9.00	8.00
x m m	166.00	70.00	63.00	25.00	7.00	0.20	2.00	0.00	0.13	1.10	9.90	9.40
C	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00
o. 1												
	211.33	75.00	87.27	57.58	6.88	0.00	16.33	0.03	0.00	1.59	11.75	6.18
	203.50	75.50	94.00	65.00	7.00	0.01	10.50	0.04	-0.02	1.90	13.00	4.50
	200.00	75.00	97.00	66.00	7.00	0.02	11.00	0.04	-0.02	1.90	13.00	6.00
R	60.00	13.00	90.50	56.00	4.43	0.10	87.00	0.06	0.38	2.23	13.10	12.00
m m	200.00	65.00	6.50	10.00	4.57	-0.05	2.00	0.00	-0.20	-0.03	1.90	2.00
x m m	260.00	78.00	97.00	66.00	9.00	0.05	89.00	0.06	0.18	2.20	15.00	14.00
C	12.00	12.00	13.00	12.00	13.00	13.00	12.00	10.00	11.00	12.00	12.00	10.00

Table 7.4: Summary groundwater quality statistics for selected wells along Napier - Ngatarawa geological cross section.

Groundwater quality data from a well at Roys Hill (well no. 10371 / V21/309715) is typical of the quality of water entering the Heretaunga Plains from the Ngaruroro River, with lowest values for almost all variables. The mean and median electrical conductivity values are almost identical to those of the Ngaruroro River itself. This data indicates that the aquifer lithology (greywacke gravel) has a negligible influence on groundwater quality in the recharge zone. The highly transmissive fluvial gravel of predominantly inert greywacke clasts do not allow sufficient residence time for groundwater - aquifer lithology interaction, dissolution and mineralisation to occur.

Groundwater quality at the well located at the HBRC Work Group, Guppy Road (well no. 9068 /V21/413769) indicates changes in quality relative to the recharge. Calcium concentrations are similar to those in the Ngatarawa Valley. Other variables have increased in concentration relative to the recharge, but not to the extent observed in the Ngatarawa Valley. This slight mineralisation is evidenced by an increase in electrical conductivity from about 144 at the Ngaruroro River major recharge to 163 µS/cm at Guppy Road. The greatest increase is observed for calcium concentrations. This indicates that the limestone of the hills to the west of the Heretaunga Plains at Omaranui and Puketapu and the Scinde Island Limestone which historically joined Scinde Island to the mainland may extend to the southwest, and influence water quality in the Taradale area.

The quality of groundwater observed in the Aquarium well confirms increasing mineralisation with distance from the recharge, as well as the localised influence of limestone dipping to the southeast below Napier from Napier Hill.

7.5.3 Roy's Hill - Havelock North Geological Cross Section

Water quality data for five wells situated approximately along this cross section are summarised in Table 7.5. While the spatial conformity with the cross section line is not good, the data illustrate a clear pattern of transition in water quality. This is the cross section that extends from the Ngaruroro River major recharge zone along the direction of groundwater flow. West of and including well no. 2328 (Fig. 7.20), groundwater has low electrical conductivity and does not appear highly mineralised. Concentrations of sodium and magnesium appear to increase slightly, while that of sulphate appears to decrease. These data are typical of wells that lie within the zone of maximum transmissivity in the centre of the Heretaunga Plains aquifer system (Fig. 5.4). The two southern wells in the area between Hastings

	E r C .	r	A y	C m	C r	Ir	m		N r	P	m S	m S
o. 10 1												
	144.00	50.30	47.09	16.39	7.68		2.19		0.27	1.66	8.43	9.52
	140.00	48.00	47.00	16.00	7.00		2.10		0.25	1.10	8.00	9.00
	140.00	46.00	49.00	16.00	6.00		2.00		0.40	0.90	8.00	9.00
R	180.00	35.00	24.00	12.00	20.00		1.30		0.68	13.20	8.00	11.00
m m	90.00	36.00	36.00	12.00	2.00		1.60		0.02	0.80	7.00	4.00
x m m	270.00	71.00	60.00	24.00	22.00		2.90		0.70	14.00	15.00	15.00
C	25.00	23.00	23.00	23.00	25.00		23.00		12.00	23.00	23.00	25.00
o. 16												
	149.85	54.54	52.00	17.05	7.93	0.34	2.78	0.00	0.21	1.17	8.61	8.48
	149.00	55.00	52.00	16.90	8.00	0.37	2.80	0.00	0.18	1.15	8.40	8.00
	150.00	56.00	52.00	16.90	8.00		2.80		0.17	1.30	9.00	8.00
R	61.00	14.00	9.00	4.00	5.80	0.12	0.50	0.04	0.34	0.30	2.20	5.00
m m	130.00	50.00	48.00	15.00	5.70	0.27	2.60	-0.02	0.00	1.00	7.90	7.00
x m m	191.00	64.00	57.00	19.00	11.50	0.39	3.10	0.02	0.34	1.30	10.10	12.00
C	13.00	13.00	13.00	11.00	13.00	3.00	10.00	2.00	13.00	10.00	11.00	11.00
o. 8												
	138.50	55.33	64.33	14.00	7.00	0.78	5.00	0.10	0.00	1.00	9.00	5.33
	138.50	56.00	66.00	15.00	7.00	0.55	4.00	0.10	0.00	1.00	9.00	5.00
			66.00						0.00			
R	7.00	4.00	5.00	9.00	2.00	1.40	5.00	0.00	0.00	0.00	0.00	7.00
m m	135.00	53.00	61.00	9.00	6.00	0.30	3.00	0.10	0.00	1.00	9.00	2.00
x m m	142.00	57.00	66.00	18.00	8.00	1.70	8.00	0.10	0.00	1.00	9.00	9.00
C	2.00	3.00	3.00	3.00	3.00	4.00	3.00	1.00	4.00	1.00	1.00	3.00
P P o. 61												
	234.00	94.75	88.00	29.25	20.50	0.50	5.25	0.00	0.23	1.00	15.00	7.25
	234.00	99.00	89.00	30.00	24.00	0.25	5.50	0.00	0.00	1.00	15.00	8.50
			89.00		24.00		6.00		0.00			
R	90.00	61.00	8.00	23.00	18.00	1.50	2.00	0.00	0.90	0.00	0.00	10.00
m m	189.00	60.00	83.00	17.00	8.00	0.00	4.00	0.00	0.00	1.00	15.00	1.00
x m m	279.00	121.00	91.00	40.00	26.00	1.50	6.00	0.00	0.90	1.00	15.00	11.00
C	2.00	4.00	4.00	4.00	4.00	4.00	4.00	1.00	4.00	1.00	1.00	4.00
P t o. 1 9												
	262.00	103.22	90.78	32.52	22.67	0.53	5.29	0.15	0.01	1.64	14.88	9.72
	260.00	102.00	91.00	31.00	22.00	0.53	5.30	0.15	0.01	1.60	14.90	9.70
	250.00	102.00	91.00	29.40	22.00		5.20		0.00	1.60	15.00	10.00
R	40.00	24.00	8.00	12.90	4.00	0.17	0.50	0.02	0.04	0.40	1.60	2.00
m m	250.00	96.00	88.00	29.40	21.00	0.44	5.00	0.14	-0.01	1.40	14.00	9.00
x m m	290.00	120.00	96.00	42.30	25.00	0.61	5.50	0.16	0.03	1.80	15.60	11.00
C	9.00	9.00	9.00	9.00	9.00	2.00	9.00	2.00	9.00	9.00	9.00	9.00

Table 7.5: Summary groundwater quality statistics for selected wells along Roys Hill - Havelock North geological cross section.

and Havelock North show a significantly different water quality signature. The water is more highly mineralised, with electrical conductivity increasing from around 145 to about 250 µS/cm. Concentrations of all major ionic species increase, particularly calcium, chloride and sodium. The presence of relatively highly mineralised groundwater arising from the hills surrounding the Heretaunga Plains has already been noted. The groundwater quality of the eastern margin of the Heretaunga Plains is likely to be the product of a mixing of groundwaters which have reached the area by different flow paths, at different flow rates and which may have been in contact with different sediment and rock types forming aquifers. Piezometric contour maps (Figs. 5.5 and 5.6) suggest that the westward flowing groundwater from the southern sector (Bridge Pa - Pakipaki) of the Heretaunga Plains aquifer system mixes with the high transmissivity central sector groundwater in the Havelock North area.

7.5.4 Pakipaki - Haumoana Cross Section

Water quality data from wells along this section indicates a steady decrease in mineralisation from west to east (Table 7.6). In the sector of the Heretaunga Plains from Pakipaki to Havelock North this is probably the result of the mixing of fringe (southern sector) groundwater with a relatively high mineral component, with the high transmissivity central sector groundwater with low values for almost all variables (see 7.5.3) to the east of Hastings. Possible dilution of this mineralised water with groundwater derived from the Tukituki River may also be entering the system in the Mangateretere area. The low sulphate concentrations in the easterly wells tends to indicate that the water is predominantly derived from the Ngaruroro River through the main aquifer system. Low sulphate concentrations have been associated with groundwaters that have been within an aquifer system over a prolonged period, allowing anaerobic processes to occur. Investigations regarding water quality in the Havelock North-Mangateretere Road area have been undertaken on a number of occasions over the past 20 years. These investigations have included that of Barnett (1980) and Burn (1983). Burn (1983) noted difficulty with defining the aquifer systems in the vicinity of Havelock North. Cross sections across the Havelock North - Mangateretere - Lawn Road area were constructed and water quality compared to the stratigraphy. The findings of the survey were not entirely conclusive. It was noted that the main aquifer system lost water through the springs in this area.

	E r C .	r	A y	Amm	C r	C m	C r	C r	Ir	m		N r	P m	S m	S
		o. 88													
	423.75	176.25	141.33	0.24	144.50	48.23	0.00	51.42	0.16	14.23	0.25	0.07	5.13	24.61	17.00
	442.50	174.00	140.50	0.25	145.00	45.80	0.00	51.50	0.16	14.25	0.25	0.02	5.15	24.55	17.00
	445.00	172.00	142.00	0.25			0.00	52.00		13.90		-0.01	5.30	25.00	18.00
R	325.00	30.00	15.00	0.09	14.00	21.30	0.00	9.00	0.18	1.00	0.04	0.33	0.70	2.40	4.00
m m	175.00	166.00	136.00	0.19	137.00	42.30	0.00	47.00	0.07	13.70	0.23	-0.01	4.70	23.70	15.00
x m m	500.00	196.00	151.00	0.28	151.00	63.60	0.00	56.00	0.25	14.70	0.27	0.32	5.40	26.10	19.00
C	12.00	12.00	12.00	5.00	4.00	12.00	4.00	12.00	2.00	12.00	2.00	11.00	12.00	12.00	12.00
	T T		*o. 99*												
	346.82	138.64	111.73	0.02	114.00	43.97	0.00	31.45	0.04	8.00	0.11	19.09	2.15	17.88	16.45
	345.00	138.00	112.00	0.02	113.00	42.30	0.00	31.00	0.04	8.00	0.11	1.61	2.20	18.00	16.00
	340.00	140.00	112.00				0.00	30.00		8.00		1.70	2.10	18.00	16.00
R	35.00	17.00	15.00	0.02	13.00	18.70	0.00	7.00	0.03	1.10	0.02	194.17	0.60	2.30	5.00
m m	330.00	130.00	106.00	0.01	108.00	39.00	0.00	29.00	0.03	7.30	0.10	0.83	1.80	16.80	15.00
x m m	365.00	147.00	121.00	0.02	121.00	57.70	0.00	36.00	0.06	8.40	0.12	195.00	2.40	19.10	20.00
C	11.00	11.00	11.00	4.00	3.00	11.00	3.00	11.00	2.00	11.00	2.00	11.00	11.00	11.00	11.00
			o. 11 0												
	160.43	60.09	67.96	0.41	67.89	18.20	1.11	7.91	0.51	3.17	0.08	0.43	1.58	10.30	3.48
	159.00	59.00	66.00	0.14	64.00	17.95	0.00	8.00	0.30	3.00	0.05	0.07	1.40	9.80	2.35
	150.00	56.00	60.00	0.32	72.00	18.40	0.00	8.50	0.52	3.00	0.00	0.00	1.40	9.00	2.00
R	60.00	30.00	38.00	3.00	37.00	9.10	6.00	5.30	4.26	2.70	0.27	2.48	2.70	6.90	7.30
m m	140.00	50.00	56.00	0.01	56.00	14.90	0.00	5.70	0.04	2.30	0.00	0.00	1.00	9.00	0.20
x m m	200.00	80.00	94.00	3.00	93.00	24.00	6.00	11.00	4.30	5.00	0.27	2.48	3.70	15.90	7.50
C	23.00	23.00	23.00	12.00	9.00	12.00	9.00	23.00	19.00	12.00	11.00	23.00	12.00	12.00	12.00

Table 7.6: Summary groundwater quality statistics for selected wells along Pakipaki - Haumoana geological cross section.

It was suggested that the spring outflow was replaced by water derived from the Tukituki River. Water quality data appeared to be of little value in distinguishing the sources of groundwater.

Groundwater quality in the Havelock North area has been the subject of additional monitoring since July 1994 and a network of wells has been sampled on a number of occasions. While the interactions of the various lithologic units, aquifers and their effects on groundwater quality are still not clear, a number of features can be discerned. These include:

- To the east of the Karamu/Clive River system there is a zone of wells having low electrical conductivity, and low concentrations of all variables. This is typical of the main aquifer system fed from the Ngaruroro River.
- To the south of Hastings, groundwater increases in mineralisation, indicated by increasing electrical conductivity and calcium concentrations.
- Relatively highly mineralised groundwater is associated with the limestone and siltstone hills on the eastern margin of the Heretaunga Plains near Havelock North. Groundwater in this area has the highest values for these variables.
- North of Havelock North groundwater becomes less mineralised, becoming indistinguishable from the main Heretaunga Plains groundwater.
- To the west of the Tukituki River, groundwaters have an intermediate electrical conductivity, but a characteristically low sulphate concentration.
- Near Pakipaki groundwater becomes increasingly mineralised due to the adjacent limestone and siltstone hills.

The spatial differences detected from this additional monitoring are similar in some respect to those noted by Barnett (1980), who recognised three specific zones on the basis of electrical conductivity. An attempt was also made to distinguish zones of water quality based on concentrations of nitrate. Elevated concentrations of nitrate were noted to the west of Havelock North. The elevated nitrate concentration in groundwater is attributed to a combination of landuse and interaction between groundwater and the aquifer lithologies.

7.6 LANDFILL AND WASTE DISPOSAL SITES

Landfills on the Heretaunga Plains have been categorised according to size, period and nature of operation.

- Larger municipal sites which operated over an extended period of 20 years or more.
- Smaller sites which represent a potentially high level of risk of contamination due to their location and/or due to specific hazardous wastes that are known to have been or thought to have been accepted.
- Smaller generally rural sites, often closed or about to be closed that do not exhibit the potentially high level of risk of contamination associated with the first catagory.
- Refuse transfer stations and recycling stations, as well as any landfills which were closed prior to 1960. Figure 7.21 shows the locations of various currently operational and closed landfills on the Heretaunga Plains.

The Heretaunga Plains currently operational and closed landfill sites are shown in Fig. 7.21 and listed in Table 7.7. In this table the HBRC catagory is compared with the LeGrand groundwater contamination potential rating system (LeGrand 1964 and 1983). Brown (1994) applied the LeGrand (1983) rating system to Hawke's Bay landfills in an assessment of the geology and hydrogeology of the site and the surrounds, in terms of potential of leachate from the landfills to contaminate groundwater, surface water and wetlands. This rating system is designed to evaluate waste disposal sites to protect groundwater from contamination. Four key hydrogeologic factors are considered. These are:

- distance to water supply (usually wells);
- depth to water table;
- hydraulic gradient;
- permeability - sorption as indicated by the geologic setting.

The range of LeGrand ratings is:

A - a probably acceptable site and operation;
B - probably acceptable or marginally unacceptable;
C - acceptance uncertain;
D - probably unacceptable;
F - almost certain to be unacceptable.

