Dr M. R. JOHNSTON

Consulting Geologist

395 Trafalgar Street
NELSON 7010

An Assessment of the Groundwater Potential in Nelson City

Prepared for Nelson City Council

December 2014

EXECUTIVE SUMMARY

- Utilising existing geological information the groundwater potential of Nelson City has been assessed. The geology of the city is varied, containing a wide range of rocks of different types and ages, which markedly influences the groundwater potential.
- For the purpose of this assessment nine geological units have been defined and which broadly relate to the major geological divisions:
  - I – Holocene floodplain gravels deposited by the major rivers
  - II – Other Holocene terrestrial deposits
  - III – Older river gravels
  - IV – Holocene and Late Pleistocene fan gravels and estuarine deposits
  - V – Holocene marine sand and gravel
  - VI – Moutere Gravel
  - VII – Port Hills Gravel
  - VIII – Jenkins Group and Bishopdale Conglomerate
  - IX – Basement rocks
- The greatest potential for groundwater is Unit I comprising geologically recent gravel that forms the present day floodplains of the major rivers. Where sufficiently permeable the gravel forms unconfined aquifers that are recharged primarily from the rivers.
- The main areas of Unit I are in the lower Maitai valley and to a lesser extent lower Wakapuaka and Whangamoa valleys. Storage capacity within the Maitai River floodplain has been significantly reduced due to lowering of the riverbed as a result of the development of Port Nelson.
- Being unconfined there is a significant risk of contamination in Unit I depending on land use on the floodplains, including in built up areas leaking stormwater and particularly sewer pipes.
- The floodplain gravels become progressively more restricted and thinner inland and water takes correspondingly have a greater potential to affect river flows.
- Away from the major rivers the recent sediments (Unit II) have a high proportion of fine material resulting in a very low permeability and a corresponding very low groundwater potential.
- The older gravels forming terraces in the major valleys (Unit III) have low permeability but contain scattered minor confined aquifers. Yields are likely to be very small although water quality is expected to be good.
- Geologically recent and older fans (Unit IV) form the Stoke Fan Gravel and are largely confined to the area between Annesbrook and Champion Road. Minor aquifers are present with low yields. In the upper parts of the fans the aquifers are unconfined and therefore tend to become dewatered during dry summers.
- Geologically recent marine sands and gravels (Unit V), principally in the Tahunanui area, are permeable other than when estuarine deposits are present. They form an unconfined aquifer recharged principally from rainfall and, in the south, Jenkins Creek and locally in the east small creeks and runoff from the Port Hills. Freshwater in the aquifer rests on saline water and is readily depleted during dry spells. There is a high potential for contamination from surface land use.

- The Moutere Gravel (Unit VI) underlies the Stoke Fan Gravel and geophysical data indicates that it is over a 1000 m thick. Although clay bound it contains scattered thin poorly permeable lenses that form confined aquifers that can yield a low and consistent flow from deep boreholes, particularly if several such lenses are intersected. The potential from interference is high if boreholes are closely spaced.
- The Port Hills Gravel (Unit VII) is similar to the Moutere Gravel but is transitional to a rock. Consequently, the groundwater potential is considerably lower than for Moutere Gravel although very minor seepages from the formation are known.
- The Jenkins Group and Bishopdale Conglomerate have very low permeability and negligible groundwater potential.
- The basement rocks, although hard, have numerous planes of weakness thereby giving them a low permeability. Deep boreholes, particularly if sited in shear zones, are likely to yield small, but consistent, flows of water. Some of the rock units comprising the basement rocks are weakly to locally strongly mineralised and this may affect water quality, particularly in very deep boreholes.
- Nelson City is considered to have overall a low groundwater potential with the most significant yields from floodplain gravels (Unit I). Over exploitation, particularly inland where the gravels are restricted, will have a detrimental effect on river flows. Smaller, but reliable, yields can be obtained from Units III and IV and deep boreholes penetrating Units VI and IX also have the potential of consistently yielding small volumes of water.

1. INTRODUCTION

1.1 As terms of a contract dated 1 October 2014, the groundwater potential of Nelson City has been assessed although the area extending from Annesbrook through Stoke to Champion Road is only briefly referred to, having been recently the subject of a report by Aqualinc Research Limited[1].

1.2 The present report is based on published geological maps[2] supplemented by information known to the writer.

1.3 Nelson City extends eastwards from the southern shores of Tasman Bay and the Waimea Inlet to the crest of the northeast-trending Bryant Range that reaches its highest point at Saddle Hill (1214 m) and which terminates at Cape Soucis. Draining from the Bryant Range are the major rivers in the city, which are, from north to south, Whangamoa, Wakapuaka, Maitai and Roding although the latter joins the Wairoa River that flows through the adjacent Tasman District and, as part of the Waimea River, discharges into the Waimea Inlet.

1.4 The city is largely hilly with flat land restricted to the mouths of the major rivers, particularly the Maitai River and its major tributary The Brook, along with the head of Nelson Haven and more extensively to the east of the Waimea Inlet from Tahunanui Beach to Champion Road. The low hills extend along the eastern edge of the haven, through the Port Hills, to Champion Road. East of the hills, and the shoreline north of Nelson Haven, are hills of intermediate height (392 to 873 m) comprising, from northeast to southwest, Drumduan, Wells, Fringed and Jenkins hills, Grampians and Barnicoat Range, which are cut by the rivers draining westwards from the Bryant Range.

1.5 The flat land and much of the lower hill country has been urbanised with industrial development largely confined to parts of Tahunanui and Stoke, along with reclaimed land at Port Nelson. Towards the south, along the toe of the Barnicoat Range, the hills are in pasture. The higher hills to the east, comprising the Barnicoat Range. Jenkins, Fringed and Wells hills and Drumduan, are largely planted in exotic forest although there are areas of pastoral farming, much of which is reverting to indigenous forest or has been developed into “life style” blocks. Indigenous forest covers all of the Bryant Range except where the Dun Mountain Ophiolite Belt or, as it is locally called, the “Nelson Mineral Belt”[3], crops out. The belt is best exposed in the city from the head of the North Branch of the Maitai River southwestwards along the Bryant Range and reaches its greatest development at Dun Mountain (1129 m).

---

[1] *Stoke Deep Moutere Gravels Groundwater Management Guidelines* (Aqualinc Research Report No. C14096/1).

[2] Johnston, M. R. 1979: Geology of the Nelson Urban Area (1:25 000). New Zealand Geological Survey urban series Map 1.
Johnston, M. R. 1981: Sheet O27AC – Dun Mountain. *Geological Map of New Zealand 1:50 000*.
Johnston, M. R. 1982: Part sheet N27 – Richmond. *Geological Map of New Zealand 1:50 000*.
Johnston, M. R. 1993: Geology of the Rai Valley Area. *Geological & Nuclear Sciences map 5*.
Rattenbury, M. S.; Cooper, R. A.; Johnston, M. R. 1998: Geology of the Nelson Area. *Institute of Geological & Nuclear Sciences 1:250 000 geological map 9*.

[3] The Dun Mountain Ophiolite Belt, of Permian age, is dominated by mafic (basalt and gabbro) and ultramafic (serpentinite and, locally at Dun Mountain, dunite) igneous rocks.

Most of the Bryant Range is in the Mt Richmond Forest Park or, in southeast, the city's waterworks reserves that contain the Maitai and Roding dams.

2. GEOLOGICAL OUTLINE

2.1 The topography within the city reflects the underlying geology with the up stepping of the landscape due to progressive uplift across the northeast trending active Waimea-Flaxmore Fault System (Fig. 1). The fault system separates the Moutere Depression, flooded by the sea in the north to form Tasman Bay and the Waimea Inlet, from the eastern Nelson Ranges. The major faults within the system dip steeply southeast and comprise an unnamed concealed fault to the west of the Port Hills, the Flaxmore Fault separating the low hills from the intermediate hills and Waimea and Whangamoa faults between the latter and the Bryant Range. Also branching off the Waimea Fault is the Eighty-eight Fault that crosses the western face of the Barnicoat Range. In addition to these major northeast trending faults there are numerous faults striking more or less east-west. Total vertical throw on the fault system is in the order of 5 km. As well as vertical uplift, the major northeast-trending faults have a small component of horizontal (dextral) movement.