New Zealand has not adopted national standards for the evaluation, stabilisation, and remediation of landfill sites. However, broad based documents such as the "Proposed Guidelines for the Treatment of Sites Contaminated with Timber Treatment Chemicals," and the "Australian and New Zealand Guidelines for the

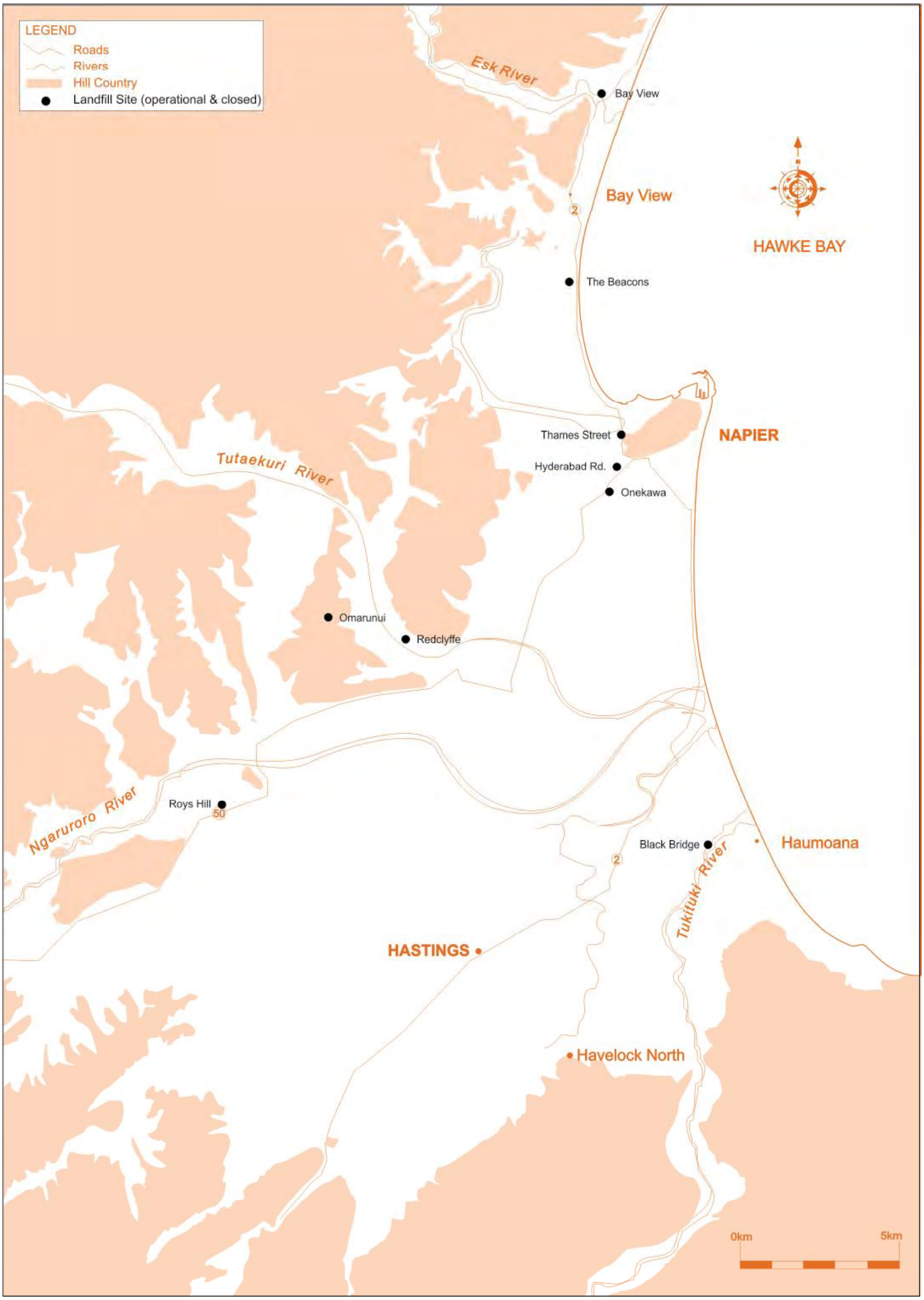


Figure 7.21: Locations of the Heretaunga Plains currently operational and closed landfill sites.

N m	L	r R .	y / r y	O r r	S	RC C ry	L r R
Omaranui	Omaranui	V21/365795	Pleistocene siltstone /limestone low hills and valleys	HastingsDistrict Council	Opened 1986	1a	C
Roys Hills	Fernhill	V21/319715	Gravel sand and siltalluvial plain	FormerHastings City Council	Opened ?Closed 1986	1a	F
Redclyffe	Taradale	V21/378768	Gravel, sand and silt river channel	Napier City Council	Opened ?Closed ?Transfer Station	1a	F
Bay View	Whirinaki	V20/439942	Gravel, sand and silt river channel	Former Hawke's BayCounty Council	Opened ?Closed ?	a	D
Black Bridge	Haumoana	V21/474703	Gravel, sand andsilt river channel	?	Opened ?Closed ?	1a	F
Onekawa	Onekawa	V21/443814	Lagoonal silt andbeach sand	?	?	a	C
Westshore	Westshore	V21/430878	Lagoonal silt andbeach sand	?	?	a	B

Table 7.7: Heretaunga Plains landfill and waste disposal sites.

Assessment and Management of Contaminated Sites," (ANZECC, 1992), provide a framework for the proper assessment and management of contaminated sites by Regional Councils. The final acceptance or rejection of a site for the intended purpose is the responsibility of the HBRC and may depend on special requirements or on feasibility of the site.

7.6.1 Omaranui Regional Landfill

Omaranui landfill is the regional landfill situated about 6 km west of Taradale, between Omaranui Road and Swamp (Moteo) Road, west of the Tutaekuri River, in an area of relatively gentle sloping hills rising to about 100 m. At the landfill site and its surrounds are outcrops of Pleistocene age siltstones and limestones. Test drilling shows siltstones and limestones underlie the site. These Pleistocene limestone and siltstones form an "island" in the Omaranui area, bounded in the west by the Moteo Valley (a former Tutaekuri River valley), in the northeast by the present Tutaekuri River valley, and in the south by the Heretaunga Plains and the Ngaruroro River. Limestone and siltstone underlies the valleys and extends to the south beneath the Heretaunga Plains and has the potential to form a groundwater flow path from the Omaranui area to the fluvial gravel aquifers of the valleys and the Heretaunga Plains aquifer system. Thick deposits of greywacke gravels form the flood plains of the surrounding Tutaekuri and Ngaruroro rivers, and infill the Moteo Valley to the west of the landfill site. Piezometric contours suggest groundwater flow in an easterly direction from the landfill area. In September 1990, ponding of leachate occurred following blockage of the leachate drain. The basal sealing layer failed to hold the ponded leachate and leachate leaked through the basal sealing layer (Dravid 1991b). Subsequent investigations included drilling three testbores to detect lateral and vertical leaks in the immediate vicinity of the refuse disposal area. During the drilling of these wells water circulation was lost on several occasions. The investigations concluded that preferential groundwater flow paths exist beneath the landfill and that investigations of groundwater quality in the vicinity of the landfill including a long-term comprehensive monitoring strategy for the Omaranui landfill is required (Dravid 1991b).

7.6.2 Roys Hill

This landfill is now closed but prior to 1986 all types of refuse was dumped at the site. The landfill is located between State Highway 50 and the Ngaruroro River on the Heretaunga Plains in the vicinity of Fernhill. The landfill is located on the historic (pre-1867) floodplain of the Ngaruroro River and is underlain by fluvial gravel, sand and silt. The river gravel and sand is very permeable and the water table seasonally fluctuates between 5 to 8 metres below ground level. The landfill site is on the northern side of the major recharge zone for the Heretaunga Plains aquifer system from the Ngaruroro River. Piezometric contours (Figs. 5.5 and 5.6) show that groundwater flows from the river, passing beneath the pit and heading towards Hastings (Dravid 1991a). The HBRC has a network of monitoring wells at and adjacent to the landfill and these are sampled frequently. So far no significant contamination has been detected. This may be a result of the high permeability of the aquifer and resultant dilution by the groundwater of any leachate present.

It might be worthwhile reviewing the positioning of the monitoring well network and the determinands analysed for in the regular analysis.

7.6.3 Redclyffe Transfer Station

This former landfill now operating as a transfer station, is located on the northern bank floodplain of the Tutaekuri River adjacent to Springfield Road about 3 km west of Taradale. The site is underlain by permeable river gravel and sand and silt. Leachate from the landfill is seeping to groundwater which is about 2 m below ground surface. Diluted leachate is seeping into the drain at the northern boundary of the landfill at the northeastern corner of the site. There may be wells adjacent to the landfill site which obtain water from the river gravel aquifer for domestic, stock and irrigation water supply. Although the hydraulic gradient and the direction of groundwater flow have not been established, there is a possibility that the groundwater flows beneath the landfill and intersects with the surface flow of the Tutaekuri River. It is necessary to formulate a comprehensive monitoring strategy involving surface water and groundwater adjacent to the refuse transfer station.

7.6.4 Bay View (Tait Road)

Although, the Bay View (Tait Road) landfill is outside the Heretaunga Plains, it is located on the peripheral unconfined aquifer of the Esk River valley and deserves brief description. This former landfill is located on the northern bank floodplain of the Esk River just upstream of State Highway 2 bridge. The landfill is located on a terrace about 2-3 m above the Esk River bed. The site is underlain by over bank river silt and permeable well sorted river gravel and beach gravel and coarse sand. The water table is 2-3 m below ground surface at river level. The hydraulic gradient and the direction of groundwater flow have not been established but the flow is likely to be to the east. It is necessary to evaluate the site and establish the need, if any, for groundwater monitoring in wells adjacent and downstream from the landfill site.

7.6.5 Black Bridge

This former landfill now operating as a transfer station is located on the northern (Clive) bank of the Tukituki River at Black Bridge, Mill Road at a former gravel excavation site, about 2 km from the Hawke bay coast. The site is underlain by permeable river gravel and sand, and beach and estuarine sand and silt. The water table is almost at ground surface. The hydraulic gradient and the direction of groundwater flow have not been established. It is necessary to evaluate the site and establish the need, if any, for groundwater monitoring in wells adjacent to the landfill site.

7.6.6 Other Former Landfill Sites

There are other former landfill sites (e.g. Onekawa and Westshore) within the Napier City boundary which although closed for refuse disposal for many years, may still warrant assessment for potential to contaminate groundwater because of the content of refuse. It is necessary to compile a list of all known historical landfills so that each site can be evaluated especially in terms of toxicity of refuse that could have been dumped.

7.6.7 Napier Gas Works Former Site

The Napier gas works site, located on Wellesley Road, Napier (V21/465825) was used over a number of decades for the manufacture of gas from coal. An adjoining area was also used for this purpose. The gas works site is underlain by beach gravel and a deep (>50 m) confined artesian aquifer. However, there are localised perched aquifers at shallow depth. An investigation undertaken in February 1994 involved the digging of a number of test pits from which soil samples were taken for analysis. The results indicated significant concentrations of chemicals and metals associated with the gas manufacturing process in soils at a number of places on the site. A second assessment was conducted during May 1994. The HBRC undertook drilling of 4 shallow (<4m deep) monitoring wells, followed by groundwater sampling. The HBRC monitoring wells confirmed the lateral extent of contamination of soil which extended down to a depth of about 2 m (Hudson & Porter 1995). Recommendations were made to investigate the vertical extent of contamination. Further investigation and monitoring work was undertaken by Pattle Delamore Partners Ltd, Auckland in 1995 and 1996. Two on-site and six off-site wells were sampled for total cyanide, total sulphur and semi-volatile organic compounds. The results suggested that semi-volatile organic compounds were present at, and only a short distance away from the site. It is proposed to continue sampling through 1997.

7.7 SUMMARY OF THE HERETAUNGA PLAINS GROUNDWATER QUALITY

Groundwater quality within the Heretaunga Plains has been discussed generally and in certain areas, in particular. Considerable variation in quality is apparent spatially, and the causes for these variations examined. Groundwater quality within the Heretaunga Plains aquifer is a function of numerous inter-related parameters, including:

- recharge water quality;
- geology;
- aquifer lithology;
- landuse;
- location;
- volumes and timing of abstractions;
- point sources of pollution.

Despite the variety and range of these parameters, the quality of the groundwater can usually be summarised quite simply:

- Groundwater underlying the Heretaunga Plains occurs in a multilayered leaky aquifer system with multiple sources of recharge including infiltration of rain.
- The quality of the bulk of groundwater in the Heretaunga Plains aquifer system is determined by the major source of recharge water, the Ngaruroro River and to a lesser extent, the Tukituki, Tutaekuri and Esk rivers.
- The original quality of the groundwater is determined by the major recharge sources and is modified by minor, but locally important sources of groundwater.
- These localised sources of groundwater recharge probably exert an influence on water quality that varies from season to season depending on groundwater abstraction. Normally high summer abstraction would result in deteriorating groundwater quality.

Spatial examination of the considerable data that are available indicates:

- Generally low mineralisation of groundwater in the central Heretaunga Plains area, corresponding to the area of maximum transmissivity within the aquifer.
- Slight increase in mineralistion of groundwater from recharge in the Roys Hill area east toward the coast related to increasing residence period (age) of groundwater within the aquifer system.
- Increasing mineralisation of groundwater in the main Heretaunga Plains aquifer south toward the Pakipaki, Pukahu and Havelock North areas, and north and west toward Napier and Poraiti are associated with increased residence period, and groundwater contributions from limestone and other sedimentary rock, forming the hills surrounding the Plains and underlying the Heretaunga Plains margins.
- In the southwest (in the Mangateretere - Havelock North area), complex structural and hydrogeological factors control the blending or mixing of groundwater derived from the Tukituki and Ngaruroro rivers and seasonal variation also appears to be a dominant factor.
- In the Moteo Valley, groundwater is derived from the Tutaekuri River as well as the limestone and siltstone hills surrounding the valley.
- In the Poraiti and adjacent hills area, groundwater quality in the limestone aquifer indicates a blend of the Ngaruroro River recharge and groundwater from the limestone hills.
- Groundwater in the Esk River valley is influenced by the quality of the Esk River, recharge from the limestone hills into which the valley is incised and saline intrusion at the coast.

Specific water quality problems do not appear to be a cause for concern for most of the Heretaunga Plains area. Specific areas where water quality issues need to be addressed include:

7.7.1 Unconfined Aquifer Area

- Landuse is changing rapidly, with new types of landuse emerging.
- Development is proceeding without the provision of full infrastructure, specifically reticulated stormwater and sewer systems.
- Reliance on septic tank systems and the unavoidable diffuse discharge to ground that results from general development may exert a noticeable and adverse influence on water quality in the main aquifer system.
- Activities and facilities that pose an identifiable risk of contamination, such as above and below ground storage tanks, manufacturing activities and risks that may result from road transport accidents, need to be recognised.
- While no hazardous material has been detected in groundwater flowing beneath the closed Roys Hill landfill site, the historical and current monitoring strategies of the site and other potential hazardous contamination sites, need to be considered carefully, particularly with regard to advances in analytical methodology and risk assessment.
- In the Ngatarawa Valley area, while the maximum concentrations of nitrate in groundwater appear to have declined from those observed historically,

persistently higher concentrations are observed relative to the main Heretaunga Plains system - specific monitoring needs to be undertaken to ensure that no health risk is posed either by nitrate or possible associated faecal contamination.

7.7.2 Southern Peripheral Aquifer Areas

- General water quality data indicates that the hills fringing most of the Heretaunga Plains provide a small but locally important sources of groundwater - the importance of these sources needs to be estimated more accurately.
- Impacts of landuse on the quality of this locally important water needs to be assessed more accurately through appropriate monitoring strategies.

7.7.3 Coastal Beach Gravel Aquifers

- Assessment of water quality data in the Esk River valley has indicated that saline intrusion adversely affects groundwater quality, particularly in the northern and southern extremities of the coastal zone.
- Improved and intensive monitoring is required for this area.
- Assessment of the results of this monitoring needs to be undertaken by the HBRC, Hastings District Council and Department of Health, with appropriate community involvement.
- The provision of alternate sources of water supplies should be considered.

7.7.4 Irrigation Drainage

- Limited monitoring of drain water quality in the main Heretaunga Plains area has revealed residues of commonly used herbicides, most noticeably in urban areas where such residues would not be anticipated due to landuse.
- Poor quality water draining from the horticultural areas of the Plains has been associated with water quality problems in the lower Clive River and the Ahuriri Lagoon.
- The relationship between irrigation water allocation, application and the fate of excess irrigation water needs to be investigated thoroughly and addressed through monitoring and policy.

7.8 ISOTOPE CHEMISTRY (By C.B. Taylor)

7.8.1 Conclusions and Questions arising from Isotopic Data

The concentrations of the hydrogen isotope tritium in groundwater provide valuable clues in distinguishing the old (pre-1953) and modern (post-1953) groundwaters. The concentration of the isotope oxygen 18 provide clues as to the origin and sources of groundwaters in hydrologic systems. Tritium and oxygen-18 have been measured for a limited selection of river water, groundwater and rain samples over the period September 1991 - February 1995 (Fig. 7.22). The isotopic concentration (tritium and oxygen 18) in the Heretaunga Plains groundwater has been monitored from 30 sites which are shown in Figure 7.22. Table 7.8 lists the location details of the Heretaunga Plains isotope monitoring sites together with the isotope content data.

Tritium concentrations are expressed as Tritium Ratios (TR) + 1 standard measurement error at the date of sample collection. TR =1 corresponds to a T/H ratio 10^{-18}. Oxygen-18 concentrations are expressed as the conventional - values, where ^{18}O is the difference between the ^{18}O/^{16}O ratio of the water sample and that of Vienna Standard Mean Ocean Water (V-SMOW); the experimental precision is about 0.1 in these units.

Prior to this sampling period, atmospheric tritium concentrations (rain and vapour) had declined from the bomb-peak years (1960s - 1970s) to a level which corresponds to the natural cosmic-ray level (about TR = 1.5) plus a small component of bomb tritium returned to the atmosphere by ocean evaporation. This is shown in Fig. 7.23 as the record of TR in precipitation at Kaitoke, near Wellington (mean annual values calculated over July - June). This record is considered to be relevant to the Hawke's Bay area. Tritium decays with a half-life of 12.43 years (i.e. by about 5.4% per year). The lower line indicates how much of this tritium has survived to the period of this study (taking January 1994 as a mean sample date). As an essential guide to the interpretation of the recent Hawke's Bay results, Fig 7.24 shows an expanded version of the decayed line of Fig. 7.23. TR values greater than 2 during this sampling period indicate a substantial component of the water precipitated during the bomb peak period. In contrast, TR values less than 2 contain components precipitated before 1960, and those less than 0.2 are predominantly pre-bomb water.