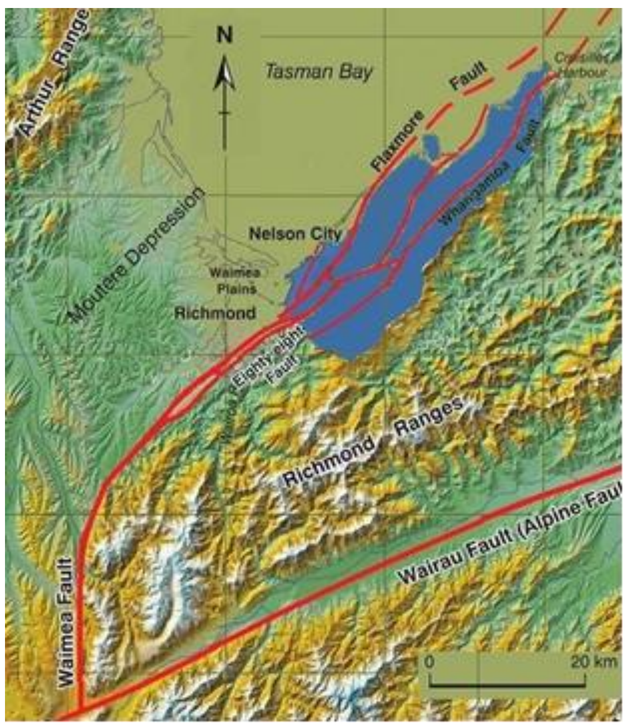


Fig. 1: Waimea-Flaxmore Fault System
(compiled from Rattenbury et al. 1998)

2.2 The flat to gently sloping land close to sea level is composed of river and fan gravels along with, at Tahunanui, the head of Nelson Haven and locally elsewhere, marine sands and gravels and estuarine deposits. These rocks are divided into two: those are currently being deposited or have accumulated in geologically recent time known as the Holocene and immediately older deposits of Late Pleistocene age. The Holocene and Late Pleistocene deposits, collectively part of the Late Quaternary, have in the past been mapped using conventional stratigraphic names but are now classified according to their oxygen isotope age. Holocene deposits are assigned to Q1 whereas last Glaciation deposits are Q2 (Fig. 2).

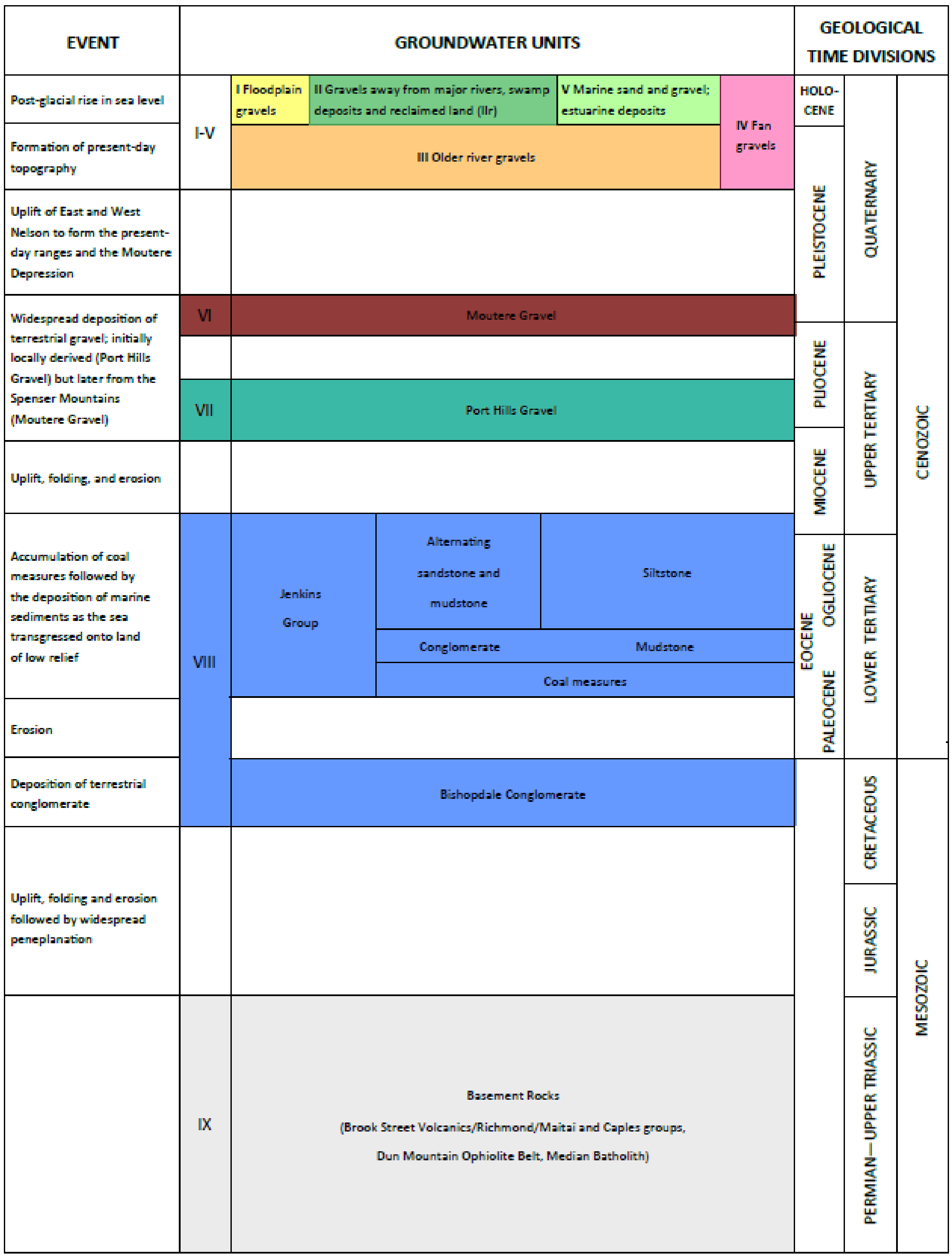


Fig. 2: Major rock and groundwater units in Nelson City

2.3 The low hills are composed of Port Hills Gravel formation, of Pliocene age, and a variety of terrestrial and marine sediments belonging to the Jenkins Group, of Eocene to Early Miocene age, and the Late Cretaceous Bishopdale Conglomerate. The Jenkins Group includes coal measures, siltstone, conglomerate, alternating sandstone and mudstone beds and lenses of limestone. The group largely crops out from Magazine Point to Annesbrook and from the head of Collingwood Street to Enner Glynn although there are slivers of these rocks along many of the major faults. Although not exposed in the city, the Moutere Gravel, of Late Pliocene to Early Pleistocene age, is known beneath the fan gravels at Stoke and crops out extensively within the Moutere Depression in the Tasman District. The Moutere Gravel has a clay-rich matrix enclosing rounded pebbles and small boulders of greywacke sandstone derived from the Spenser Mountains south of the Alpine Fault. In contrast the older Port Hills Gravel is transitional to a rock so that its matrix has, except where weathered, more the characteristics of a weak siltstone. It also differs from the Moutere Gravel in that its pebbles and boulders are derived from the more varied basement rocks in and adjacent to the city. The Jenkins Group and Bishopdale Conglomerate are relatively weak and shearing is widespread, particularly where they are in proximity to the major faults.

2.4 The intermediate hills and the Bryant Range are composed of a variety of hard indurated rocks, here collectively referred to as "basement rocks". The rocks are divided into the sedimentary Drumduan, Richmond, Maitai and Caples[4] groups and the Dun Mountain Ophiolite Belt. Between the head of the Nelson Haven and Delaware Bay the Drumduan Group is intruded by igneous rocks of the Tasman Intrusives (Echinus Granite, Cable Granodiorite and Palisade Andesite) that constitute part of the Median Batholith. Although the basement rocks are generally hard, being well indurated, they contain numerous planes of weaknesses.

3. GROUNDWATER POTENTIAL

3.1 The groundwater potential is discussed under the following geological units, whose distribution in the city is shown on Fig. 3:

I – Holocene floodplain gravels deposited by the major rivers
II – Other Holocene terrestrial deposits (II) and reclaimed land (IIr)
III – Older river gravels
IV – Holocene and Late Pleistocene fan gravels
V – Holocene marine sand and gravel and estuarine deposits
VI – Moutere Gravel
VII – Port Hills Gravel
VIII – Jenkins Group and Bishopdale Conglomerate
IX – Basement rocks

[4] Mapped as Pelorus Group on the 1:50 000 geological map (Johnston 1981).

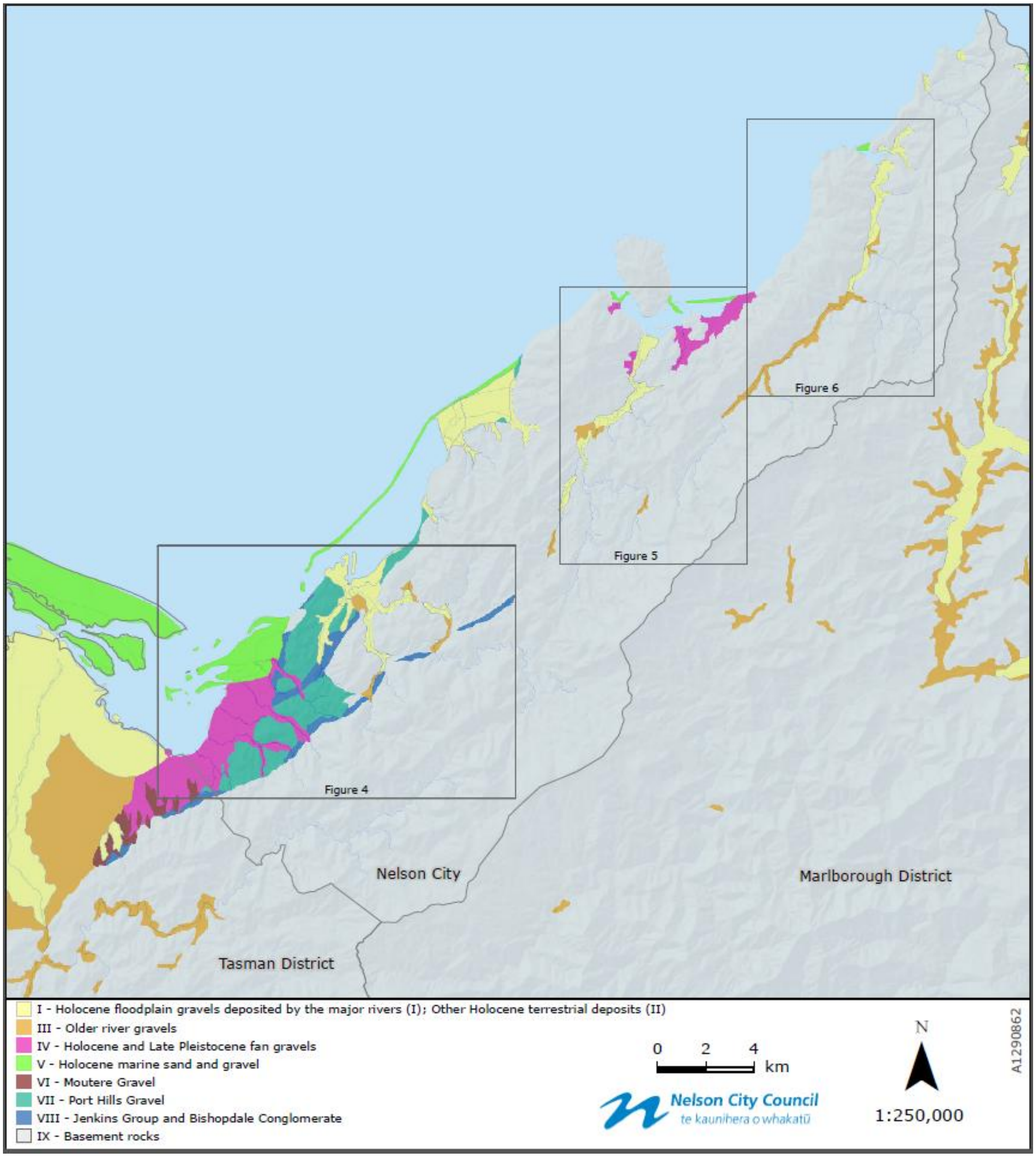


Fig. 3: Broad surface distribution of the groundwater units in Nelson City. For details of the distribution of units I to V see figs. 4, 5 and 6 (modified from Johnston 1981, 1882, 1993; Rattenbury et al. 1998)

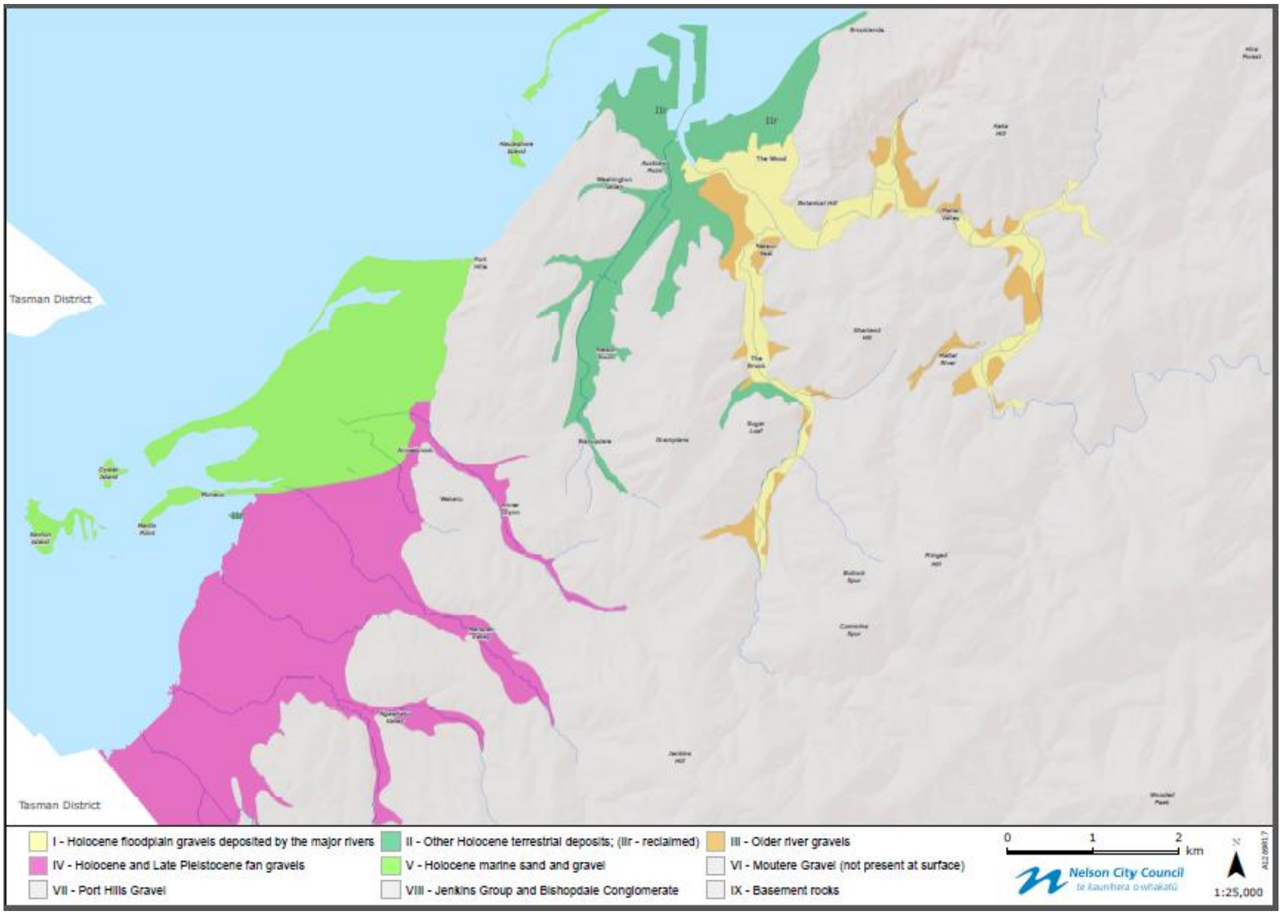


Fig. 4: Distribution of Units I to V in the urban area of Nelson City (boundaries modified from Johnston 1979)

4. FOODPLAIN GRAVELS (Unit I)

4.1 *Distribution* – the Holocene gravels forming the floodplains of the major rivers and are most extensive at the southern end of Nelson Haven at the mouth of the Maitai River (Fig. 4). Smaller areas of gravels exist at the mouths of the Wakapuaka (Fig. 5) and Whangamoa rivers (Fig. 6) and locally elsewhere. The gravels had been mapped as Appleby Gravel but are now assigned to oxygen isotope age 1 on the published 1:250 000 geological maps where the stage numbers are prefixed by the letter Q. Inland from the coast the floodplain gravels become narrower and also progressively thinner. They were deposited under warm (interglacial) climatic conditions and because finer grained material tended to be removed by a process known as degradation, the pebbles and small boulders are poorly to well sorted and the matrix typically ranges from silty clay to fine silty sand. In the reserve beside Riverside Pool the floodplain gravels extend to a depth of about 6.7 m below the surface (Fig. 7) but at Hanby Park they are only about 2.7m thick (Fig. 8).