In the Hawke's Bay situation, some contrast is expected between the average concentrations of oxygen -18 in precipitation on the Plains and those of the major rivers (contributions of the water precipitated at the higher altitude in the hill catchments). Groundwater recharged from the rivers may be expected to show more

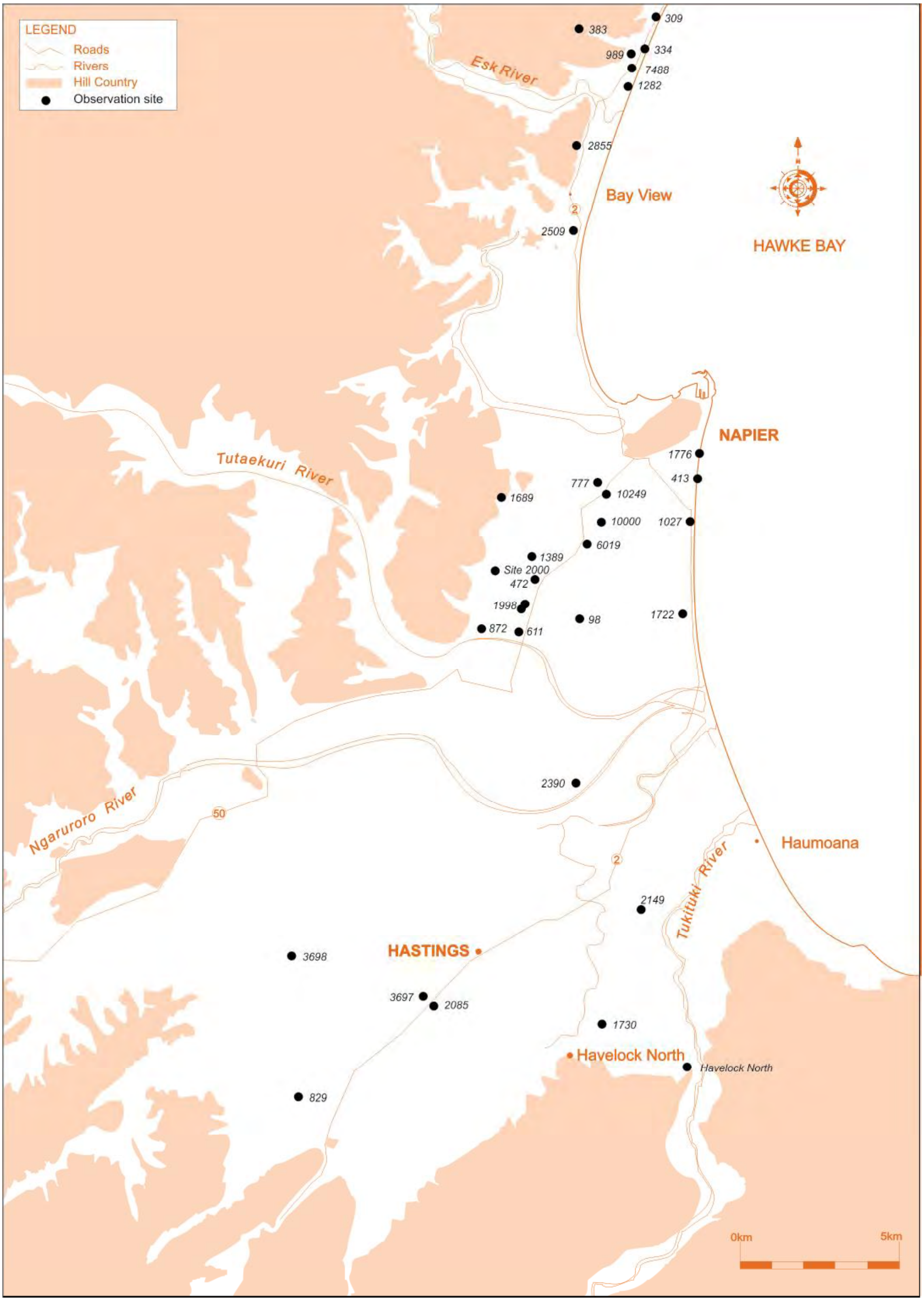


Figure 7.22: Location of the Heretaunga Plains isotope (tritium and oxygen 18) quality observation sites

Ar / L	S m Ty	r .R .	N .	(m)	S m	TR	m TR	18O
Rainwater @ Tukipo	Rain	U22/928324	n/a	n/a	24.02.93	2.04	0.09	-6.38
Ngaruroro River @Fernhill	River	V21/330728	n/a	n/a	08.12.94	3.14	0.11	-7.84
Ngaruroro River @Chesterhope	River	V21/426712	n/a	n/a	08.12.94			-7.22
Irongate Stream	River	V21/367667	n/a	n/a	24.02.93	3.01	0.1	
Raupare Stream.	River	V21/398714	n/a	n/a	24.02.93	2.62	0.09	
Tutaekuri River @Waiohiki	River	V21/396767	n/a	n/a	08.12.94	2.84	0.12	-7.75
Tutaekuri River @Puketapu	River	V21/356812	n/a	n/a	08.12.94	2.31	0.11	-7.4
Tukituki River @SH50	River	U22/965356	n/a	n/a	24.02.93	2.7	0.09	-7.34
Tukituki River @ River Rd	River	V21/469632	n/a	n/a	08.12.94	2.68	0.09	-6.85
Tukituki River @Black Bridge	River	V21/476702	n/a	n/a	08.12.94			-6.74
Flaxmere testbore	Groundwater	V21/343667	3698	51.8	09.09.91	1.64	0.1	
Flaxmere testbore	Groundwater	V21/343667	3698	81.9	24.09.91	1.4	0.09	-8.12
Flaxmere testbore	Groundwater	V21/343667	3698	96.3	21.01.92	3.62	0.1	-7.96
Flaxmere testbore	Groundwater	V21/343667	3698	108	??.01.92	3.57	0.11	
Flaxmere testbore	Groundwater	V21/343667	3698	125	03.03.92	3.62	0.12	
Flaxmere testbore	Groundwater	V21/343667	3697	125	22.09.92	3.29	0.16	
Tollemache Orch. testbore	Groundwater	V21/384654	3697	56	22.10.92	4.25	0.11	-7.54
Tollemache Orch. testbore	Groundwater	V21/384654	3697	77	04.11.92	3.79	0.11	-7.62
Tollemache Orch. testbore	Groundwater	V21/384654	3697	115	18.11.92	0.365	0.02	-8.19
Tollemache Orch. testbore	Groundwater	V21/384654	3697	122.5	24.11.92	0.011	0.014	-8.2
Tollemache Orch. testbore	Groundwater	V21/384654	3697	152	09.02.93	0.046	0.017	-8.19
Tollemache Orch. testbore	Groundwater	V21/384654	3697	163.5	16.02.93	0.048	0.018	-8.12
Tollemache Orch. testbore	Groundwater	V21/384654	3697	248	22.02.93	0.255	0.03	
Awatoto	Groundwater	V21/452744	3699	101	07.02.94	4.35	0.2	-8.14
Awatoto	Groundwater	V21/452744	3699	117	07.02.94	0.016	0.022	-8.4
Awatoto	Groundwater	V21/452744	3699	162	07.03.94	-0.01	0.016	-8.41
Awatoto	Groundwater	V21/452744	3699	245.3	14.09.94	0.039	0.02	
Awatoto	Groundwater	V21/465776	1722	70	24.02.93	0.909	0.054	-7.94
Awatoto	Groundwater	V21/441738	1450	46	10.03.94	4.23	0.11	-7.97
South Hastings	Groundwater	V21/388651	2085	37	09.02.93?	4.01	0.12	
Pakowhai	Groundwater	V21/422752	1702	68	10.03.94	4.24	0.11	-8.21
Pakipaki	Groundwater	V21/351611	Mixed	45	18.02.95			-7.57
Pakipaki?	Groundwater	V21/367628	1083	40.5	14.12.94	0.146	0.017	*
Pakipaki	Groundwater	V21/346-623	829	31.09	23.02.95	2.26	0.09	-7.11
Mangateretere	Groundwater	V21/453-682	2149	35.7	24.02.95	2.46	0.1	-8.07
Te Awange	Groundwater	V21/497675	1810	44	11.03.94	0.979	0.036	-6
Havelock North	Groundwater	V21/468632	1940	70	10.03.94	1.56	0.07	-6.57
Havelock Nth.	Groundwater	V21/468632	1940	66.4	15.12.94	1.45	0.11	-6.66
Havelock North	Groundwater	V21/443645	1730	36	24.02.95			-6.63
Haumoana	Groundwater	V21/491698	Mixed	60	18.02.95			-8.2
Napier/Meeanee	Groundwater	V21/435797	2390	64.3	18.02.95	3.04	0.12	-8
Meeanee	Groundwater	V21/436-774	46	52	24.02.95	3.93	0.16	-8.02
Greenmeadows	Groundwater	V21/408-813	1689	8.53	24.02.95			-6.9
Taradale	Groundwater	V21/415-778	1998	51.2	27.09.94	4.04	0.15	-8.05
Taradale	Groundwater	V21/411783	480	70	18.02.95	2.49	0.1	-8.06
Taradale	Groundwater	V21/419788	472	89.92	18.02.95	2.75	0.11	-8.02
Taradale	Groundwater	V21/419794	1389	41	18.02.95	2.55	0.1	-8.03
Taradale	Groundwater	V21/404772	872	42.85	18.02.95	3.12	0.13	-8.09
Taradale	Groundwater	V21/417779	1998	51.2	18.02.95			-7.94
Taradale	Groundwater	V21/399773	?	38	18.02.95	3.57	0.14	-8.09
Taradale	Groundwater	V21/414770	611	39.32	24.02.95	3.41	0.14	-7.96
Napier	Groundwater	V21/468827	1776	95	24.02.95	0.026	0.016	-8.1
Napier	Groundwater	V21/466805	1027	77.11	24.02.95	0.09	0.016	-8.19
Napier	Groundwater	V21/469819	413	85.34	24.02.95	0.054	0.014	-8.25
Napier	Groundwater	V21/465818	10035	83.8	18.02.95	0.062	0.016	-8.21
Napier	Groundwater	V21/436797	6019	49.7	18.02.95			-8.01
Onekawa	Groundwater	V21/440818	777	91.44	24.02.95	0.052	0.018	-8.3
Onekawa	Groundwater	V21/443814	10249	58.8	18.02.95	0.689	0.033	-8.15
Coverdale	Groundwater	V21/441805	10000	77.7	18.02.95	0.345	0.022	-8.18
Bay View	Groundwater	V20/437-938	3290	17	18.03.94	2.78	0.09	-6.37
Poraiti	Groundwater	V21/398829	3301	37	14.03.94	2.11	0.08	-6.86
Whirinaki	Groundwater	V20/453954	?	17	15.08.94	2.24	0.09	*
Whirinaki	Groundwater	V21/407790	?	c.25	23.09.94	1.34	0.02	*
Bayview	Groundwater	V20/435993	2047	10	24.08.94	0.016	0.019	
Bayview	Groundwater	V20/458967	3097	8.4	15.08.94			-4.47
Bayview	Groundwater	V20/454955	334	10.7	15.08.94			-6.59
Bayview	Groundwater	V20/447944	1282	10.05	15.08.94			-6.7
Bayview	Groundwater	V20/433-925	2855	14.6	23.02.95	2.03	0.09	-6.48
Whirinaki	Groundwater	V20/451-950	7488	11.5	24.02.95	0.707	0.035	-6.78
Whirinaki	Groundwater	V20/449-954	989	11.2	24.02.95	2.24	0.09	-6.67
Bay View	Groundwater	V21/432-989	2509	4	23.02.95	2.61	0.1	-6.94

Table 7.8: Heretaunga Plains isotope (tritium and oxygen 18) chemistry data

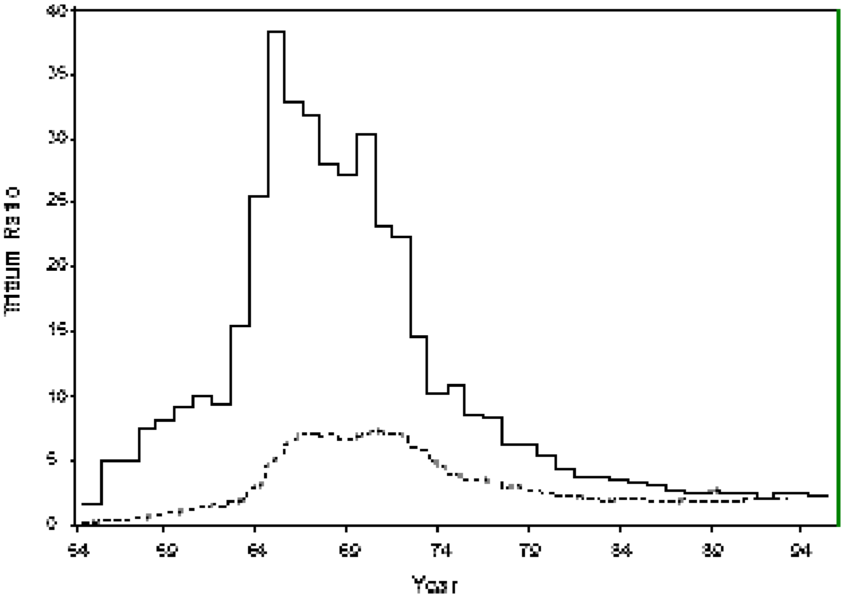


Figure 7.23: Tritium record in Kaitoke rainwater. Dotted line shows decay to January 1994.

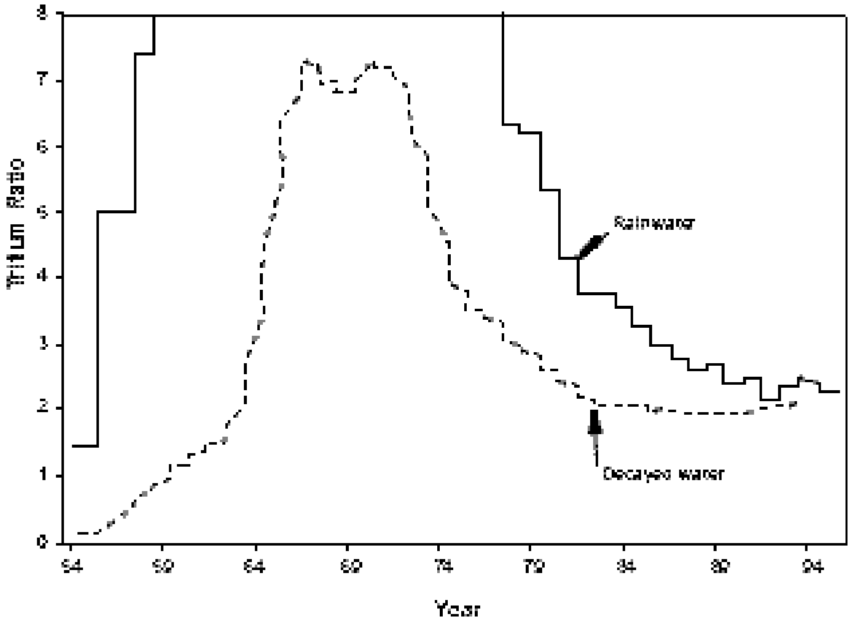


Figure 7.24: Tritium ratios in rainwater decayed to January 1994.

negative ^{18}O than that deriving from local infiltration of rainwater. Another contrast may be encountered in the shallow groundwater very close to the coast, where shallow groundwater may show less negative ^{18}O values due to seawater intrusion (which should be evident from chemical analyses)

Marked seasonal variation characterises ^{18}O of the New Zealand precipitation (sinusoidal on average, with summer maximum and winter maximum). From data at other New Zealand stations, it can be judged that the peak-to-peak average amplitude of ^{18}O on the Heretaunga Plains would be about 3, with that in the hill catchments of the major rivers being slightly greater. The geology of these hill catchments suggests that mean water retention time will be sufficient to reduce, but not completely smear out this seasonal variation; complete attenuation would require water retention time of a year or greater. The average ^{18}O of the rivers cannot therefore be judged from the very few results presently available. At the same time, the tritium data, which can be supplemented by some results from April 1970, confirms that water delivered by the rivers to groundwater on the Plains will have tritium concentrations closely matching the precipitation record shown in Fig. 7.23. 1970 results from Ngararuro, Tutaekuri and Tukituki rivers are a close match to the values measured at Kaitoke over that period. Similarly, the major river results for 4 December 1994 (Table 7.8) correspond quite closely to the Kaitoke rainwater values over the 3 months preceding these samples (Sept. 94, TR = 2.73 + 0.10; Oct; 94 TR = 2.63 + 0.11; Nov; 94, TR= 2.03 + 0.09). It may be concluded that water fed by the rivers to the Plains groundwater has tritium concentrations matching the record shown in Fig.7.23, but with smoothed ^{18}O values which represent river averages rather than those indicated by the very few river ^{18}O results in the Table 7.8.

The isotope results confirm the presence of the broad band of Ngaruroro-recharge water coastward of recharge areas between Maraekakaho and Roys Hill and at Fernhill, of which the latter appears the most important. This groundwater has ^{18}O in the range -7.9 to -8.4, which may be considered as an indicator of groundwater sourced mainly from this river. With some exceptions, confined water in a broad area between south Hastings and Napier shows tritium concentrations high enough to recognise that substantial components were recharged within the period of the bomb peak (1964-74). Flow velocities are thus rather slower than those estimated by Grant-Taylor & Taylor (1967) using tritium data for samples collected in 1957 from a series of shallower wells between Fernhill and the coast. The depth range of the recently sampled wells with bomb-peak water is 37 -125m.

The closest test bore to the Ngaruroro River is at Flaxmere, and this shows a marked anomaly. Whereas the deeper sampled levels (96-125m) showed the higher tritium concentrations discussed in the previous paragraph, those at 52m and 82m showed TR values (1.64 ±0.10 and 1.40 ± 0.09) which reveal the presence of the older water, i.e. a component recharged before 1964. Only the deeper of these two samples was measured for ^{18}O, revealing Ngaruroro River origin. Three possibilities are suggested by tritium anomaly: (a) both groups are recharged at Fernhill; lower permeability at the shallower depths slows the flow to Flaxmere compared to the deeper levels; the shallower flow is blocked coastward of Flaxmere; (b) the shallower group is recharged between Maraekakaho and Roys Hill, and the deeper group at Fernhill; (c) the reverse of (b). In view of the presence higher of TR values in the Hastings area (c) appears to be a more probable interpretation than (b).

The Awatoto test bore (at depth 99.5m) and another (depth 46m) in the area between the near- coastal Ngaruroro and Tutaekuri rivers both show the high tritium concentration evident at Flaxmere (depth range 96 -125m) and Tollemache Road (depths 56 and 77m). Further north, at Meanee and in several wells at Taradale, the groundwater to the north of both rivers has similar isotope characteristics to Ngaruroro-sourced water, but some of the Taradale wells shows TR in the range 2-3, which is noticeably lower than the high values at the other locations.