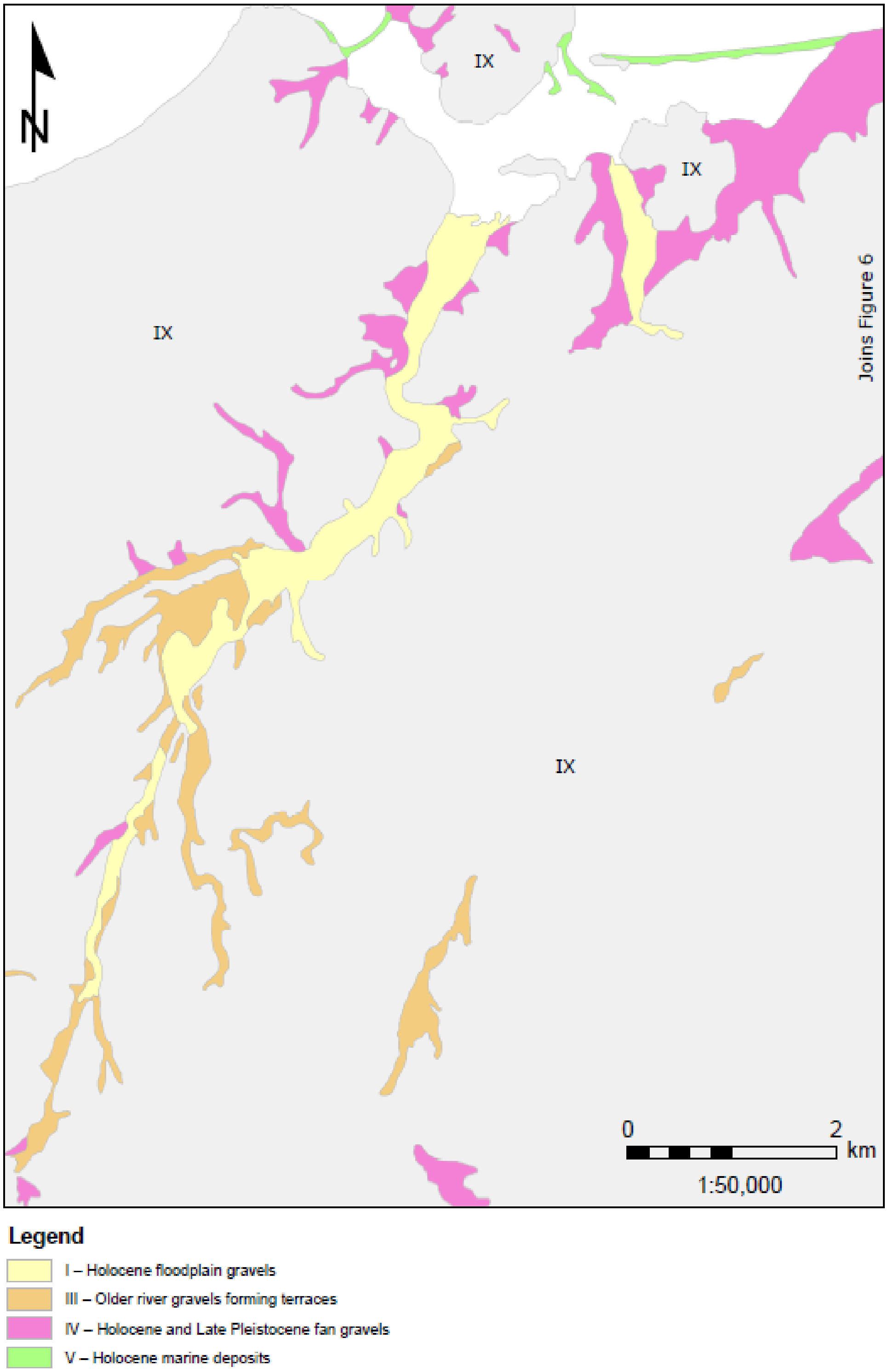


Fig. 5: Outcrop of Units I, III, IV and V in the lower Wakapuaka valley (boundaries modified from Johnston 1981)

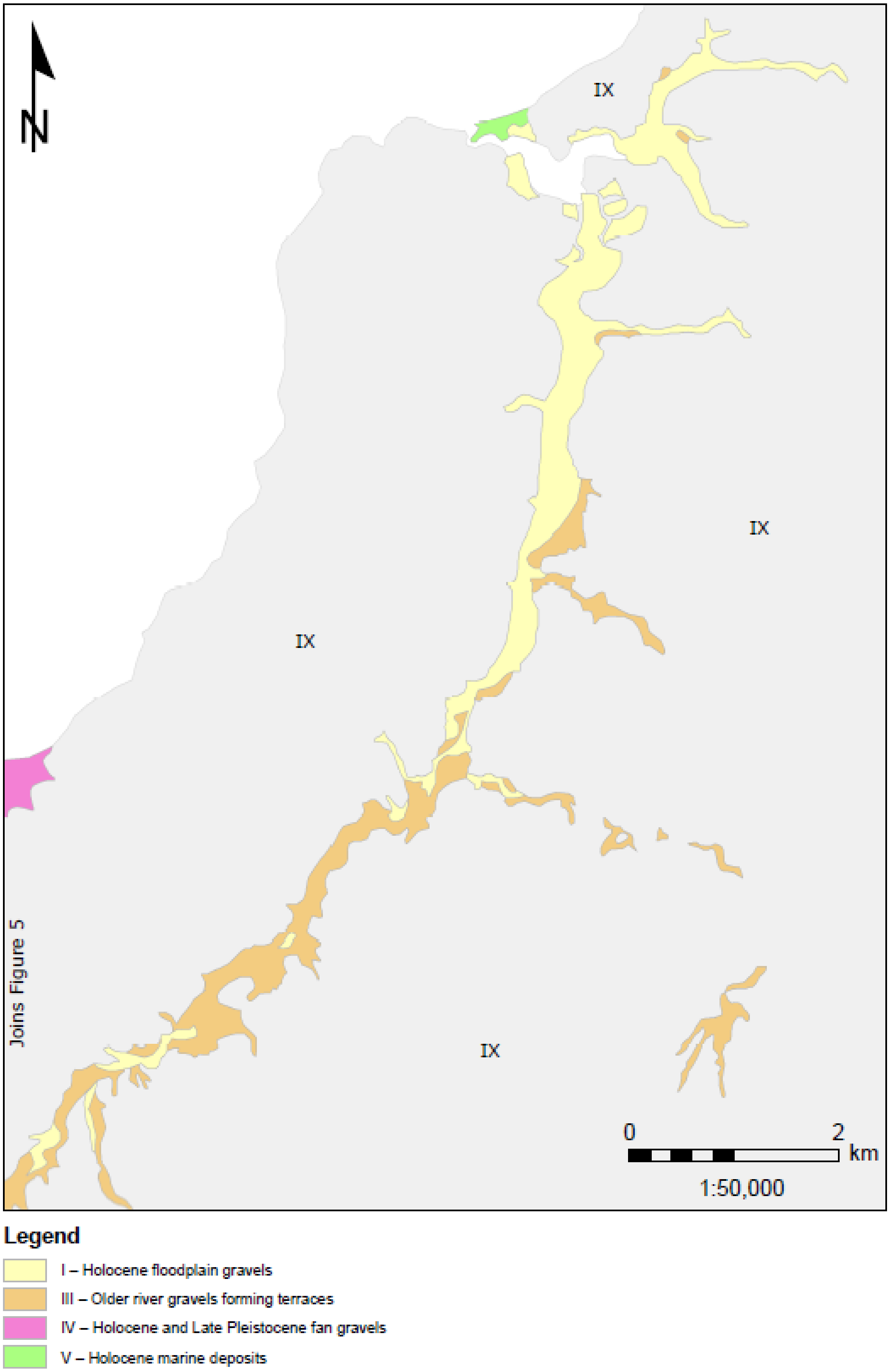
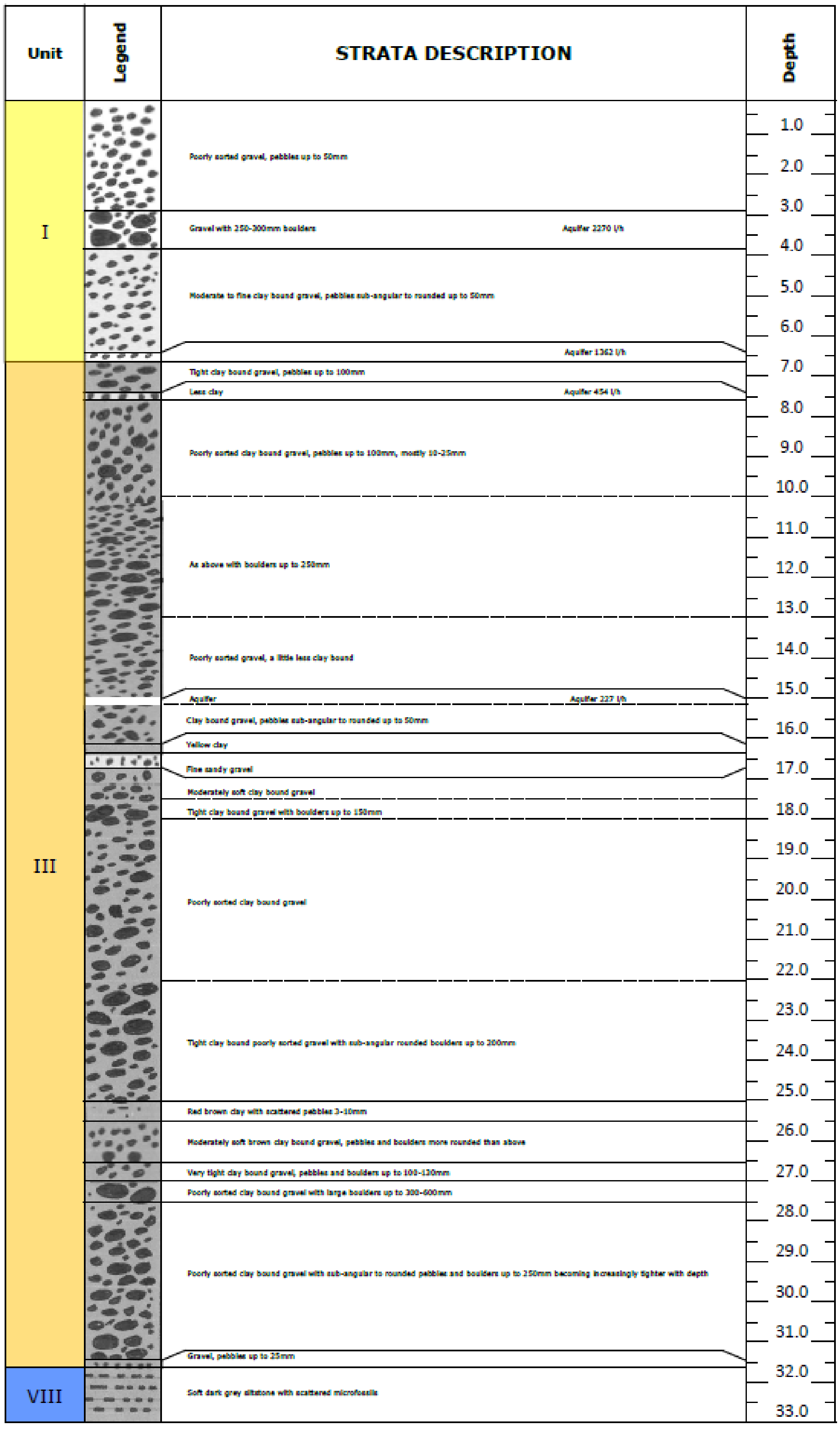


Fig. 6: Outcrop of Units I, III, IV and V in the lower Whangamoa valley (boundaries modified from Johnston 1982).


Unit
Legend
STRATA DESCRIPTION
Depth
I
III
VIII
Poorly sorted gravel, pebbles up to 50mm
Gravel with 250-300mm boulders
Aquifer 2270 l/h
Moderate to fine clay bound gravel, pebbles sub-angular to rounded up to 50mm
Aquifer 1362 l/h
Tight clay bound gravel, pebbles up to 100mm
Less clay
Aquifer 454 l/h
Poorly sorted clay bound gravel, pebbles up to 100mm, mostly 10-25mm
As above with boulders up to 250mm
Poorly sorted gravel, a little less clay bound
Aquifer
Aquifer 227 l/h
Clay bound gravel, pebbles sub-angular to rounded up to 50mm
Yellow clay
Fine sandy gravel
Moderately soft clay bound gravel
Tight clay bound gravel with boulders up to 150mm
Poorly sorted clay bound gravel
Tight clay bound poorly sorted gravel with sub-angular rounded boulders up to 200mm
Red brown clay with scattered pebbles 3-10mm
Moderately soft brown clay bound gravel, pebbles and boulders more rounded than above
Very tight clay bound gravel, pebbles and boulders up to 100-120mm
Poorly sorted clay bound gravel with large boulders up to 300-600mm
Poorly sorted clay bound gravel with sub-angular to rounded pebbles and boulders up to 250mm becoming increasingly tighter with depth
Gravel, pebbles up to 25mm
Soft dark grey siltstone with scattered microfossils
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
24.0
25.0
26.0
27.0
28.0
29.0
30.0
31.0
32.0
33.0
EOH: 33.0m

Caption for previous page: *Fig. 7: Borehole adjacent to Riverside Pool, Nelson (NZTopo50-BQ26 241311)*
(redrawn and simplified from log held by GNS Science)

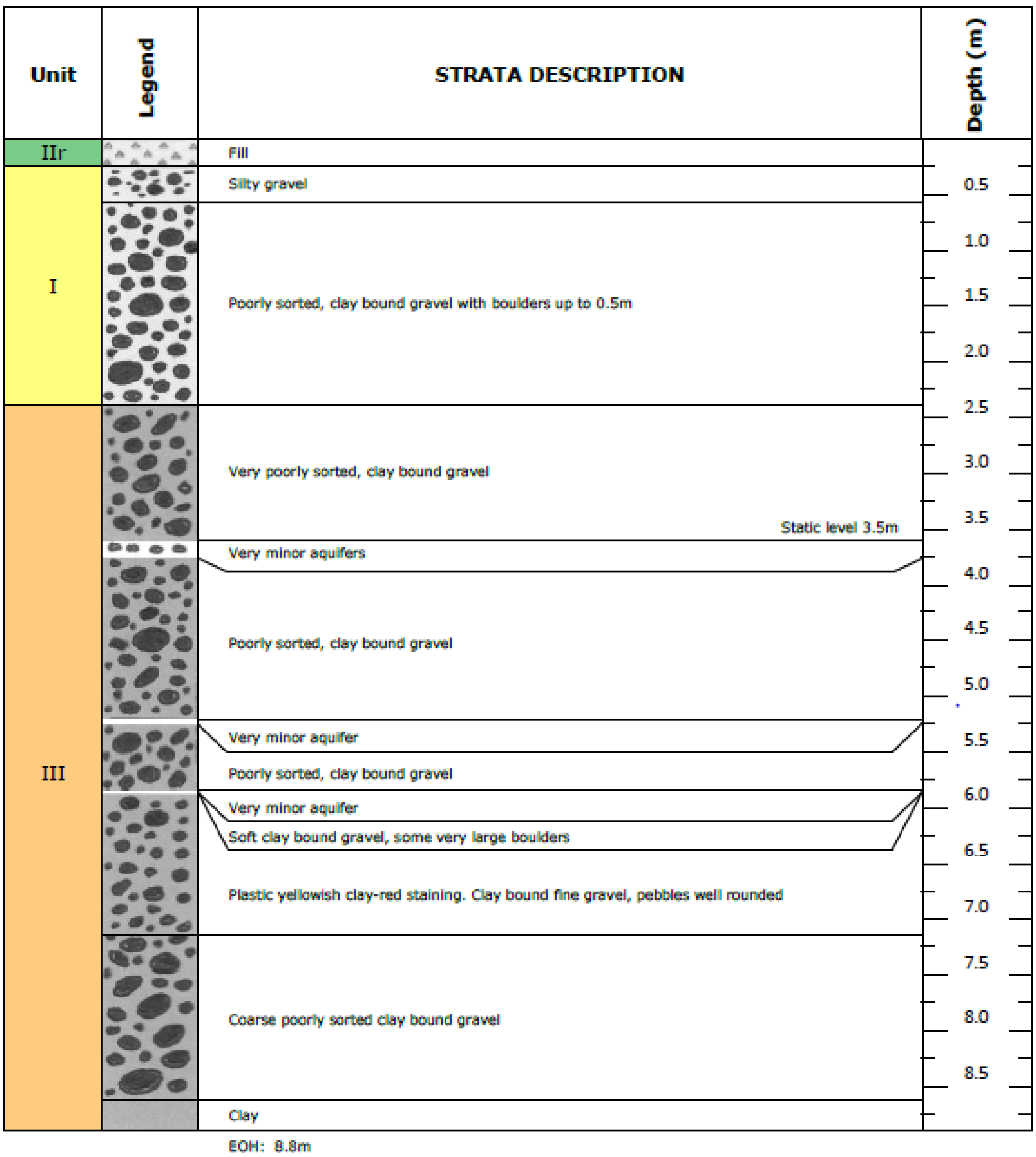


Fig. 8: Borehole Hanby Park, Nelson (NZTopo50-BQ26 254307)
(redrawn and simplified from log held by GNS Science)

4.2 *Groundwater potential* – the gravels being better sorted that most of the other Quaternary deposits have a low to high degree of permeability. Where water saturated they form an unconfined aquifer although aquicludes at depth can result in confined aquifers. Recharge is primarily from the adjacent river. In Nelson City the gravels were extensively exploited prior to the introduction of a piped water supply from the Brook Stream in the 1860s and usage continued subsequently for horticulture, particularly in the many commercial tomato growing glasshouses that existed in The Wood until relatively recently. Known present takes are in the city council reserves of Queens Gardens and the Botanics. Since the development of the modern Port Nelson, commencing in the 1950s, the deepening of the harbour has caused the Maitai River to lower its bed as far inland as Hardy Street. The placement of rock at the Normanby Bridge has arrested this headward deepening of the river bed. However, the lowering of the riverbed has reduced the recharge of the unconfined aquifer and also the likely volume of water stored in it. Further up the Maitai River and The Brook, and in the Wakapuaka and Whangamoa valleys, the gravels are thin, with considerably less storage capacity.