Another isotope anomaly occurs at the site of the Tollemache Road bore (south Hastings), where the two shallowest samples, although carrying the bomb-peak tritium signature, have rather less negative ^{18}O values (-7.54, -7.62) revealing inflow of water from another area, presumably the hill areas SW of Hastings. A shallow well (well 829, 31m) at Pakipaki had a tritium concentration (TR = 2.06 ± 0.09) implying very recent origin, with ^{18}O = -7.11. But slightly deeper water at Pakipaki seems to be more flow-restricted (well 1083, 40.5m TR = 0.146 ± 0.017) in combination with the ^{18}O value -7.57 at well 1761 (45m), appears to illustrate mixing of the main Ngaruroro-sourced body of groundwater with locally-sourced water at the system's southern margins.

The deeper samples at Tollemache Road have ^{18}O indicating origin from Ngaruroro River and predominantly pre-bomb origin. TR decreased to below detection limit at 125m but increased again at greater depths, reaching TR = 0.255 ± 0.030 at 248m, which implies a small amount of bomb tritium (assuming that the sample contains no drilling fluid). Close to the coast, in the south of Napier, low tritium concentrations were encountered at shallower levels (70-100m), while the deep samples at Awatoto are all below detection limit.

Only two wells were sampled for isotopes in the Havelock North area, both between the township and Tukituki River. The river samples are insufficient to judge the average river concentration, so one cannot infer that the two wells derive from the river. The ^{18}O values of these wells are very similar to those in the near-coastal wells at Bay View and Whirinaki (north of Napier), and are therefore probably indicative for groundwater recharge by precipitation in this area. The agreeing TR values for separate samples from well 1940 are less than the recent TR of the river, and indicate some contribution of the water from the period before the bomb peak.

^{18}O values in the range -6.4 to -6.9 are encountered at Havelock North and in the Bay View- Whirinaki wells north of Napier. At present it is unclear whether the more negative values in this range are indicative of recharge from Tukituki River (at Havelock North) or on the hills to NW of Napier (at Bay View and Whirinaki). Some of the Bay View-Whirinaki wells have TR indicating very recent recharge, but some (e.g. well 2047) have surprisingly low TR. Less negative $d^{18}O$ values (e.g. well 3097, Whirinaki; well 1810, Te Awanga) are likely to be caused by saltwater intrusion very close to the coast.

7.9 PROPOSALS FOR FUTURE MONITORING

Groundwater quality monitoring has been undertaken for the Heretaunga Plains aquifer system as part of a comprehensive and inter-related surface water and groundwater monitoring programme since July 1994. Currently a network of wells covering the Heretaunga Plains has been established for:

- Identifying and establishing monitoring objectives (monitoring programme design criteria).
- Establishing a monitoring network of groundwater sites which have been sampled using the same procedures (sampling requirements).
- Analysis of the same variables using robust, repeatable techniques with adequate quality control features (analytical requirements).

An excellent overview of spatial variation in water quality is beginning to emerge. To ensure the provision of good quality information all of the above requirements must continue to be met. It is recommended that the current monitoring programme be continued at least until 1998. The influence of hydrogeological, landuse and other factors is becoming apparent, and the real water quality issues are more obvious. This will provide information so that appropriate and robust policy can be firmly and defensibly established. Full assessment of the results of monitoring should be made before serious modifications are made to the programme.

Groundwater quality issues need to be resolved and good consistent quality information is required. The current monitoring programme should be expanded to address these issues. They include:

- Saline intrusion in the Esk River valley, particularly along the coastal strip at Whirinaki; possibly associated with localised bacteriological contamination of domestic water supplies.
- Saline intrusion in the southern area of the Plains, in the Haumoana - Clifton area.
- Nitrate contamination of groundwater in the limited recharge areas comprising the hill country fringing the main Heretaunga Plains.
- The impact of increased and intensified landuse development in the unconfined areas of the Heretaunga Plains on groundwater groundwater quality.
- Improved monitoring of the former Roys Hill landfill and at other operating or closed landfill and industrial sites which may be contaminated and where groundwater quality could be affected.
- the impact of excess irrigation water on surface water quality.

CHAPTER 8

CONCLUSIONS

8.1 GEOLOGY AND STRUCTURE

The Heretaunga Plains and southern Hawke's Bay (Fig. a) infill a basin (Heretaunga depression-Kingma 1970) about 150 km west of the converging Australian and Pacific plates at the Hikurangi subduction zone (Fig. 1.1).

The northeast-southwest oriented "basin and range" topography and faults of Hawke's Bay are the onshore products of the interaction of plates. Seismic surveys undertaken for groundwater exploration across the Heretaunga Plains from Bridge Pa to Pukahu suggest a 900 m deep basin structure with the deepest part below Bridge Pa (Fig. 4.4). Offshore oil exploration seismic surveys suggest that the basin structure extends at least 30 km off the Hawke Bay coast in a northeast direction (see 4.3.2). The Heretaunga depression and its infilling are a result of tectonic and sedimentation processes during the Quaternary (last 2 million years) with folding, thrust faulting, changes in sediment sources as rivers adjusted to tectonic processes, and sedimentation response to global climate cycles and related sea level changes. The sediments that infill the Heretaunga depression to form the Heretaunga Plains aquifer system are the product of depositional paleoenvironments influenced by glacioeustatic sea level changes in the range of a few metres above to 150 m below present sea level and subsidence of the basin at a rate of about 1 m/1000 years over the last 250 000 years (see 2.2, 2.3, 4.4 and Fig. 2.6).

8.2 HYDROGEOLOGY

Four distinct paleoenvironments have influenced sediment deposition to determine the aquifer, aquiclude and aquitard sequence underlying the Heretaunga Plains. Paleoenvironmental depositional processes resulted in:

- Reworked and redeposited fluvial gravel, beach gravel and marine and coastal margin sand and silt sediments, often containing interbedded shells and driftwood, deposited during temperate interglacial periods and associated high sea level.
- Gravel, sand and silt eroded from the hills and mountain ranges to the west, deposited by the Ngaruroro and Tutaekuri rivers mainly during cold glacial periods.
- At the end of the last glacial period about 14 000 years BP when sea level rose and the sea transgressed over the coastal land, shelly silt and sand sediments were deposited, while rivers reworked and redeposited gravel river channel deposits.
- About 6 500 years BP sea level stabilised at the present day level with the coast a maximum distance of about 12 km inland to the west of Hastings. The Heretaunga Plains have built out (prograded) from the inland marine transgression coast to the present coast. The sediments deposited were river channel gravel and sand (including pumaceous material), overbank silt, and beach, estuarine, lagoonal and coastal swamp deposits of gravel, sand, silt, clay, shell and peat.

The Heretaunga Plains aquifers are mainly the river floodplain gravel deposits, which have been reworked and redeposited by the rivers adjusting to fluctuating sea levels during glacial and interglacial periods of the last 250 000 years. Aquicludes and aquitards consist of marine and marginal marine silt, clay and shell deposits that accumulated during high sea level interglacial periods, overbank flood silt deposits, and poorly sorted floodplain gravel and silt. To the east of the former interglacial and postglacial sea level shorelines, sinuous gravel river channels and the intervening interglacial marine aquitards have been buried in the subsiding basin to form a complex interconnected layered aquifer system.

The Ngaruroro River has built up the central and southern part of the Heretaunga Plains, while the Tutaekuri River has mainly infilled the area from south Napier to Meeanee. The Tukituki River which has only flowed across the Heretaunga Plains in the last 20 000 years, degraded (entrenched into) the Plains when sea level was rising (to 6 500 years BP) and since then has reworked and redeposited gravel at the eastern part of the Plains.

The deep exploratory bores have provided new information on underlying strata which has been used in conjunction with well logs to draw geological cross sections correlating aquifers, lithologic and stratigraphic units. This information and geological mapping has provided a basis to broadly delineate an interconnected gravel aquifer system. A limestone aquifer system underlying the Heretaunga Plains adjacent to the western and southern margins of the Heretaunga Plains and peripheral floodplain and valley aquifer systems are also delineated. In total six aquifers are recognised as underlying the Heretaunga Plains and environs. These are:

- the Ngaruroro-Tutaekuri aquifer system or main aquifer system;
- the Tukituki aquifer system;
- the Moteo Valley aquifer system;
- Valley aquifer systems;
- the Esk (Whirinaki-Bay View) aquifer system;
- the peripheral limestone aquifer system.

The Ngaruroro - Tutaekuri main aquifer system, underlies most of the Heretaunga Plains and extends to explored depth (250 m) at Awatoto and Hastings. On the edges of the main aquifer system, shallow aquifer systems deposited by the Tutaekuri (Moteo Valley), Tukituki and Esk rivers can be delineated and there are shallow water table aquifers underlying the Ngaruroro and Tutaekuri river valleys, and their tributary valleys.

8.3 AQUIFER CHARACTERISTICS

8.3.1 Main Aquifer System

The main aquifer system is approximately 250 km^2 in area and is encountered by wells from Napier in the north to Bridge Pa, Pakipaki and Pukahu in the south, and from Havelock North and the Hawke Bay coast in the east, to Maraekakaho, Roys Hill and Taradale in the west (Fig. 5.1). The aquifer is unconfined in the west and becomes gradually confined to the east. The unconfined aquifer is formed of heterogeneous deposits of coarse to fine fluvial gravels and sands, with localised lenses and layers of siltbound gravels. The thickness of the unconfined aquifer is at least 137 m at the unconfined-confined aquifer transition area in the Flaxmere deep exploratory testbore.

Infiltration of Ngaruroro River surface flow occurs into former river channels underlying the western sector of the Heretaunga Plains. A major recharge zone occurs between Roys Hill and Fernhill and a minor recharge zone occurs from Maraekakaho to Roys Hill towards Ngatarawa and Pakipaki. The groundwater infiltrates into the unconfined aquifer, and then the confined aquifer. The continuous water level data suggest that the amount of water infiltrating into the groundwater system depends upon the river levels at the recharge zone and groundwater levels. In the central parts of the Heretaunga depression where many river channels have been buried, interconnections between channels facilitate recharge to the deeper parts. Gradual decrease in piezometric pressure with depth beneath the inland Plains indicates a leaky aquifer system. The increase of piezometric pressures with depth at the Awatoto coast suggests partly confined deeper aquifers with limited offshore extension and possible upward vertical recharge.

Heretaunga Plains piezometric contour maps (Figs. 5.5 and 5.6) shows that groundwater generally flows from the Ngaruroro River towards the southeast but near the coast moves in an easterly to north easterly direction out under Hawke Bay.

Transmissivity provides a measure of the capability of the aquifer to transmit groundwater throughout its full thickness. High transmissivity equates with high yielding wells. The transmissivity contour map (Fig. 5.4) of the main aquifer area shows:

- Highest transmissivities of >20 000 m^2/day are recorded in the central part of the main aquifer system beneath Hastings.
- Zones of high transmissivities (>20 000 m^2/day) in the central area of the aquifer system are aligned along former channels of the Ngaruroro River and the major recharge zone.
- The channels of the minor recharge zone have relatively low transmissivities (<5000 m^2/day).
- Zones of very low transmissivities occur adjacent to the southern and western foothills and at the coast from Haumoana to Te Awanga.
- Yields are low near Havelock North with measured transmissivities of 200 to 2000 m^2/day.

The Tollemache Orchard and Awatoto exploratory testbores suggest a multilayered leaky deep (>250 m) aquifer system interconnected to the Ngaruroro River recharge zone. The Awatoto testbore penetrated six flowing artesian aquifers to a depth of 254m. The Ngaruroro River recharged aquifer system may extend beyond this depth but the combination of low permeability and difficult drilling conditions make it unlikely that production water wells would ever be drilled deeper than 200 m.

The Flaxmere exploratory bore log shows that the saturated gravels extend to a depth of at least 137 m. Based on a measured porosity of gravel near Roys Hill of 0.22

(Thorpe 1977) and the extent of the major recharge area (30 km^2), the volume of groundwater stored in the major recharge area is about 900 million cubic metres. The total area of minor recharge is about 15 km^2. Aquifer pump tests suggest relatively low transmissivity ranging from 200 - 2000 m^2/day and an average specific yield of 0.15 in the minor recharge area. Based on this hydraulic information, the total volume of groundwater stored in the minor recharge area is estimated at 90 million cubic metres. Aquifer tests undertaken in the confined aquifer area suggests a transmissivity range of 2000 - 15000 m^2/day and a storativity of 1×10^{-3} to 1×10^{-4}. Based on a thickness of 200 m and an aerial extent of 300 km^2 (includes an offshore extension of the aquifers of 150km^2), an estimate of the total volume of water stored in the confined aquifer is 60 million cubic metres. The total volume of water stored in the main aquifer system is estimated at 1050 million cubic metres. This is about 17% of the volume of water stored in Lake Waikaremoana (Dravid & Brown 1995).

8.3.2 Peripheral Aquifer Systems

8.3.2.1 Moteo Valley Aquifer System

The Moteo Valley area, which was formerly occupied by the Tutaekuri River, extends south from the present Tutaekuri River valley upstream of Puketapu to near Fernhill on the Heretaunga Plains. The following summarises occurrance of groundwater in the valley:

- Well logs suggest two distinct water bearing gravel aquifers underlie the valley. There is a shallow 3 to 6 m thick subartesian aquifer underlying 5 m of clay, silt and peaty material, and a deep (>15 m depth) artesian aquifer underling soft mud and clay.
- The Moteo Valley gravels are hydraulically interconnected to the Tutaekuri River. Losses from the Tutaekuri River are in the order of 0.8 m^3 between Silverford and Puketapu.
- Piezometric contours of water levels in the Moteo Valley suggest a general movement of groundwater down the valley from the Tutaekuri River and onto the Heretaunga Plains where it contributes to the flow of the Tutaekuri - Waimate Stream. The shape of the contours also suggest that groundwater is derived from the surrounding mudstone-limestone catchments into the Moteo Valley.
- Pump tests undertaken on the wells tapping the Moteo Valley aquifer system suggests unconfined to semiconfined aquifer condition and a storativity of 0.015.
- The total volume of groundwater stored in the Moteo Valley aquifer system is about 2 million cubic metres.

8.3.2.2 Tukituki Aquifer System

At the eastern coastal margin of the Heretaunga Plains, the Tukituki River contributes water to a shallow semiconfined to confined aquifer system underlying its floodplain and interbedded with and overlying the main aquifer system. The terrace east of the Mangateretere-Havelock North Road is at about the western limit of the Tukituki River floodplain and aquifer system. The Tukituki aquifer system is about 20 km^2 in area. The river flow gaugings on the Tukituki River between Red Bridge and Black Bridge suggest losses from the river in the range 0.63 to 1.34 m^3/s. Geological cross sections suggest that between 25 and 50 m depth, the Tukituki and the main aquifer systems merge and there is a mixing zone of the respective groundwater. Pump tests undertaken on the main aquifer system at 50 m depth suggest leaky conditions with a high transmissivity in the order of 10 000 to 25 000 m^2/day.

Higher piezometric pressures in the deeper main aquifer system generally prevent seepage from the shallow low pressure Tukituki aquifer system. During extended drought and peak summer abstraction periods, piezometric pressures in the main aquifer decline due to increased abstraction from the groundwater storage coinciding with minimum recharge. When the main aquifer groundwater piezometric pressures decline below those of the overlying Tukituki aquifer system, a reversal of hydraulic gradient occurs and mixing of groundwater from the interbedded aquifer systems takes place. Piezometric levels suggest that the direction of groundwater movement is from west to east rather than directly to the sea in a northeasterly direction. The total volume of groundwater stored in the Tukituki aquifer system is estimated to be about 6 million cubic metres.

8.3.2.3 Valley Aquifer Systems

Before the Ngaruroro and Tutaekuri river courses cross the Heretaunga Plains their river valleys and adjacent flood plains and tributary valleys are underlain by shallow (<15 m depth) gravel aquifers hydraulically interconnected to the river.

8.3.2.4 The Esk (Whirinaki - Bay View) Aquifer System

A coastal predominantly beach gravel and sand aquifer extends along the tombolo from Scinde Island to Bay View and across the Esk River to the Whirinaki area.

The system is mostly unconfined in the coastal area and becomes progressively confined inland from the coast where it is interbedded with river silt, sand and gravel deposits. Most coastal wells are less than 15 m depth and the static water level fluctuates with tides and is generally around 4 to 6 m below the ground level.

8.3.2.5 Peripheral Limestone Aquifer System

The peripheral limestones that forms the hills on the southern and western margin of the Heretaunga Plains also contains groundwater. The following summarises occurrance of groundwater in the peripheral limestone:

- Test pumping has shown the average transmissivity of the limestone aquifers is in the order of 90 to 250 m^2/day and storativity in the order of 2.2 x 10^{-3} to 1 x 10^{-4}, which suggests confined condition.
- The piezometric contours of the water levels in the Poraiti area (Fig. 5.40) suggests that the direction of groundwater flow is towards east.
- The static water levels range from 1 m to 25 m below ground level. Continuous water level data suggests a seasonal fluctuation from 3 m to 25 m depending on the location and the depth of the bore. Water levels fluctuate in response to rainfall with the main recharge being during the winter months.
- Recharge to the peripheral limestone aquifer system is by direct infiltration of rainfall and runoff.
- Isotope (tritium) data analysis suggests a component of older (>50 years) groundwater is present in the limestone aquifer system reflecting long-term slow circulation of groundwater in parts of the aquifer.
- The groundwater storage of the limestone aquifers on the western margins of the Heretaunga Plains is estimated at 12.5 million cubic metres, based on average porosity of limestone of 0.05 and the total thickness and area of the western peripheral limestone to be about 25 m and 10 km^2 respectively.
- The estimated groundwater storage of the limestone aquifers on the southern margins of the Heretaunga Plains is estimated at 7.5 million cubic metres, based on an area of 15 km^2, average porosity of 0.05 and thickness of 10 m.

8.4 GROUNDWATER BALANCE

8.4.1 Input

8.4.1.1 River Infiltration

Ngaruroro River

Streamflow measurements have established that for the Ngaruroro River residual flows of up to 35 m^3/s:

- The major recharge reach (Roys Hill - Fernhill) contributes a constant 4.2 m^3/s to the groundwater system.
- 0.8 m^3/s is contributed by the minor recharge reach (Maraekakaho - Roys Hill).
- For river flows greater than 35 m^3/s, the rate of recharge is likely to be higher but can not be quantified.
- The Ngaruroro River contribution to the aquifer is estimated as 5 m^3/s (157.7 million cubic metres/ year).

Tutaekuri River

Low flow river gaugings on the Tutaekuri River show:

- Flow loss of 0.82 +/- 0.28 m^3/s between Silverford and Puketapu.
- The Tutaekuri River contribution to aquifer is estimated as 0.8 m^3/s (25.2 million cubic metres/ year).

Tukituki River

Tukituki River gaugings show:

- A loss of river flow in the order of 2.7 m^3/s between Red Bridge and the Black Bridge.
- A loss of river flow in the order of 1.3 m^3/s between Tennants Road and Red Bridge.
- The Tukituki River recharges a relatively shallow unconfined to semiconfined aquifer and spring flows but does not make a significant contribution to the main aquifer system.

8.4.1.2 Rainfall Infiltration

Simulation studies of rainfall infiltration to groundwater through the unconfined aquifer area suggests 5 million cubic metres/year of rainfall recharge occurred for 1994/95.

8.4.1.3 Artificial Recharge

From July 1994 to June 1995, the artificial recharge system has operated intermittently at variable rates ranging between 500 to 1000 litres/s. The period of operation and the corresponding discharge rates were not recorded and it is estimated that from July 1994 to June 1995, artificial recharge operated for about 7 to 10 days at a median discharge of 500 l/s. The efficiency of artificial recharge has not been studied adequately. For the Heretaunga Plains water balance estimation, the artificial recharge input is minimal and hence ignored.

8.4.2 Outputs

8.4.2.1 Abstractions and Outflows

Urban water supply
From July 1994 to June 1995 the total quantity of groundwater abstracted for Napier, Hastings and Havelock North urban water supply was about 24.1 million cubic metres, and about 2 million cubic metres of groundwater was abstracted for rural domestic supply.

Industrial water supply
From July 1994 to June 1995 period about 11 million cubic metres of groundwater was abstracted for industry. Industry is predominantly meat, fruit and vegetable processing and water use is at a maximum during the January to March period, often with peak industrial water demand occurring in January.

Irrigation water supply
From July 1994 to June 1995 the total quantity of groundwater abstracted for irrigation purposes was about 23.9 million cubic metres, with an estimated further 2 million cubic metres for frost protection.

Shallow groundwater (dewatering) abstractions
Pumping stations operated by the HBRC, abstracted about 3 million cubic metres of groundwater from shallow water table aquifers for the Heretaunga Plains coastal and inland dewatering during July 1994 to June 1995 period.

Outflow from Springs and Spring-fed Streams
This is the largest (natural and pumped) of all outputs from the main aquifer system. The Heretaunga Plains important spring-fed streams and creeks include the Tutaekuri-Waimate Stream, Raupare Stream, Mangateretere Stream, Irongate Stream and the Karamu Creek. The Tutaekuri-Waimate Stream derives water from both the Ngaruroro and the Tutaekuri rivers with the larger proportion of flow derived from the Ngaruroro River upstream of Fernhill. The Ngaruroro River recharged groundwater contributes a mean summer flow of 2.1 m^3/s to the Tutaekuri-Waimate, 0.4 m^3/s to the Raupare, 0.3 m^3/s to the Irongate and 0.68 m^3/s to the Karamu streams. The Karamu Stream also receives about 0.72 m^3/s of excess irrigation drainage during summer along its course between Havelock North and the outlet at Floodgate. The Mangateretere Stream derives its water from the Ngaruroro and the Tukituki rivers. In a typical summer, it is estimated that the recharge component to the confined aquifer is about 1.9 m^3/s whereas the spring flow (overflow) component is about 2.1 m^3/s.

Outflow from Offshore Springs
It has not been possible to locate submarine outflow from the freshwater springs offshore from the Heretaunga Plains in Hawke Bay.

8.4.3 Summary of Groundwater Balance

Figure 6.16 graphically illustrates the Heretaunga Plains groundwater balance. The aquifer inputs and outputs for the year July 1994 - June 1995 are given in Table 8.1.

INPUT (m^3/yr x 1000000)		**OUTPUT (m^3/yr x 1000000)**	
SOURCE	**INPUT**	**SOURCE**	**INPUT**
Ngaruroro River	157.7	Public Water Supply	24.1
Tutaekuri River	25.2	Rural Domestic	2
Rainfall	5	Industries	11
		Irrigation	23.9
		Frost Protection	2
		Drainage Dewatering	3
		Total Pumped	***66.00***
		Spring Leakage	119.8
		Submarine Outflow	unknown
		Total natural	***119.8***
TOTAL	**187.9**	**TOTAL**	**185.8**

Table 8.1: Heretaunga Plains July 1994 - June 1995 groundwater balance

Due to many uncertainties involved in estimating aquifer inputs and outputs and the unknowns in th water balance equation, the current water balance will require ongoing refinement as more accurate information is collected in the future. The water balance equation shows a difference between inputs and outputs that would be equal to the change in storage. Although there is a seasonal change in groundwater storage (summer depletion - winter recovery) there is no evidence for long-term change in groundwater storage.

8.4.4 Groundwater Allocation

Over the last decade, irrigation has become an increasingly important component of the Heretaunga Plains horticulture and agriculture. 92 % of total water use consents in the Heretaunga Plains are for irrigation purposes (Tim Waugh, HBRC, pers. comm. 1995). About 80 % of the total allocated quantity of groundwater is used for irrigation.

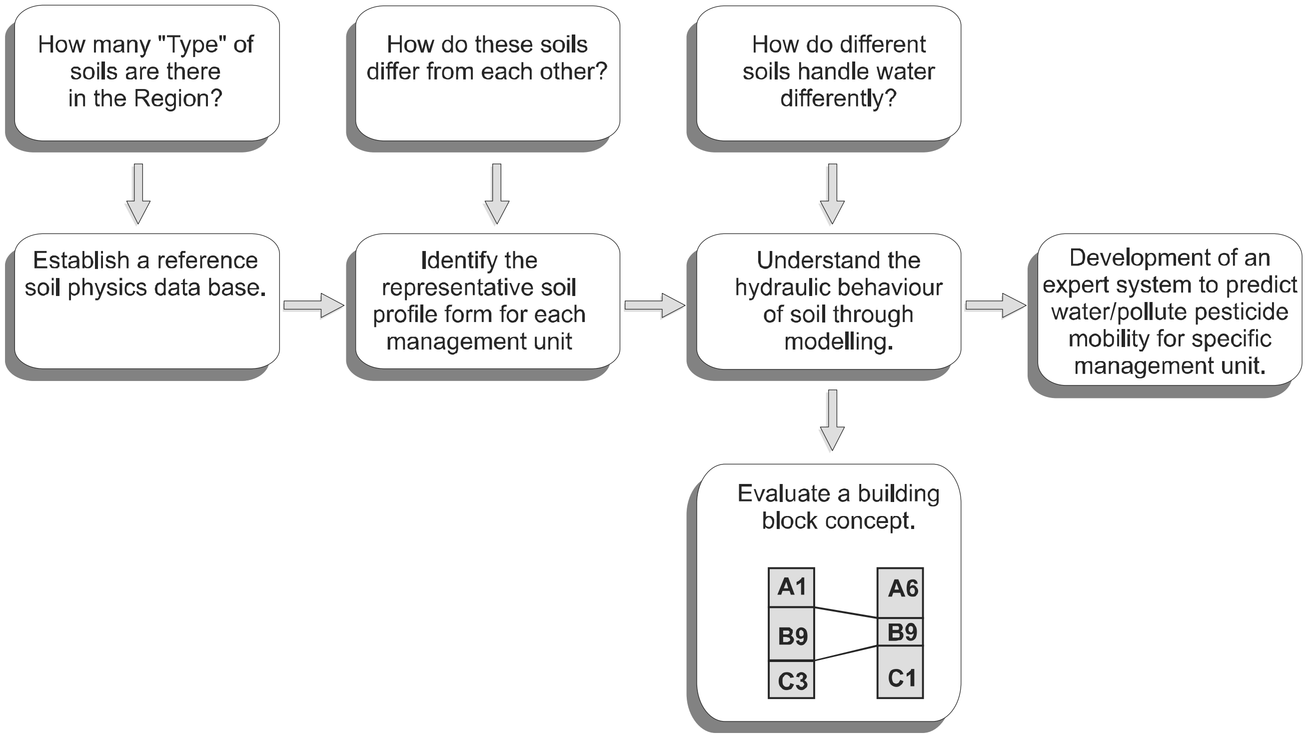
Under the Resource Management Act 1991, users of groundwater on the Heretaunga Plains for all purposes other than reasonable domestic requirements of individual households, and stockwater drinking must obtain a water permit from the HBRC. While groundwater requirements for industrial and water supply purposes are able to be estimated based on the specific demand, irrigation water requirements are difficult to quantify due to variable soil hydraulic properties and different crop-specific water requirements (Fig. 8.1). Currently the Heretaunga Plains irrigation water assessments are based on a perceived water-need of a crop as 65 mm/hectare/fortnight. The present irrigation water allocation policies does not take into account considerations such as land and soil to accept, store, and transmit water, the water need of a crop, and the water application and management system used.

Under the present procedures the "appropriateness" of an irrigation water take consent to a specific soil, a specific crop, and a specific management is not practiced by any authority in the country (Beanland et al. 1994, Dravid et al. 1995b and Watt et al. 1993 and 1995). The Hawke's Bay irrigation water allocations are currently defined on the basis of an assumed evapotranspiration equivalent of 6.5 mm/day/hectare applied on an area basis. The Heretaunga Plains estimated irrigation water use during the year July 1994 - June 1995 was 3 million cubic metres. Based on the current irrigation water allocation criteria and a total irrigated area of 10 000 hectares (one third of Heretaunga Plains), the total volume of irrigation water allocated over the 4 month (mid-November - mid March) irrigation period becomes 56.8 million cubic metres. This volume is more than double the estimated irrigation water use for July 1994 - June 1995 period. This suggests that not only is groundwater allocated in excess of use, but actual use may be excessive to irrigation requirements and may be affecting surface waters.

A crop-specific irrigation water allocation method is currently under investigation (Watt et al. 1996)

8.5 IRRIGATION DRAINAGE

Typical summer flow patterns along the Karamu Stream suggest runoff of excess irrigation water in the order of 0.7 cubic metres/second into the stream from the adjacent Plains area. Nutrient enrichment and the associated weed growth in the recent years within the Heretaunga Plains streams and drains suggests nutrient and fertiliser leaching through the soil by way of excess irrigation. Any improvement in irrigation efficiency is a "plus" in terms of reduced energy costs, reduced through flow to depth, reduced leaching, and reduced pesticide pollution.



8.6 CHEMICAL AND ISOTOPE QUALITY OF AQUIFERS

8.6.1 Chemical Quality

The quality and extent of historical data that exists for the Heretaunga Plains aquifer system is less than ideal in a number of respects. When considered as a whole, however, the chemical characteristics of the groundwater system begin to emerge. Groundwater quality can be summarised as follows:

8.6.1.1 Major Recharge Zone

The quality of the major recharge determines the overall quality of the groundwater system. The Ngaruroro River is characterised by generally good water quality, with:

- Consistently low concentrations of dissolved salts, and as a result, low electrical conductivity values.
- Salinisation of the source water is not considered an issue.
- Nitrate concentrations are generally low, with a median concentration of 0.1 mg/l, which is less than 1/100th of the New Zealand Drinking Water Standard concentration.
- The quality of water in the unconfined region of the aquifer is dominated by the quality of the recharge water.
- Limited impact due to specific landuse activity (particularly the Roys Hill landfill) is apparent and has been occurring for a number of years.
- High porosity and transmissivity of the aquifer ensure rapid and consistent dilution of leachate from the landfill and contaminants from other landuse activities in the unconfined area of the aquifer.
- While the data are not entirely adequate for the purpose there is no indication at present of decreasing quality down-gradient of the area of major recharge.

8.6.1.2 Minor Recharge Zone

Groundwater quality in the minor recharge zone is also subject to the impact of landuse activities. While there is limited evidence to indicate decreasing quality over the period that monitoring has taken place, this needs to be confirmed through an appropriate future monitoring programme.

Spatial change in the quality of water in the minor recharge area is apparent - groundwater quality issues associated with landuse (including on-site sewage disposal) need to be given careful consideration to ensure that future water quality deterioration does not occur.

Bacterial quality in the area should definitely be included in future monitoring activities.

8.6.1.3 Central Heretaunga Plains Area

The central area of the Heretaunga Plains aquifer system is also characterised by water of excellent quality, requiring no treatment for a large variety of domestic, industrial and agricultural uses. Groundwater quality is characterised by:

- low concentrations of dissolved chemical constituents;
- limited seasonal difference in quality;
- limited variability in quality with depth in the uppermost layers of the aquifer system.

As a result, users of water have access to a reliable supply of consistently good quality water , requiring no treatment prior to use. The relatively shallow depth and ease of access to the groundwater has greatly encouraged development in the region.

While no deterioration in quality is evident from the data currently available, the importance of the resource should be recognised and safeguarded through implementation and maintenance of an appropriate on-going monitoring programme.

8.6.1.4 Northern Fringe Area

The data available at present indicates a limited and localised impact on the quality of water in this area due to the recharge contribution from Tertiary age limestone, siltstone and sandstone strata forming the adjacent hill country to the west. While this impact is associated with increased hardness and mineralisation of water, this has not restricted groundwater use. On-going monitoring should be implemented to ensure that the localised water quality problems that exist in the Poraiti and western hills area do not encroach into the major aquifer system, and affect the quality of water used by Napier.

8.6.1.5 Western and Southern Fringe Area

Considerable localised impairment of water quality is evident in this area. While the impact of stratigraphy and geological structure is central to the impairment observed, the role of landuse cannot be discounted. Increased concentrations of nitrate indicate a probable impact of landuse on water quality - this needs to be quantified through implementation of an appropriate monitoring programme. Future monitoring should also have as an objective identifying the role of the Tukituki River system in the hydrogeology of the southeast part of the groundwater system.

8.6.1.6 Esk River Valley Area

The quality of water in this area is cause for immediate concern, with considerable temporal and spatial variability of groundwater quality. While intrusion of sea water into the localised aquifer system is the major and most readily apparent groundwater quality problem, localised water quality problems due to on-site effluent disposal cannot be discounted. Both problems pose significant human health issues, which deserve implementation of a comprehensive monitoring programme aimed at establishing the extent of the problem. The scale of the problem demands involvement of all relevant agencies.

The trends in quality of groundwater observed across the Heretaunga Plains aquifer system have been consistent with geological and structural evidence. The benefits of an integrated consideration of all resource data have been revealed by this inter-disciplinary investigation. The role of future water quality monitoring in the on-going management of the system should not be ignored. It provides the only effective method of ensuring that existing and future landuse and abstractive uses of groundwater do not adversely affect water quality. The role of pro-active monitoring in responsible management of this unique water supply must be recognised by both Regional and Territorial Local Authorities.

8.6.2 Groundwater Isotopic data Applications

Groundwater isotope analyses are listed in Table 7.8. The oxygen 18 analyses suggest that the Ngaruroro and Tutaekuri rivers are the main groundwater recharge source for the Heretaunga Plains aquifer system. It is not possible to separate the Ngaruroro River from the Tutaekuri River on the basis of the $\delta^{18}O$ values. Other data including groundwater chemistry, piezometric contours, water level fluctuations and river flow gaugings confirm that the Ngaruroro River is the primary recharge source with the Tutaekuri River relatively unimportant by comparison.

The Tukituki River water is distinct with less negative $\delta^{18}O$. This allows groundwater with a component of Tukituki River recharge to be recognised in wells (well nos. 1810 and 1730) on the floodplain at the eastern margin of the Heretaunga Plains adjacent to the Tukituki River.

North of the Heretaunga Plains aquifer system northern limit (Tamatea, Onekawa, Pandora), groundwater in shallow wells and in wells penetrating limestone aquifers is derived from coastal rain. Further north at Whirinaki adjacent to the Esk River floodplain, local rainfall and seepage from the Esk River contribute to groundwater recharge.

Grant-Taylor & Taylor (1967) report tritium concentrations from the Heretaunga Plains aquifers which include an estimate of travel time for the shallow confined artesian aquifer at Clive of 7 years since the water seeped into the groundwater aquifers from the Ngaruroro River recharge area near Fernhill. The groundwater samples collected from various depths in the Tollemnache Orchard and Awatoto exploration bores as they were drilled, show a significant aging and longer travel time for the deeper groundwater compared with the shallow groundwater. This suggests that the groundwater flow through the upper confined aquifers is faster than the flow through the deeper aquifers supporting the concept that only the upper gravel aquifers outcrop on the sea floor and discharge fresh water into the ocean through the springs in the Hawke Bay sea floor. The groundwater chemistry and isotope characteristics of the deeper aquifers suggest these aquifers are “blind” without a direct offshore outflow in Hawke Bay (Fig. 2.25). Groundwater flow through the deep aquifers can only be attained as a result of extraction of groundwater from wells and by upward leakage through aquitards and aquicludes into the shallower last glaciation and postglacial gravel aquifers.