4.3 *Water quality* – the groundwater water is at risk from surface contamination, leaking stormwater and sewer pipes in built up areas and in rural areas septic tanks and farming activities. Bores and wells for the former commercial glasshouses near the coast were also at risk of saltwater intrusion if over pumped, particularly on the upper part of the tidal cycle. Soil underlying former glasshouses may be contaminated by pesticides that could have the potential to leak into groundwater.

4.4 *Comment* – the floodplain gravels form important unconfined aquifers and locally confined aquifers that are largely recharged from the river that deposited them and to a much lesser extent rainfall and, where there is urbanisation, leaking pipes. The most extensive area of gravel is in the central city although the potential for recharge has been diminished by the confining of the river in its lower reaches, which has been subsequently compounded by the lowering of its bed as a result of the deepening of Port Nelson. There could be some contamination of the aquifer from leaking pipes and current and former land use. Inland the floodplain gravels become progressively thinner and therefore their storage capacity diminishes proportionally. Thus inland the taking of groundwater has the potential to progressively impact on river flows as distance from the coast increases. Adjacent to the coast over-pumping could cause saltwater intrusion.

5. OTHER HOLOCENE TERRESTRIAL DEPOSITS (Unit II)

5.1 *Distribution* – the Holocene deposits (Q1), including those of anthropogenic origin, away from the major floodplains are characterised by high proportion of silt and clay. The most extensive deposits are those comprising the Nelson Alluvium, which fills valleys draining the Port Hills and Bishopdale (Fig. 9). Extensive estuarine and swamp deposits fill the head of Nelson Haven and reclaimed land (IIr) is widespread around the southern end of the haven from Atawhai Drive to Port Nelson and locally at Monaco. Land reclaimed at Nelson Airport by infilling of the estuary of Jenkins Creek has characteristics similar to the adjacent natural ground and is, consequently, included, in Unit V.

5.2 *Groundwater potential* – The deposits have a very low permeability and consequently the groundwater potential is correspondingly low. Very thin aquifers may locally exist in the Nelson Alluvium capable of yielding extremely small, but probably reliable, volumes of water.

5.3 *Water quality* – depending on the recharge area the water may be subject to contamination from past and existing land use.

5.4 *Comment* – the terrestrial deposits (other than the floodplain gravels – Unit I) because of their high proportion of fines have a very low groundwater potential. Consequently, such deposits can be disregarded as a significant source of groundwater.

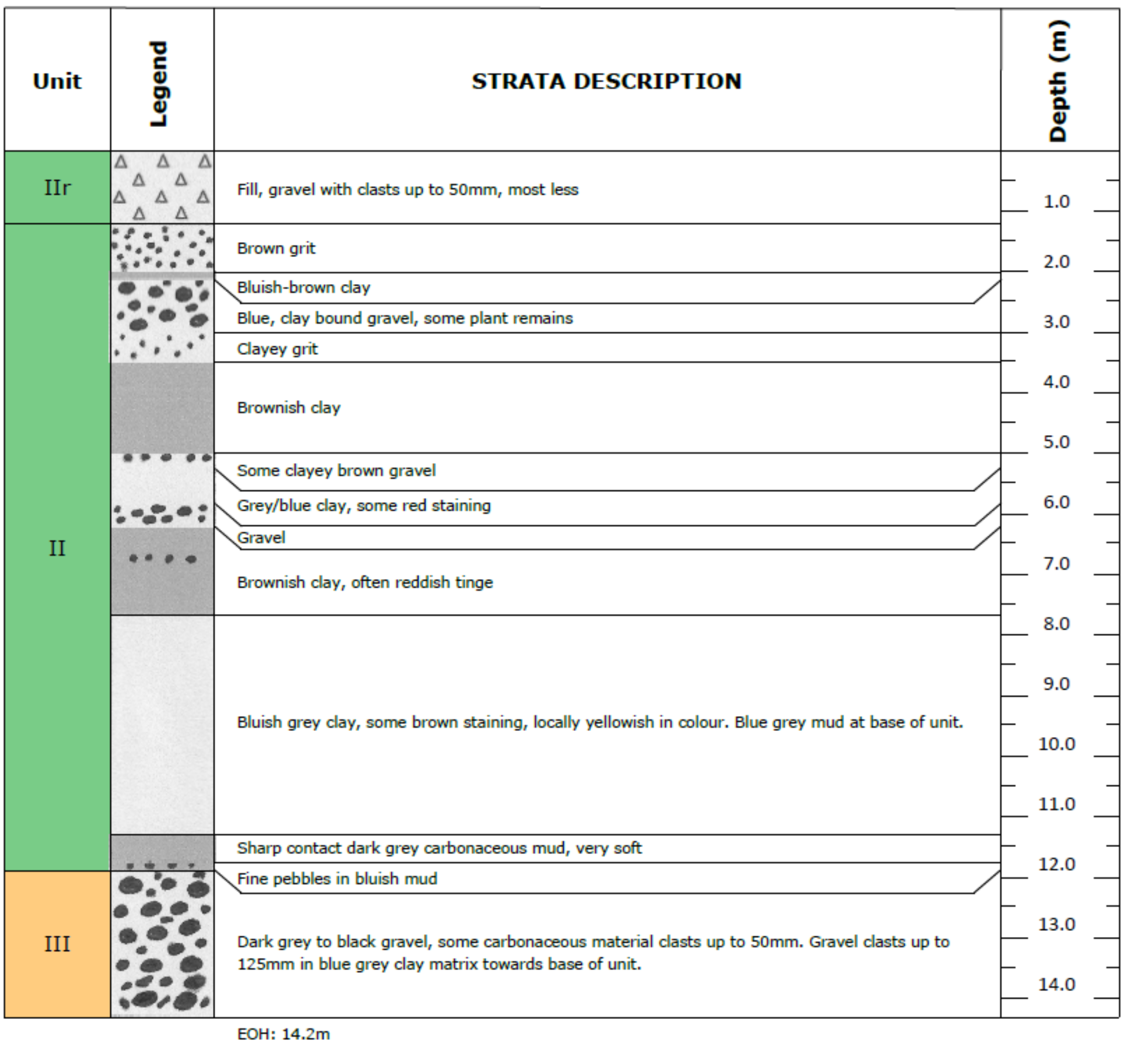


Fig. 9: Borehole Hardy Street in Unit II Nelson Alluvium (NZTopo50-BQ26 237310) (redrawn and simplified from log held by GNS Science)

OLDER RIVER GRAVELS (Unit III)

5.5 *Distribution* – the older river gravels form terraces in the major valleys and were previously mapped as Hope Gravel. They were deposited under cold climatic conditions of the late Pleistocene, largely during the last glaciation (Q2) but eroded remnants deposited during older glaciations (Q4, Q6) are locally present. Although known as glacial outwash or aggradation deposits, no glaciers existed within the city. The gravel is about 25 m thick in the borehole adjacent to the Riverside Pool where it rests on the Jenkins Group at a depth of 32 m below the ground surface.

5.6 *Groundwater potential* – typically the outwash gravels were deposited relatively rapidly, in contrast to the degradational floodplain gravels (Unit I). The generally poor sorting and an abundance of silty-clay forming their matrix results in the deposits having very low permeability. Consequently their groundwater potential is limited although sparse thin permeable, commonly pebbly, layers exist, and tend to be more common in the upper part of the gravels deposited as the climate began warming. In the Riverside Pool borehole two thin aquifers, each with an estimated flow of several hundred litres an hour, were encountered at depths of approximately 7.4 m and 15 m below the surface (Fig. 7).