TR’s for groundwater in the wells tapping postglacial and last glaciation gravel confined aquifers at the Heretaunga Plains margin (Napier, Te Awanga, Mangateretere, Havelock North and Pakipaki) also show a mixing of pre-1955 groundwater. This may be a symptom of the aquifer response to the increasing groundwater abstraction over the whole Heretaunga Plains aquifer system and indicate groundwater derived from deeper aquifers and possibly interconnected other aquifer systems (e.g. limestone).

Groundwater in the unconfined sector of the aquifer system is post-nuclear as is groundwater in the post-glacial-last glaciation confined aquifer adjacent to the unconfined - confined aquifer boundary (Fig. 5.1) at Taradale, Pakowhai, Flaxmere, Pakipaki. Postglacial and last glaciation gravel confined aquifers in the high transmissivity central sector of the Heretaunga Plains aquifer system also show a predominance of post-nuclear groundwater. This is the Meeanee, Awatoto, Clive, Whakatu and Hastings areas and provides further confirmation of a highly permeable aquifer with an offshore outflow and virtually unimpeded recharge of abstracted groundwater from the unconfined sector of the system and the Ngaruroro River.

TR's of groundwater from wells to the north (Bay View and Whirinaki) of the Heretaunga Plains aquifer system do not show any distinct trends related to site location or aquifer lithology or depth. The groundwater in this area is derived from coastal rain and seepage from the Esk River. The TR's show groundwater is a mixture of pre-nuclear and post-nuclear groundwater although there are two shallow wells (Well nos. 2047 and 7488) at Bay View and Whirinaki with groundwater sourced from predominantly pre-nuclear precipitation. The Bay View -Whirinaki aquifers are the product of changing geological processes and environments (fluvial, lagoonal and beach environments) influencing sediment deposition and reworking. As a result permeabilities and groundwater flow rates vary over short distances due to lithology changes. The postglacial - last glaciation heterogeneous aquifer system overlies early Pleistocene limestone, siltstone and mudstone sedimentary deposits. Upward percolation of groundwater from these underlying sediments (especially limestone) may be occurring.

Figure 8.2: Oil spill on the Heretaunga Plains unconfined aquifer. *(photo: Terry Jamieson, HBRC)*.

Figure 8.3: Heretaunga Plains near Bridge Pa showing dry conditions, January 1995.
(photo: Lloyd Homer, IGNS CN 34155b).

CHAPTER 9

MANAGEMENT OF GROUNDWATER

9.1 BACKGROUND

Since the first successful artesian well was drilled in 1867 there have been a number of changes of attitude towards the groundwater resources of the Heretaunga Plains which have resulted in many investigations and changes of management strategies. Twenty years ago, groundwater management was directed towards the exploitation of the resource without consideration of possible environmental consequences. Today the management emphasis is on sustainable development, protection and conservation.

The objectives of the Heretaunga Plains Groundwater Study were designed to quantify the “safe yield” of the aquifers, and identify potential risks to the quality of groundwater. The safe yield is the quantity of groundwater that can be abstracted from the aquifers for a prolonged period without over-extracting or “mining” the groundwater and causing undesirable consequences. Mining results in continuous and/or permanent lowering of groundwater levels which may result in:

- Interference between production wells resulting in a decline in well water levels and therefore a reduction in the quantity of water that can be abstracted.
- Damage to the physical structure of the aquifer (e.g. compaction of gravel) causing a permanent reduction in the water-bearing capability of the aquifer, and also land subsidence.
- Excessive drawdowns adjacent to another water resource that is hydraulically connected to the aquifers, resulting in an inflow of the other water (e.g. poorer quality groundwater from the peripheral limestone aquifers).
- A landward shift of the seawater/freshwater interface and intrusion of salt water into production wells.
- A reduction in the piezometric level in an aquifer and reversal of the present upwards hydraulic gradient between adjacent semiconfined aquifers resulting in downwards leakage from the surface.
- A reduction in the volume of springflow resulting in lower flows in spring-fed streams.

This chapter discusses and summarises the considerations that are required for quantifying the safe yield of the groundwater resource of the Heretaunga Plains. Pertinent sections of this chapter also assess and discuss in detail:

- The present abstraction and predicted future demand for groundwater.
- The effects that abstractions to date have had on the groundwater resource.
- The abstractive safe yield and the problems associated with over-abstraction.
- The possible management strategies for the protection of the quality of the Heretaunga Plains groundwater.

9.2 Groundwater Management Considerations

A number of groundwater management considerations for the main aquifer system have been identified from the Heretaunga Plains Groundwater Study. These are to:

- Achieve a balance between availability and demand for groundwater.
- Maintain the yield and quality of groundwater.
- Ensure use of resources efficiently within their capability.

Since the primary focus of the Heretaunga Plains Groundwater Study is on the management of the main aquifer system, it has not been possible to quantify the safe yield for the peripheral aquifer systems. These peripheral aquifer systems include the Esk (Whirinaki-Bay View) aquifer system, and peripheral limestone aquifers on the southern and western margins of the Heretaunga Plains. Detailed water balance investigations for these peripheral aquifer areas will be undertaken as part of a groundwater investigation programme that commenced in mid-1996.

The groundwater management considerations listed above for the main aquifer system and the areas adjacent to the margins are grouped under six catagories, which are:

- groundwater usage and demand;
- groundwater storage, long-term recharge and safe yield;
- groundwater quality management;
- groundwater protection issues;
- groundwater allocation and efficient use;
- community education and conservation.

9.2.1 Groundwater Usage and Demand

The Heretaunga Plains total annual water use during the year July 1994 - June 1995 was estimated at 66 million cubic metres. This represents an average abstraction rate of 1.99 m^3/s (17 194 m^3/day). The total daily abstraction during peak water use periods was 207 456 m^3/day at a rate of 2.4 m^3/s. The peak rate is reduced to about 41% (0.98 m^3/s or 84 762 m^3/day) of this quantity during low water demand periods.

The Heretaunga Plains annual groundwater abstraction for municipal and industrial water supply has increased from about 22 million cubic metres in 1989/90 to about 35 million cubic metres during 1994/95; an increase of 60% in 6 years or an average 10% per year. From 1992 to 1995 an average of about 50 new wells were sunk on the Heretaunga Plains each year, with most at the margin of the Heretaunga Plains aquifer system. The number of wells sunk each year on the Heretaunga Plains, and the allocated volume of groundwater for irrigation (including frost protection) suggests that irrigation water demand is increasing by about 5% (1.3 million cubic metres/year) each year. Extrapolating the current rate of increase in industrial and municipal abstractions (Fig. 9.1), and assuming a 20% increase in irrigation abstraction during the next four years, suggests the total groundwater abstraction by the year 2000 could be 79 million cubic metres/year. This represents a 25% increase from the total groundwater use during 1994/95 (66 million cubic metres).

9.2.2 Groundwater Storage, Long-term Recharge and Safe Yield

9.2.2.1 Main Aquifer System

The total main aquifer storage is estimated to be about 1000 million cubic metres which is the equivalent of 17% of the volume of water stored in Lake Waikaremoana (5836 million cubic metres). The total volume of groundwater abstracted from the Heretaunga Plains aquifer system during the July 1994 - June 1995 period (66 million cubic metres) is about 6.6% of the estimated main aquifer storage. However, all of the groundwater stored in the main aquifer system is not available for use.

Recharge to the main aquifer system is seepage from the Ngaruroro and Tutaekuri rivers and direct infiltration of rainfall on the unconfined aquifer. The Ngaruroro River contributes at least 5 m^3/s on a sustained basis to the main aquifer system. Flow measures of springfed streams suggest that about 1.9 m^3/s remains as groundwater in the aquifer system whereas about 3.1 m^3/s resurfaces as springs. The rainfall recharge is minimal during the summer period of increased groundwater use. Therefore it is appropriate to consider 1.9 m^3/s (c. 60 million cubic metres/year) as the minimum net addition to confined aquifer storage on a sustained basis. The Heretaunga Plains estimated groundwater use during 1994 - 1995 was about 66 million cubic metres. Of this about 20 million cubic metres was pumped from the unconfined part of the aquifer and about 46 million cubic metres

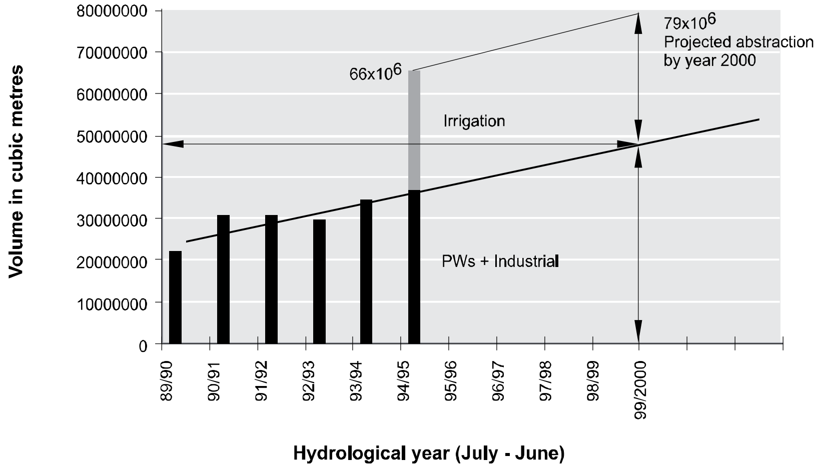


Figure 9.1: The Heretaunga Plains estimated demand for groundwater for public water supply and industries by year 2000

from the confined aquifer (based on average 10 hr/day and 200 day/year pumping) (see 5.3.3). If the total groundwater use progressively increases to 79 million cubic metres/year by the year 2000 (Fig. 9.1), the primary effect will be an increase in the peak abstraction rate. An increase in the peak abstraction rate in turn will increase the amplitude of seasonal fluctuation in aquifer levels. The continuous groundwater level data shows that the range of seasonal fluctuation has increased over the years, suggesting a response to a progressively increasing level of abstraction from the groundwater storage during the summer.

The Heretaunga Plains groundwater levels fluctuate seasonally in response to increased drawoff from the groundwater storage during the summer period which often coincides with minimum surface flow in the Ngaruroro River. The normal seasonal trend for the Heretaunga Plains unconfined and confined aquifers is a summer decline followed by a winter recovery. Long-term groundwater levels from the wells tapping the unconfined aquifer suggest a small but significant decline in groundwater levels has occurred over the last twenty years. It is estimated that a four-fold increase in the groundwater abstraction has taken place during the past twenty years. The amplitude of seasonal fluctuations in the piezometric pressure in two wells tapping the confined aquifers has increased over the past ten years (Figs. 5.10). Piezometric pressures recover during the winter in the central high transmissivity part of the confined aquifer system suggesting that winter groundwater flow from the unconfined to the confined sector of the aquifer replaces most of the abstracted groundwater.

The springs which occur along the transition boundary of the unconfined to confined aquifer, could be an important guide as to whether permanent groundwater depletion is occurring in the confined aquifer. If the aquifer was being permanently depleted there would be downstream movement of the headwater spring locations in the spring-fed streams and drains, and consequently lower stream flows. The spring flow (overflow) from the system is about 3.8 m^3/s at the unconfined - confined aquifer boundary while recharge to the confined aquifer is about 1.2 m^3/s (see 2.8). A decrease in spring flow would indicate an increase in recharge to compensate for increased abstraction of groundwater from the confined aquifer. Spring flows are not regularly measured.

A number of important inferences can be derived from long-term water level and aquifer pressure observations (see 5.3.3):

- Groundwater abstraction is the critical factor affecting water levels (unconfined aquifer) and piezometric pressures (confined aquifer).
- The slight but significant decline in the unconfined aquifer water level suggests that the current level of abstraction from the Heretaunga Plains main aquifer system has exceeded the long-term abstractive safe yields.
- Long-term changes in storage take place in the unconfined aquifer and are possibly related to intensified landuse, low rainfall and prolonged low flow in the Ngaruroro River.
- The increasing amplitude of the seasonal fluctuation in the confined aquifer is due to increased abstraction during the summer with winter recharge replacement of groundwater.
- There is no evidence of saltwater intrusion or permanent decline for the piezometric head in the confined aquifer sector of the main aquifer system.
- The increasing amplitude of seasonal fluctuations and decline in groundwater levels (and therefore the yields) of the shallow and closely spaced bores sunk at the southern margins of the main aquifer system is perhaps the first manifestation of groundwater depletion.

9.2.2.2 Marginal Aquifer Areas

On the southern and eastern margins of the main aquifer system the groundwater availability is limited by a combination of factors. These are the restricted aquifer thickness, the variable permeability of the aquifer material, and the limited hydraulic connection to main recharge channels. As a consequence well water levels in the marginal areas fluctuate seasonally in the order of 3 - 5 m compared to 2 - 3 m for wells in the central part of the Heretaunga Plains aquifer system (Fig. 5.11). In recent years many wells have been drilled at the southern margin of the Heretaunga Plains due to land subdivision and increased need for irrigation water supply.

Many of the old domestic and stock water supply wells at the southern margin of the Heretaunga Plains areas only partly penetrate into the aquifer. These wells will "go dry" when the groundwater level falls below the pump intake. Irrigation abstraction bores that extend to greater depth because of their need for high yields are therefore less susceptible to problems caused by water level changes. In the areas where the water table is shallow, domestic wells use centrifugal pumps installed on the well at ground level. These pumps have a limited suction head, and can not raise water should the water table fall below about 7 m.

The "inferences" derived from long-term water level and aquifer pressure observations and listed in 9.2.2.1 suggests that with the current level of abstraction the safe yield of the main aquifer system has either been exceeded or is on the verge of being exceeded. There is evidence that the following adverse environmental effects have occurred on the southern margin of the main aquifer system:

- increasing range of seasonal fluctuation in groundwater levels (Fig. 5.10);
- reduction in summer springflow (see 6.4.5);
- interference between bores (see 5.3.3);
- inflow of poor quality recharge water (see 7. 4.3.1, 7.4.3.2 and Figs. 7.6, 7.7 and 7.9).

Therefore specific groundwater management considerations may be required to protect and manage the groundwater resources on the southern margin including ongoing groundwater quantity and quality monitoring. Five groundwater management options are suggested for the continuing sustainable management of groundwater resources in the marginal areas of the main aquifer system. These are:

- to maintain minimum aquifer water level requirements;
- to establish criteria for well spacing;
- to encourage sinking of deeper wells in suitable areas;
- to encourage water transfer from central to the marginal areas;
- to encourage utilisation of alternative water supply sources.

The final management plan may involve a combination of parts of some or all of these suggested options.

- Water Level Requirements

  To set management criteria, it would be necessary to define limits for water levels in the central area of the main aquifer system and then to manage the water balance of surrounding marginal aquifer areas appropriately. The long-term groundwater level data suggests that the range of seasonal fluctuation in the unconfined aquifer has increased from about 1 m in 1974/75 to about 2.5 m in 1994/95 due to about 150 % increase of groundwater abstraction. This fluctuation in the unconfined aquifer level relates to an approximate 3 to 5 m seasonal fluctuation on the margins of the main aquifer system. Based on an estimated future water demand of 79 million cubic metres per year by 2000 (Fig. 9.1), the seasonal fluctuation in the main aquifer system could increase by 1 m by 2000. This increase in fluctuation in the main aquifer system has a potential to lower the groundwater level in the semiconfined aquifer on the southern margins of the Plains by up to 3 m.

  This would be a difficult option to justify as it would impose restrictions on groundwater abstraction in areas where supplies were copious, to maintain supplies where aquifer hydraulics restricted groundwater availability. Also criteria for the setting of minimum water levels at the marginal aquifer areas will need to be established. This could be 5-6 m below ground surface so that centrifugal pumps can continue to provide domestic water supplies.

- Criteria for Bore Spacing

  Drawdown effects from pumped bores can be estimated from the hydraulic characteristics of the aquifers using the groundwater flow equation to discharging bores. The Theis (1935) equation describes transient radial flow from an idealised confined aquifer to an ideal production bore:

where:

u = $\frac{r^2S}{4\ Tt}$ and W(u) is bore function;
s = the drawdown (m) at any point near the production bore;
Q = the discharge rate of the production bore (m^3/day);
T = transmissivity of aquifer (m^2/day);
r = the distance (m) between the production bore and observation point or radius of influence;
S = the aquifer storage coefficient;
t = pumping period.

An idealised aquifer is represented by homogeneous, isotropic medium of uniform thickness and infinite extent, conditions that are rarely satisfied in nature. The Theis equation also assumes that the discharge Q is constant through time and no water enters the aquifer through leakage from adjacent strata. The Theis equation shows that the drawdown effects at individual bores depend on many factors such as aquifer characteristics and the nature of hydraulic interconnection between the bore and the aquifer. The extent of lateral and vertical variation in aquifer characteristics, hydraulic interconnection, multiple sources of recharge and variable depth of groundwater basement observed in the Heretaunga Plains marginal aquifer areas, makes it difficult to determine a particular bore density for the entire peripheral aquifer area. Applying the Theis equation to the aquifer characteristics (Table 5.1) in the southern marginal areas of the Heretaunga Plains, a 200 m bore spacing can be recommended.

- The implementation of bore spacing criteria for new bores is a relatively simple task. However, there are already closely spaced (often within 50 m and some 10 m apart) interfering bores existing in the southern marginal aquifer area and therefore resolution of the problem on a case by case basis needs to be considered. There inevitably will be restrictions on drilling additional wells and some existing wells will also be shut down, if this management option is applied.

✏ Deepening of Bores in Suitable Areas

- Although most of the southern marginal aquifer areas are generally characterised by shallow groundwater basement, often less than 30 m depth, there are areas where deepening of wells or the sinking of deep wells is a viable proposition. The majority of old bores (pre 1970's) in the marginal areas have been drilled just into the confined aquifer. These partly penetrating bores require deepening to at least groundwater basement, to accommodate increased seasonal fluctuation in groundwater levels occurring with progressively increased abstraction. It is proposed to delineate specific areas on the margin of the Heretaunga Plains where bores can be usefully deepened providing the 200 m bore spacing criteria is observed. Consultation with well owners (current and prospective) and well drillers will be required.

✏ Flexible Water Transfer

- The abstracted groundwater from the central high transmissivity part of the main aquifer system is replenished more readily than in the marginal low transmissivity areas. Therefore, allowing flexibility and encouraging transfer of Water Permits from the central part of the aquifer to the marginal areas is an important tool to provide equitable water allocation and sustainable management of groundwater. The only technical consideration involved in such transfer would be to ensure that the quantity of water transferred is sustainable at the place of extraction. However, further work is required to formulate a specific strategy on flexible transfer of water permits.

✏ Alternative Supply Sources

- Another groundwater management option would be to encourage the residents and or the irrigators at the southern margins of the Heretaunga Plains to use an alternative source for water supply rather than local wells. The water would be imported into the area by water race or pipeline and could be sourced from the groundwater, surface water or runoff from the local hills stored in a dammed lake. It may be that if irrigators were compelled to use an alternative supply source to local wells, then domestic and stock water supplies from wells could be maintained without being affected by the lowering of water levels associated with depletion.

✏ Artificial Recharge

- Some parts of the southern margins of the Heretaunga Plains are suitable for artificial recharge through channel spreading and injection techniques but these options require feasibility studies and pilot investigations to quantify their effectiveness.

9.2.3 Groundwater Quality Management

During the past twenty years there has been expanding rural and urban developments on the Heretaunga Plains involving modification of the natural environment, which has affected the quality of shallow groundwater. This process continues today. Two principle groundwater quality management considerations for the Heretaunga Plains aquifer system are nitrate contamination and storm water drainage.

9.2.3.1 Nitrate Contamination

The results of groundwater quality monitoring surveys undertaken on the Heretaunga Plains prior to 1994 had suggested elevated concentrations of nitrate in scattered areas. The 1994/95 groundwater quality monitoring confirmed that there were elevated concentrations of nitrate in four isolated areas (Fig. 7.14):

Ngatarawa Valley	(see 7.4.3.7, 7.4.4.2, Table 7.2, Figs. 7.2 and 7.14);
Haumoana	(see 7.4.3.7, Figs. 7.2 and 7.14);
Western and southern peripheral hill areas	(see 7.4.4.5, Figs. 7.2 and 7.14);
Whirinaki	(see 7.4.4.6, Figs. 7.2 and 7.14).

The major sources of nitrate in the groundwater in rural areas are septic tank effluent, fertilisers, landfill, waste disposal sites and industrial effluent. Although the volume of water discharged may be insignificant in comparison to the volume of groundwater flowing through the aquifer, there is a direct relationship between elevated nitrate concentrations of up to 2 mg/l and these activities. Heretaunga Plains areas where point source contamination has been identified include parts of Whirinaki, Poraiti, Ngatarawa, Bridge Pa, Pakipaki, Haumoana and Te Awanga. In the Whirinaki, Poraiti and Haumoana areas a correlation between the occurrence of nitrate concentration exceeding 1 - 2 mg/l and the distribution of septic tanks can be identified (7.4.3.7). The highest nitrate concentrations for the groundwater of the Heretaunga Plains aquifer system of up to 20 mg/l, are observed south of Hastings and are likely to be associated with point source contamination. Nitrate concentrations do not appear to have altered appreciably during the last ten years but as landuse in various areas has changed significantly during this period, it is difficult to relate historical data to more recent data. Generally, nitrate concentrations appear to comply with the New Zealand drinking water standard of not exceeding 11 mg/l. Regular and additional monitoring and investigation should be undertaken to ensure that no public health risks exist or occur.

Septic tanks are identified as the most likely source of nitrates in the Heretaunga Plains groundwater, especially where the aquifer is unconfined or semiconfined with shallow water table. It has not been possible to assess the number of septic tanks installed in the Heretaunga Plains but the Hastings District Council estimate is more than 500. Most dwellings, fruit packing sheds, vineyards, cow sheds and various commercial, industrial and agricultural developments outside the urban areas use septic tanks. It is necessary to assess the susceptibility to contamination from septic tanks for areas of the Heretaunga Plains.

9.2.3.2 Storm Water Drainage

Storm water run-off can contain high levels of nutrients, litter, bacteria and chemicals under normal circumstances. Storm water also has the potential for serious pollution as a result of industrial chemical spills. Currently local authority storm drainage systems intersect or directly discharge into groundwater at the Heretaunga Plains unconfined - confined aquifer transition zone. The potential for pollution of the unconfined groundwater in this transition area is high because of high permeability of the fluvial gravel aquifer channels. Discharge of storm water directly into the spring-fed drains and streams should also be reviewed because of potential to contaminate surface water. An on going storm water quality monitoring programme is necessary to provide information on the exact nature and type of potential pollutants and what is the best method for reducing the risk of pollution (e.g. retention basins).

9.2.4 Groundwater Protection Issues

There are areas on the Heretaunga Plains where the local geology, hydrogeology and landuse combine to produce a situation where it is necessary to control abstraction of groundwater and regulate well construction methods, to prevent pollution of groundwater and structural damage to aquifers.

9.2.4.1 Protection of Unconfined Aquifer Area

In the Heretaunga Plains unconfined aquifer area there is the potential for groundwater pollution by direct infiltration of contaminants through the highly permeable surface and subsurface fluvial gravels into the groundwater. The gravels above the unconfined aquifer have little or no capacity to absorb pollutants and prevent them from reaching the shallow (6 - 8 m below ground level) water table. Bacteria and other micro-organisms travel freely through these gravels. Concentrated pollution from a point source on or in the permeable gravel will rapidly disperse into the underlying aquifer. Therefore landuses which might give rise to such pollution should be controlled. This could include measures to restrict transport of fuel and hazardous chemicals in tankers on State Highway 50 which passes through the major and minor aquifer recharge zones. A mitigating property of the unconfined aquifer is the high transmissivity and the resultant rapid dilution and dispersion of pollutants by the groundwater. However this is not a valid reason for not considering management policies to avoid and prevent infiltration of contaminants.

9.2.4.2 Conservation of Weak Aquifer Seal Areas

A weak confining seal area occurs between the Ngaruroro and Tutaekuri river channels downstream of State Highway 50, where the strata overlying the main confined aquifer contain a perched aquifer with a high pumice sand content. This shallow aquifer also contains groundwater under pressure and only provides a weak confining seal to the underlying main aquifer. It requires specific protection to prevent uncontrolled leakage. At present the HBRC requires all wells drilled in the weak aquifer seal areas, to use a casing telescoping technique to prevent leakage up the outside of a single casing and a "blow out" of the main confined aquifer. Specific water well construction methods using a conductor casing are necessary for wells drilled in the identified weak seal areas (Fig. 5.2).

9.2.4.3 Backflow Protection

Backflow protection devices are usually installed between the well head / water main and the water supply system so that water drawn from a water well /water main does not return to that system. Backflow protection should be installed to ensure a cross connection or backflow between potable water supply and non-potable water supply system. Industrial, irrigation and public water supply bores require backflow protection devices to prevent accidental contamination of the aquifer by agrichemicals and hazardous substances during use. There are a variety of backflow protection methods and devices available. Examples where backflow protection needs to be provided include industries (commercial dish washers, boilers, cooling towers), pressurised irrigation systems, stock drinking water in troughs, effluent disposal systems and sewerage pumping stations.

Similar backflow protection measures are required for air conditioning plants which use groundwater as both a heat source and a coolant as there is potential for refrigerant to enter groundwater and the aquifer.

9.2.4.4 Agrichemical Storage Areas

All above ground and buried hazardous chemical, fuel, agrichemical storage areas on the unconfined and confined aquifer require adequate containment to prevent infiltration and site runoff.

9.2.4.5 Vulnerability to Pesticide and Fertiliser Contamination

The investigations undertaken by HBRC - Landcare at two sites on the Heretaunga Plains (Twyford and Ngatarawa) to determine the extent of leaching of pesticide and fertiliser through soil and the unsaturated zones to the water table, indicated rapid vertical and lateral dispersion of agrichemicals, especially in the unconfined aquifer area (see 3.3.2). This highlights the potential vulnerability of the unconfined aquifer to pesticide and fertiliser contamination, and the need to monitor shallow groundwater and storm water run-off quality. Groundwater vulnerability assessment methods, such as DRASTIC which was developed by USA National Water Well Association and has been used in mapping projects in the USA (Aller et al. 1988) and New Zealand (Brown et al. 1994) could be applied to the Heretaunga Plains to delineate areas of different vulnerability risk.

9.2.4.6 Landfill and Waste Disposal Areas

The Omaranui regional landfill is located on siltstone and limestone adjacent to the Moteo Valley about 4 km northwest of the Heretaunga Plains. Piezometric contours suggest groundwater flow is in an easterly direction towards the Tutaekuri River and the Heretaunga Plains from the landfill site (Dravid 1991b). Test drilling undertaken by the HBRC in 1991 near the Omaranui landfill suggested the existence of high permeability groundwater flow paths (Dravid 1991b). At least on one occasion at the Omaranui landfill, ponding of leachate occurred following blockage of a leachate drain and this resulted in leakage of leachate through or around the basal sealing layer into the groundwater in the limestone aquifer underlying the landfill. A monthly groundwater quality monitoring programme of a network of wells at and adjacent to the Omaranui landfill is now carried out because of the potential for leakage of leachate into the groundwater.

The closed Roys Hill landfill is located above the unconfined aquifer and the main aquifer recharge area between Roys Hill and Fernhill. The landfill site was a former gravel pit. The unconfined aquifer water table seasonally fluctuates between 5 to 8 metres below ground level. Since a large volume of refuse of an unknown nature was dumped at the site, it is essential to continue to monitor the groundwater quality in the vicinity of the landfill even though no refuse has been dumped since 1986 apart from hard fill. The HBRC groundwater quality monitoring wells at and adjacent to the landfill have been sampled frequently and has not detected significant contamination.

There are other former landfill sites (Redclyffe, Black Bridge, Bay View and Whirinaki) on or adjacent to the Heretaunga Plains, and within the Napier City boundary (Onekawa, Pandora, Ahuriri and Westshore) which although closed for refuse disposal for many years, that should be assessed for potential to contaminate groundwater. The site of the former Napier gasworks in Latham Road should also be assessed for potential for groundwater contamination.

9.2.4.7 Salt Water Intrusion

At the Hawke Bay coast the piezometric pressure is about 9 m above mean sea level in the main aquifer system. The fresh water / sea water interface in the aquifer is several kilometres offshore, and sea water intrusion does not seem to be a threat for the main aquifer system. However, shallow coastal aquifers at the northern and southern extremities of the Heretaunga Plains are susceptible to sea water intrusion. Groundwater in coastal beach gravel deposits in two areas, Whirinaki to Bay View in the north and Haumoana to Te Awanga in the south, have been affected by salt water intrusion. Although these occurrances of salt water intrusion involve only a localised water table aquifer they highlight the need to monitor and understand the stability of the fresh water / sea water interface for all Heretaunga Plains aquifers to prevent salt water intrusion.

9.2.5 Groundwater Allocation and Efficient Use

Irrigation practice may be inefficient in terms of the ratio of the amount of water retained in the rooting zone of a crop to the amount of water actually applied. Significant volumes of water are not taken up by the crop and seep through the strata underlying the soil down to the water table. An improvement in irrigation efficiency is a "plus" in terms of reduced energy costs, reduced through flow to depth, reduced leaching, and reduced pesticide translocation. In the context of sustainability, the maintenance of groundwater quality is very important. Land and water management must have "prevention from contamination" as a prime goal. Through flow has the potential to move nutrients and agrichemicals from the active soil layers to deeper layers and unconfined aquifers.

9.2.5.1 "Designer" Irrigation Water Allocation Consent Method

Resource consents granted by the HBRC typically address *who* has applied, *from where* the water is to be taken, the *rate* of extraction, the *purpose* of the extraction, and a *location of the irrigated area.* A "designer" consent, would authorise the taking of water in accord with a Water Management Plan submitted at the time of application. It addresses the consequences and effects of the irrigation and thus affirms the philosophy of the Resource Management Act. The designer irrigation consents would be based on a "best match" between the intrinsic hydraulic properties of the land, the water requirements of the crop being grown, and optimal irrigation management.

The "designer" consent would acknowledge the Water Management Plan as the guide document. This procedure is successfully operating in South Australia.

The joint HBRC/Landcare Research Project to develop soil-crop specific irrigation water allocation procedure has been in progress since 1992, and has established a scientific approach that involves full cognisance of soil, crop and management factors on a site by site (management unit) basis. Progress has been made in the identification and designation of appropriate soil parameters that emphasise the uniqueness of a particular site with reference to soil water transmission and storage. The concept was further developed to provide building blocks of data that can be used to numerically simulate water storage and movement through soils to at least 1.2 m root average zone depth. Based on the building block approach the concept of *"designer"* irrigation consent was introduced (Watt et al. 1993).

A "designer" consent addresses not only the volume of water allocated for irrigation, but also the irrigation schedule, and the rate and duration of water application. One option for implementing "designer" consents is through the use of land-owner Water Management Plans whereby applicants demonstrate awareness and knowledge of their land-crop-management system, and apply for only such water as can be optimally used. This would require knowledge of crop water requirements, the current performance of the irrigation system, the hydrology of the block with regard to aquifers and water ways, and the hydraulic nature of the soil. The rate and duration of irrigation would be specified, and the method of scheduling stated.

HBRC is currently evaluating the designer irrigation consent method in the Pukahu area of the Heretaunga Plains.

9.2.6 Community Education and Groundwater Conservation.

Effective public awareness programmes on resource management issues are vital as generally only a small proportion of the community affected by water resource policies are aware of their purpose and provisions. Community awareness and participation in water resource management issues is an essential requirement for sustainable management. This could be achieved by:

- Presentations and poster displays for HBRC staff and Council members, and staff and Council members of Napier City, and Hastings, Central Hawke's Bay, and Wairoa District Councils.

- Presentations, teaching kits and poster displays designed for primary, intermediate and secondary schools, and polytechnics.
- Continuing production of topic pamphlets, and media releases and presentations.
- Establish a permanent display at the Hawke's Bay Museum with equipment relevant to wells and water, photographs and a "focal point" of a chart continuous water level recorder installed on the museum well.
- Posters for sale / distribution to the general public which could include photographs and figures from this report.
- Develop "shared interest" water user groups such as well users (domestic and irrigation) at the southern margin of the aquifer where problems of groundwater depletion may be occurring.
- Audits of industrial water use to monitor efficiency and reduce water consumption.
- Field workshop and training sessions on water management issues (e.g. irrigation scheduling, soil-specific crop water requirements, groundwater contamination, etc.).

It should be recognised that water use habits will not change rapidly and that such initiatives need to take a long-term committed perspective.

9.3 MANAGEMENT CONSIDERATIONS

The review, research and technical assessments of this Heretaunga Plains groundwater study have identified five important and specific groundwater monitoring, protection and management issues that should be considered by the HBRC for immediate action. These are:

- long-term monitoring priorities;
- specific groundwater management strategies for peripheral aquifer areas;
- aquifer specific groundwater protection policies;
- specific policies to prevent irrigation drainage;
- community education.

9.3.1 Long-term Monitoring Priorities

A comprehensive groundwater quality and quantity monitoring programme for the Heretaunga Plains aquifer system is required to ensure sustainable groundwater management. The data and information needs are:

- surface and groundwater quality;
- urban water supply, irrigation and industrial abstractions;
- spring-fed stream flow discharges;
- dewatering pump abstractions;
- continuous and periodic river and groundwater level data.

9.3.2 Peripheral Aquifer Areas Priorities

Specific groundwater management strategies are required for areas on the margin of the Heretaunga Plains where only a limited quantity of groundwater is available. A number of wells on the southern margin of the Plains partially penetrate the aquifer and could be deepened to improve yield. There is a need to implement bore distance criteria for specific areas on the margins of the main aquifer system to enhance individual well performance. Groundwater use in these areas requires monitoring. Spatial and temporal variation in groundwater quality requires monitoring to establish better understanding of groundwater flow and recharge sources.

9.3.3 Groundwater Protection

Measures to prevent contamination of the unconfined aquifer require guidelines and specific policies regarding:

- on site sewage disposal (septic tanks);
- surface and subsurface storage facilities for hydrocarbon fuels;
- storm water discharges to streams and groundwater;
- landuse planning including landfills;
- irrigation and application of agrichemicals;
- hazardous chemicals and agrichemical transport and storage;
- well head construction standards to provide backflow protection devices for industrial, irrigation and public water supply bores to prevent accidental contamination of the aquifer by agrichemicals and hazardous substances.

9.3.4 Irrigation Drainage

An increase in weed growth in surface drains and streams on the Heretaunga Plains in recent years most probably relates to increased levels of nutrients associated with irrigation drainage. Run off from excessive irrigation water application can result in reduced soil fertility and the nutrient enrichment of water in drains and streams.

9.3.5 Community Education

Raising public awareness on groundwater management issues and promoting the efficient use of groundwater are essential for sustainable groundwater management. Groundwater quantity and quality problems directly involve a large number of land owners, and the management solutions will involve questions of values and community needs.

Figure 9.2: Use of hazardous agricultural chemicals near the well head. *(photo: Terry Jamieson, HBRC)*

CHAPTER 10

HERETAUNGA PLAINS GROUNDWATER STUDY: MANAGEMENT RECOMMENDATIONS

10.1 INTRODUCTION

The recommendations of the Heretaunga Plains groundwater study have been grouped into five areas:

- long-term resource monitoring priorities;
- organisation and integration of databases;
- research and investigation;
- groundwater management issues;
- community education.

10.2 LONG-TERM MONITORING PRIORITIES

It is recommended that the HBRC continue or undertake the following comprehensive long-term monitoring:

- continuous river, spring and groundwater levels;
- comprehensive groundwater quality monitoring;
- water supply, industrial and dewatering bore water abstraction;
- landuse, with revisions at 5 yearly intervals;
- annual (summer) water use surveys.