5.7 *Water quality* – the groundwater, where present, is likely to be of good quality but where slow moving and, more particularly in the older deposits, may have increased levels of iron and manganese resulting from the *in situ* weathering of the gravel and the chemical breakdown of pebbles and boulders derived from some of the basement rocks. Except possibly where there is a very high concentration of ultramafic pebbles and boulders derived from the ophiolite belt, the water should still be potable.

5.8 *Comment* – the gravels have a very low permeability but thin layers of commonly more pebbly gravel containing less clay form small confined aquifers. Those close to terrace edges have a tendency to fail when the water table lowers during dry periods. Under the Waimea Plains the similar Hope Gravel contains two major confined aquifers (see figure 17 in Johnston 1979). However, these aquifers are not aggradation gravels but are degradational gravels deposited during interglacials. They are thus buried floodplain gravels of the Wairoa-Waimea rivers. The differing gradients of the Waimea-Wairoa river at the time when the degradational and aggradational gravels were being deposited have resulted in the preservation of the latter. This rather unique situation does not appear to have existed in the major valleys in Nelson City. Therefore it is unlikely that degradational gravels, forming confined aquifers, exist at depth beneath the central city although there is a low possibility that remnants of such gravels may exist. In the only known deep borehole, at Riverside Pool (Fig. 7), only two insignificant confined aquifers were encountered in Unit III below the modern floodplain gravels. However, this borehole may not have been in the deepest part of the paleo-Maitai valley that was eroded into the Jenkins Group and Port Hills Gravel.

6. HOLOCENE AND LATE PLEISTOCENE FAN GRAVEL (Unit IV)

6.1 *Distribution* – the Stoke Fan Gravel formation is extensive in the wider Stoke area and on the east side of Delaware Bay and is locally present elsewhere. Very small fans are common at the mouths of small creeks and gullies in the hills of intermediate height and the Bryant Range. Many of these small fans grade into the adjacent degradation or aggradation gravels deposited in the main valleys and are not here distinguished from them. The fan gravel at Stoke rests unconformably on a probably undulating surface of Moutere Gravel. Although several boreholes have penetrated the fan gravels and bottomed in Moutere Gravel, the logs have not differentiated the contact between the two formations. At the Ryman Health Care site in Covent Drive the fan gravels are at least 48 m thick (Ryman 1 Borelog in Aqualinc report). However, in several of the other logs in the Aqualinc report the depth to Moutere Gravel appears to be considerably less than this, possibly 16.0 m or 21.0 m in borelog 23566 at 600 Main Road Stoke and 17.0 or 25.0 m in borelog 6759 at 16 Sargeson Street. These depths are consistent with the undulating landform developed on the Moutere Gravel in the Richmond area.

6.2 *Groundwater potential* – Although the fan gravel is generally poorly sorted much of it is composed of tabular pieces of rock, derived from finely bedded Maitai Group, giving rise to more permeable horizons. Such horizons are more abundant in the younger, Holocene gravels (Q1), rather than in the more silty-clay bound Pleistocene fans (Q2), forming remnants on the side of Marsden Valley, which are also more deeply weathered. Recharge is from rain fall and the streams that deposited the fans. The fans have a relatively steep gradient and the upper part of the underlying deposits tend to become dewatered during dry summers. As the streams are on the axes of the fans, they can become perched if the upper parts of the fans are dewatered. It was the unreliability of water supplies in the fan deposits that resulted in the demise of many of the orchards that formerly existed in the northern part of Stoke.

6.3 *Water quality* – contamination from former orchards is possible. As the Stoke area is now built on contamination of groundwater from surface stormwater drains and buried pipes could occur. However, in the south the infrastructure is relatively new and consequently contamination from pipes may not be an issue.

6.4 *Comment* – the fans can yield relatively small volumes of water but as they tend to dewater in summer there have been problems with the reliability of wells during dry summers. Deeper, more permeable, horizons will yield a more reliable supply of water. Recharge of the gravels could be enhanced by discharge of stormwater from roofs to the ground. However, this may lead to excess water flows on the lower parts of the fan adjacent to the coast during winter.

7. HOLOCENE MARINE SAND AND GRAVELS AND ESTUARINE DEPOSITS (Unit V)

7.1 *Distribution* – the marine sands and gravels underlie Tahunanui and locally elsewhere, including the Boulder Bank and a bank or tombolo of similar composition at Cable Bay. Estuarine deposits are present at the northern (The Glen) and southern (Saltwater Creek area) ends of Nelson Haven, at the mouths of the Wakapuaka and Whangamoa rivers and locally at Tahunanui. The marine sands at the Tahunanui Motor Camp are 24.5 m thick and overlie 4.5 m of dark estuarine mud. Below the mud is 3.6 m of relatively clean water bearing gravel overlying Moutere Gravel (Fig.

10). The marine sands thin towards the south, being 12.5 m thick at the northeast corner of the Nelson Golf Course, and the estuarine and marginal marine deposits are correspondingly thicker[5].

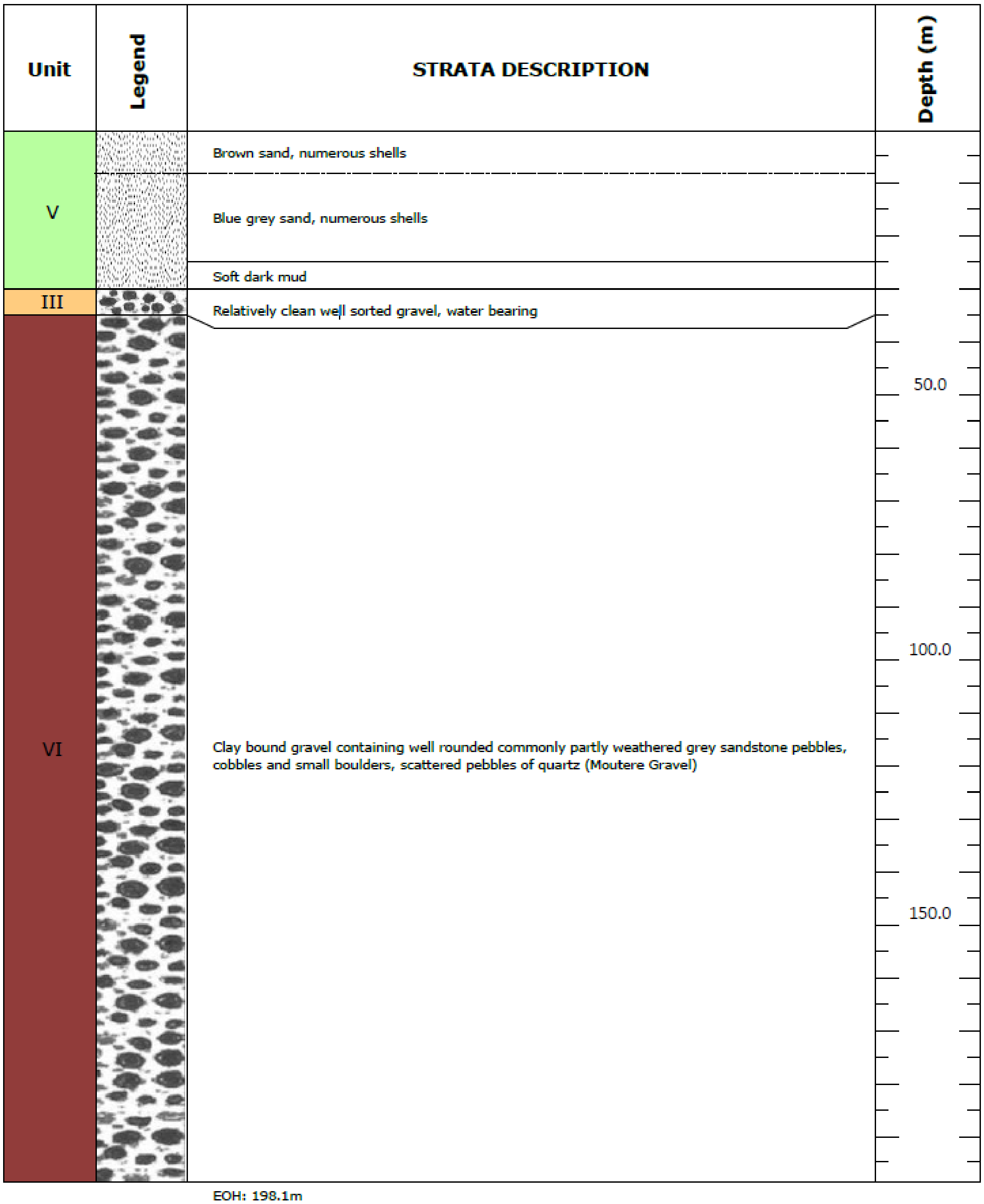


Fig. 10: Borehole Tahunanui Beach (NZTopo50-BQ26 201298)
(E. D. Wilson Drilling Ltd log held by GNS Science)

[5] Tonkin & Taylor 2013: *Tahunanui Area Liquefaction Assessment*. Unpublished client report prepared June 2013 for the Nelson City Council. This borehole terminated at 22.5 m in a marginal estuarine deposit comprising silt and silty gravel

7.2 *Groundwater potential* – The marine deposits, consisting of loose sand and gravel, have a relatively high permeability so that they form unconfined aquifers. Recharge is from rain fall, surface flows from Jenkins and other lesser creeks and, in the Tahunanui area, leakage from pipes. The freshwater overlies saline water and over use can hasten depletion of the resource in summer with the danger of saltwater intrusion. The relatively clean water bearing gravel at 28.9 to 33.5 m below the Tahunanui Motor Camp was apparently not pump tested. It reportedly had a subsurface static level suggesting that it is saline. It is possible that the gravel is a correlative of the Upper Confined Aquifer intersected at a similar depth on the eastern end of Rabbit Island and which is also salt contaminated (see figure 17 in Johnston 1979). The estuarine deposits have a very low permeability and have no groundwater potential.