10.3 ORGANISATION AND INTEGRATION OF GROUNDWATER DATABASES

It is recommended that the HBRC continue to maintain an integrated data base for environmental data, accessible for spatial and temporal analysis. The data will include:

- water well and foundation testbore log data;
- consent related data;
- water use survey data;
- river, dewatering pump, stream and spring gauging data;
- periodic and continuous groundwater level monitoring data.

10.4 RESEARCH AND INVESTIGATIONS

It is recommended that the HBRC:

- refine the current regional groundwater balance estimate;
- continue soil-crop specific water allocation investigation;
- identify aquifer vulnerability to contamination on and adjacent to the Heretaunga Plains;
- undertake further investigations to more accurately define the demand and availability of groundwater on the margin of the Heretaunga Plains main aquifer system.

10.5 GROUNDWATER MANAGEMENT ISSUES

It is recommended that the HBRC:

- delineate a Groundwater Management Area (GMA) (Fig. 10.1) where resource consents to take and use groundwater be granted for a limited duration only;
- establish a minimum seperation distance for bores for each area included in the GMA;
- obtain water use data for bores in GMA;
- encourage use of water from deeper aquifers at suitable locations in the GMA;
- require irrigators in the GMA to present adequate evidence of their actual needs together with an Irrigation Management Plan, which describes in detail the proposed method of irrigation;
- work with the Hastings District Council for appropriate landuse over the unconfined aquifer area and appropriate well head protection zones;
- make the installation of non-return valves at well heads compulsory on all industrial, public water supply and irrigation wells.

10.6 COMMUNITY EDUCATION

It is recommended that the HBRC continue to raise public awareness groundwater management issues, particularly the efficient use of groundwater. Groundwater quantity and quality problems directly involve a large number of land owners, and the management solutions will involve questions of values and community needs.

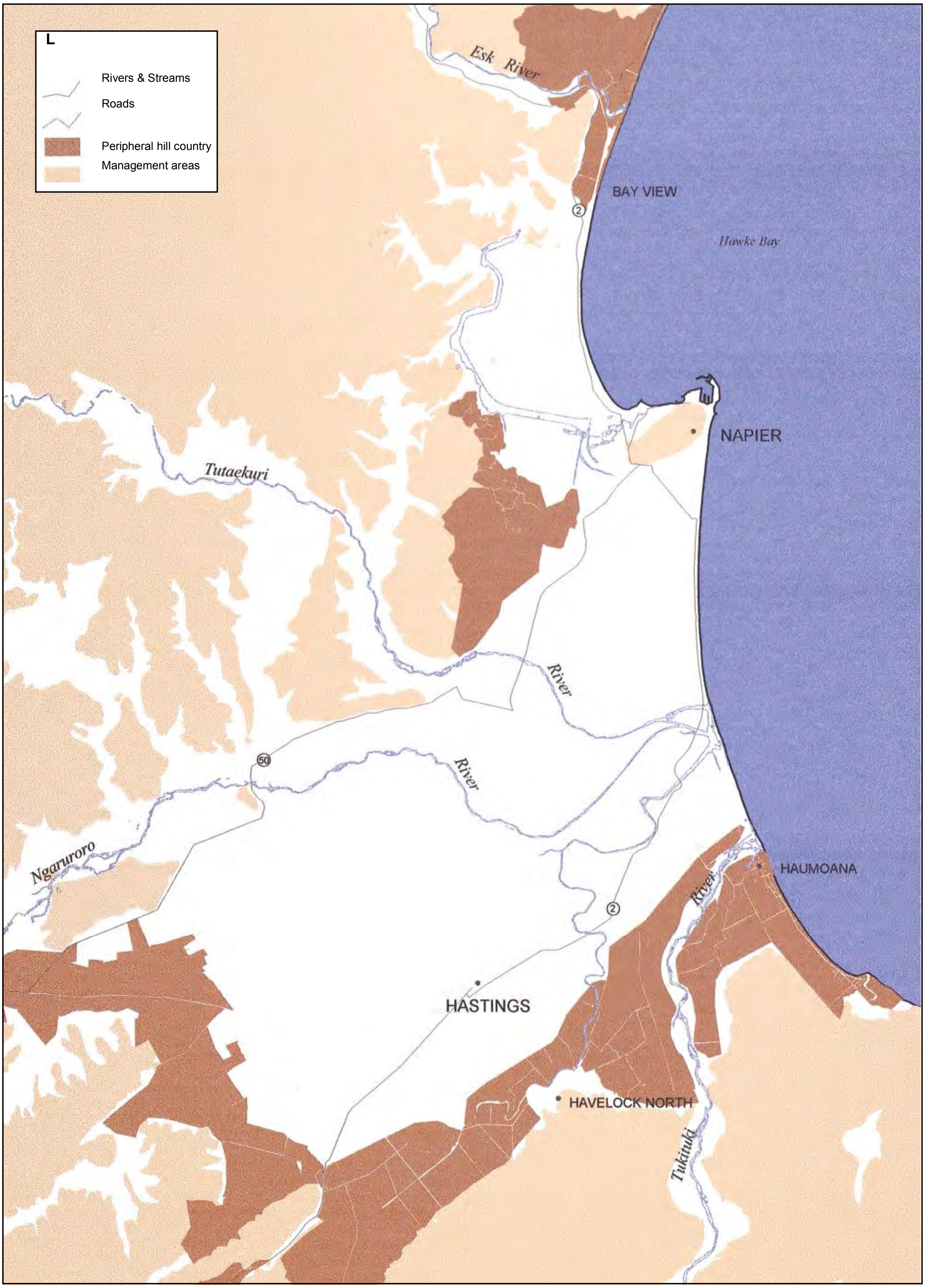


Figure 10.1: Heretaunga Plains groundwater management area (GMA).

Heretaunga Plains
GROUNDWATER STUDY

May 1997

Volume 1: Findings

Hawke's Bay Regional Council
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GEOLOGICAL HISTORY OF HERETAUNGA PLAINS AND HAWKE'S BAY

International			New Zealand		Began (Years ago)	Strati-graphic Column	Local Stratigraphic Units	Regional Geologic Events	Oxygen* Isotope Stages
Era	Period	Epoch	Series	Climatic Stage					
CENOZOIC	QUATERNARY	HOLOCENE	HAWERA	ARANUIAN	6500		Progradation	Coastal extension, tombolos connect Scinde Island to mainland.	1
		LATE PLEISTOCENE			10000 14000		Maraekakaho terrace Marine transgression	Sea level rise to 6500 yrs BP; erosion of Scinde Is. Climate warming - glacial retreat.	
				OTIRAN	70000		Pigsty terrace Waharoa terrace Salisbury terrace	Glacial advance. Interstadial warming. Glacial advance.	2 3 4
				KAIHINUAN	120000		Unnamed marine terrace - Cape Kidnappers. Marine transgression over Heretaunga Plains	Uplift and tilting at Cape Kidnappers. and Mahia Pen. Subsidence - Heretaunga Plains. Glacial retreat.	5
				WAIMEAN	200000		Unnamed fluvial deposits underlying Heretaunga Plains	Uplift and tilting at Mahia Pen. Glacial advance.	6
				KAROROAN	250000		Unnamed marine transgression over Heretaunga Plains	Uplift and tilting at Mahia Pen. Subsidence-Heretaunga Plains (1m/1000 yrs). Glacial retreat.	7
				WAIMAUNGAN	310000		Unnamed fluvial deposits underlying Heretaunga Plains	Gravel near the bottom of the 250 m deep Tollemache Orchard and Awatoto testbores deposited during the Waimaungan glacial advance.	8

A complete sequence of Haweran and Castlecliffian glacial and interglacial strata (present to 1.6 million years ago) including the Kidnappers Group deposits exposed in the cliff along the beach from Clifton to Black Reef, may underlie the Heretaunga Plains. Otherwise a period of erosion may have removed some of the deposits to produce a break (unconformity) in the strata sequence. This can only be proven by drilling.

			Series	Stage	Regional Stratigraphic Unit					
CENOZOIC	QUATERNARY	MIDDLE PLEISTOCENE	WANGANUI	CASTLECLIFFIAN	KIDNAPPERS GROUP	500000		Te Awanga Beds	Glacial retreat.	15
								Clifton Conglomerate	Glacial advance.	16
								Clifton Sands	Glacial retreat.	17
								Trig N Beds	Glacial advance.	18
						700000		Rabbit Gully Beds	Mohaka River diverted from southern to northern Hawke Bay.	19
								110 ft Conglomerate		20-22
								Mt Gordon Beds		23-30
						1000000		Maraetotara Sands	Shallow water marine. “Hawke Bay” formed when seaway connection to Wanganui Basin on west coast cut by elevation of Ruahine Range.	31

Period of erosion and continuing tectonic activity which removed and displaced coastal Hawkes Bay deposits

CENOZOIC	QUATERNARY	EARLY PLEISTOCENE	WANGANUI	NUKUMARUAN	PETANE GROUP	1600000		Petane Group comprises eleven formations including late Nukumaruan limestones that accumulated during interglacial periods. Napier Group is part contemporaneous with Petane Group includes Park Island Limestone, Taradale Mudstone and Scinde Island Limestone. Oil exploration wells (Taradale 1 Mason Ridge 1) at the western margin of the Heretaunga Plains and the Onekawa stratigraphic testbore provide information on the sequence of strata. Taradale 1 penetrated 800 m of Taradale Mudstone (no early Nukumaruan limestone) overlying Pliocene mudstone. Mason Ridge 1 penetrated Park Island Limestone (at surface) overlying Scinde Is. Limestone. Onekawa testbore and Mason Ridge 1 encountered a "pre-Scinde Is. Limestone" not exposed at the surface.	Deposition in east coast inland depression west of east coast highlands. Alternating glacial/interglacial low amplitude sea level fluctuations (60-70 m) and subsidence (2-3 m/1000 yrs). Exposed in the Tangoio area and may underlie Heretaunga Plains. Includes greywacke gravels (Tutira Formation) derived from erosion of North Island mountains uplifted about 2 million ago. Napier Group sediments are exposed along the western margin of the Heretaunga Plains. Since deposition significant displacement has occurred to Petane and Napier group sediments. As a result the sequence of Nukumaruan deposits beneath the Heretaunga Plains is likely to include several unconformities.	39
					NAPIER GROUP	2600000				

*Oxygen Isotope Stages - odd numbers temperate climate; even numbers cold climate

Continued on inside back cover

Heretaunga Plains
GROUNDWATER STUDY

May 1997

Volume 1: Findings

By

P.N. (David) Dravid
Hawke's Bay Regional Council
Napier

and

L. J. Brown
Institute of Geological and Nuclear Sciences Ltd
Lower Hutt

Base data used in Figures a, a1, 5.19 & 5.40 is courtesy of
Land Information New Zealand

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CONTRIBUTING ORGANISATIONS

The Heretaunga Plains Groundwater Study reviews the results of pre-1990 investigations of the Heretaunga Plains groundwater resources and presents the results of joint investigations undertaken during 1990-95 by Hawke's Bay Regional Council (HBRC) and Crown Research Institute's (CRI) - Institute of Geological and Nuclear Sciences (IGNS) and Landcare Research New Zealand (Landcare). The investigations were funded by HBRC with CRI research also funded by the Public Good Science Fund administered by Foundation for Research Science and Technology, Wellington.

Frontispiece: Hawke’s Bay coast south from Napier to Cape Kidnappers with Scinde Island tied to the mainland and Heretaunga Plains extending south to Havelock Hills and to the west. *(photo: Lloyd Homer, IGNS CN 1 33)*

PREFACE AND ACKNOWLEDGEMENTS

Compared to other branches of applied sciences, the science of groundwater is an emerging and relatively young science. Not long ago, the study of hydrogeology simply linked the principles of geology and hydraulics together and groundwater was thought in terms of exploration and exploitation. In the modern times, the study of groundwater has grown to encompass many disciplines of science to become a specialist multidisciplinary environmental science in its own right. In recent years, there has been an increasing reliance on a limited groundwater resource and an awareness of the much wider importance of groundwater as a water resource. Today, the emphasis is on sustainable use and preservation of the natural state of the environment for the benefit of future generations.

Sustainable management of groundwater resources requires understanding of various interlinked aspects viz. geology, aquifer delineation, groundwater flow and hydraulic interconnections, groundwater quantity, quality, natural recharge processes, pattern of groundwater use and effect of various land uses, and contamination vulnerability. Sustainable management of groundwater requires effective public policies and a robust regulatory framework. This report is designed to provide a comprehensive understanding of various inter-related aspects of the Heretaunga Plains groundwater resources to facilitate policy development for sustainable management.

The Heretaunga Plains Groundwater Study Report is presented in two volumes and an executive summary. Volume 1 collates current knowledge in the context of groundwater management issues and provides recommendations for future monitoring. Volume 2 contains copies of various investigation reports which contributed to the study.

Volume 1 (Findings) comprises ten chapters. The first three chapters discuss the background to the study, study objectives, geology and physical features of the study area and summarise the approach adopted to achieve these objectives. Chapter 4 and 5 summarise the findings of the hydrogeological explorations undertaken during the 1990 - 95 study period and describe the hydrogeology of the Heretaunga Plains aquifers. Various methods adopted to estimate the Heretaunga Plains groundwater balance during the 1994/95 period together with supporting results are given in Chapter 6. Chapter 7 discusses and summarises the groundwater and isotope chemistry. The principle conclusions of the study are summarised in Chapter 8. Chapter 9 discusses the relevant aspects of Heretaunga Plains groundwater management in the context of groundwater issues and the recommendations of the study are given in Chapter 10.

A comprehensive report like this depends upon the cooperation of a large number of people who have indirectly and directly provided assistance, data and advice. All sources of published and unpublished information and personal communications are mentioned in the text, but some people require special mention. We would like to thank the following Hawke's Bay Regional Council (HBRC) staff for their specific contribution to the report - Robin Black for providing comments on geology and structural aspects of the Heretaunga Plains and for field assistance; Neale Hudson for contributing Chapter 7 on groundwater chemistry and for providing useful comments during various stages of preparation of the manuscript; Geoff Wood for reviewing parts of the manuscript; Stewart Cameron for field assistance, compiling figures and the tables, and for detailed comments on the manuscript; David Fulton, John Bickerstaff and Charlotte Olliver for providing computer support and assistance in establishment of various groundwater data bases; Bruce Churchhouse for providing various cartoons and illustrations; Kim Coulson and Larry Withey for interpreting hydrology data bases and supplying hydrology illustrations; Darrel Hall for undertaking preparation of GIS illustrations; Stu Davey for drafting various illustrations and for preparation of manuscript for publication. We thank Michelle Crompton and Vickey Hanson for providing field assistance in groundwater sampling and chemical analysis and Hugh Norton and survey staff for organising location and elevation survey of a number of water wells included in this report. We would like to thank local historians Patrick Parsons and Laraine Knight for providing comments, references and illustrations on Maori and early European history of the Heretaunga Plains.

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We wish to thank local authority staff - Bill McWatt, Brian Gestro, Derek Wood of Napier City Council (NCC) and Peter Free of Hastings District Council (HDC) for providing assistance in compiling historical and current urban water supply statistics. We also owe a debt to the many graduate and undergraduate students for their assistance in various aspects of work undertaken for this report - Ben Altoft of Otago University for estimating Heretaunga Plains irrigation abstraction; Damian McGahan, John Watt, Grace Liu, Deepak Patel and Amandeep Kaur for preparation and checking of various tables and figures.

Well logs recorded by well drillers operating since the first wells were drilled on the Heretaunga Plains over 100 years ago have provided an important data base. Included are wells and testbores drilled by A.F. Leipst, Tommy Willan, H.A. McLean, Vic Boag & Sons, Baylis Brothers Limited, Hill Well Drillers-all based in Hawke's Bay; and J.M. Stewart, Dunedin, Richardson Drilling, Palmerston North; and Neville Webb & Sons, Levin. In particular the drillers of the three HBRC deep groundwater exploratory bores deserve special mention for their input of technical expertise and on going patience into often trying and difficult drilling conditions. These are Dick and Russel Baylis, Scott Lyall and Bryan Strong of Baylis Brothers Limited and Murray Gillies, John Hill, Ashley Hill and Vaughan Robson of Hill Well Drillers.

We thank the HBRC executives, notably Dudley Hawke and Andrew Caseley, General Managers and Rob van Voorthuysen, Resource Management Group Manager for their support and encouragement during various stages of the Heretaunga Plains groundwater investigation. Thanks are also due to Dr Ian Boothroyd and Dr. Ellen Forch, Monitoring Managers for prioritising the report work over the other routine work and comments on various sections of the manuscript. Finally, we wish to thank various elected HBRC Councillors for their unified support for the Heretaunga Plains groundwater study and for their forward looking attitude.

Without assistance and co-operation from all of these people, this report would not exist.

P.N. (David) Dravid
Environmental Scientist
HBRC, Napier

L. J. Brown
Hydrogeologist
IGNS, Lower Hutt

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Whirinaki
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Eskdale
Bay View
Rissington
Westshore
Bluff Hill
Hospital Hill
Ahuriri
NAPIER
Napier South
Te Awa
Marewa
Onekawa
Pirimai
Poraiti
Puketapu
Meeanee
Greenmeadows
Taradale
Awatoto
Waiohiki
Te Roto Kare
Oingo Lake
Runanga Lake
Omahu
Fernhill
Twyford
Pakowhai
Tutaekuri
River
Ngaruroro
Whakatu
Mangateretere
Te Awanga
Clifton
Flaxmere
Frimley
Mahora
Camberley
St Leonards
Mayfair
Parkvale
Akina
Karamu
HASTINGS
Maraekakaho
Bridge Pa
Longlands
Havelock North
Pakipaki
Te Mata Peak
Mt Erin
Mangahina Stm
Naiakokomiko Stm
Munro Stm
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Figure b: Location map showing the areas referred to in the Heretaunga Plains Groundwater Study Report.