7.3 *Water quality* – there is a risk of contamination from surface land use, buried pipes and saline intrusion. Where estuarine deposits are present water quality is likely to be affected by organic matter.

7.4 *Comment* – while the Tahunanui area comprises a large unconfined aquifer, the layer of freshwater is thin and becomes naturally depleted in summer. There is a high risk of saltwater contamination if the aquifer is over exploited.

8. MOUTERE GRAVEL (Unit VI)

8.1 *Distribution* – the Moutere Gravel, of Late Pliocene age, is only known in Nelson City from beneath the Stoke Fan Gravels between Champion Road and Annesbrook but will continue to the west and north. In the east it is inferred to be faulted against Port Hills Gravel and Jenkins Group rocks. The thickness of gravel is not known but being in the fault-angle Moutere Depression, formed by the Waimea-Flaxmore Fault System (Fig. 1), it is, from geophysical evidence, over a kilometer thick. A borehole in the Hope area of the Tasman District penetrated Moutere Gravel for 600 m. Thus there is a large volume of gravel buried beneath the east of the city. Bedding in the gravel is anticipated to dip gently northeast.

8.2 *Groundwater potential* – Although there is a large volume of gravel it has a very low permeability due to its silty clay matrix. However, it does contain small layers and lenses of more permeable material and these are capable of yielding small, but consistent, flows when encountered in deep boreholes.

8.3 *Water quality* – the quality is expected to be good, being similar to that encountered in existing boreholes in Stoke and Tasman District. Where flows are very low there could be elevated levels or iron and manganese minerals.

8.4 *Comment* – Despite its large volume, only a very small proportion of the Moutere Gravel is sufficiently permeable to yield groundwater. Nevertheless, because of its great thickness a deep borehole has the potential to intersect several permeable horizons. The low permeability results in significant drawdown during pumping and the spacing between bores has to be large to prevent interference. The groundwater resource of the Moutere Gravel in Nelson City has been recently assessed in the Aqualinc report.

9. PORT HILLS GRAVEL (Unit VII)

9.1 *Distribution* – The Port Hills Gravel formation, of Early Pliocene age, crops out on the eastern and southern margins of Nelson Haven, extensively in the Port Hills and in the low hills extending south from upper York valley to Champion Road. The formation rests with angular unconformity on the Jenkins Group south of Nelson Haven. On the east side of Nelson Haven it dips, at about 35º to 45º towards the Flaxmore Fault. Elsewhere the formation is folded into the northeast trending Port Hills and, further to the south, Marsden synclines. Dips in the western limbs do not exceed 50º but the formation is sub-vertical on the eastern limbs. The gravel contains sub-rounded to rounded pebbles to boulders over a metre across although they rarely exceed 150 mm. The pebbles and boulders are composed of a variety of rocks although sandstones derived from east Nelson are dominant. Locally there are pebbles and boulders of Dun Mountain ophiolitic rocks and, particularly in the lower part of the Port Hills Gravel, granitic rocks derived from the west.

9.2 *Groundwater potential* – The formation is a weak rock and has a very low permeability. Despite this, finer-grained horizons tend to act as aquicludes so that there is a slow movement of water along sparse bedding planes resulting in very minor seepages where they intersect the surface or are exposed in cut faces. A deep borehole drilled many decades ago in Trafalgar Square for Nelson Breweries Ltd, which was sited where the Rutherford Hotel now stands, failed to encounter any significant flows. However, it is not known how well this borehole was developed While it is anticipated that boreholes penetrating a considerable thickness of the formation, which is 500 m or more thick (and with an even greater apparent thickness depending on the dip of the formation at any particular location), could yield extremely low flows, these are expected to be significantly less than for a comparable thickness of Moutere Gravel.

9.3 *Water quality* – groundwater is expected to be high in iron and manganese although likely still potable.

9.4 *Comment* – the Port Hills Gravel is considered to have very low potential as a source of groundwater. Artificially inducing fractures to increase permeability and water flows into a deep well may have limited potential due to the formation being a soft rock.

10. JENKINS GROUP AND BISHOPDALE CONGLOMERATE (Unit VIII)

10.1 *Distribution* – The Jenkins Group, of Late Eocene to Early Miocene age, underlies the Port Hills Gravels and crops out on the limbs of the Port Hills and Marsden synclines. On the western limbs of the synclines the group is exposed from Richardson Street to Ridgeway South but is more extensive on the eastern limb of the Port Hills Syncline from Nelson South to Enner Glynn. The group also occurs as slivers along the Waimea Fault. Immediately west of the Flaxmore Fault a strip of distinctive red coloured Bishopdale Conglomerate, of probable Late Cretaceous age, is poorly exposed and has similar lithological characteristics to the Jenkins Group.

10.2 *Groundwater potential* - although the unit is lithologically variable, ranging from mudstone to conglomerate and with a sequence of alternating sandstone-mudstone beds in the west and lenses of limestone in the east, it has a very low permeability. Consequently Unit VIII has a very low potential as a source of groundwater. Where the unit is on the down faulted side of the Flaxmore and, locally, the Waimea faults it, and the pug developed along the faults themselves, tends to act as an aquiclude. Consequently, groundwater moving through the basement rocks (see below) on the upthrow side of the faults, such as The Grampians east of the Flaxmore Fault between Brougham Street and York Stream, tends to rise to the surface as a series of seepages and minor springs. Because of scree, slope wash and slope failure deposits derived from the basement rocks the location of the seepages may not coincide exactly with the faults.

10.3 *Water quality* – water is likely to be potable but with elevated levels of iron and, in the coal measures, sulphurous compounds.

10.4 *Comment* – the unit has a very low groundwater potential. Although the rocks are more indurated than in the Port Hills Gravel, artificial enhancement by fracturing is unlikely to significantly increase water yields in deep boreholes. Hard rocks more amenable to induced fracturing, such as limestone, form only very small lenses in the Jenkins Group.

11. BASEMENT ROCKS (Unit IX)

11.1 *Distribution* – Except where covered by alluvial deposits in the floors of the valleys and locally elsewhere, the basement rocks comprise the bulk of Nelson City and form all of the intermediate hills and the Bryant Range.

11.2 *Groundwater potential* – although the rocks are hard and indurated they contain numerous weaknesses, such as bedding, joint, fracture and cleavage planes. These planes give the rocks a low degree of permeability and collectively they can contain a large volume of water. It is this groundwater discharging into the valleys that sustains river flows during prolonged dry spells. While the volume of water is large, it is difficult to recover although deep, well developed boreholes, particularly those in crush zones where the rocks are more highly fractured, will yield small reliable flows.

11.3 *Water quality* – because many of the rocks are weakly mineralised, particularly in iron pyrites, water from depth is likely to be slightly mineralised. In addition to pyrite, sparse chalcopyrite is present locally in the Brook Street Volcanics, Cable Granodiorite and Palisade Andesite. Arsenopyrite is likely in the Brook Street Volcanics. The eastern, ultramafic, part of the Dun Mountain Ophiolite Belt is composed of magnesium-rich rocks with zones of chromite, copper and iron as well as sparse, but widely dispersed, nickel, mineralisation. Zones of copper mineralisation are also known within the western (mafic) part of the belt just beyond Nelson City. Consequently water from depth in the basement rocks may contain elevated levels of some minerals, although these will be less in the Maitai and Richmond groups extending from Cape Soucis to the Barnicoat Range.

11.4 *Comment* – although small quantities of water could be obtained from appropriately sited and developed boreholes, the cost is likely to make them unattractive. Bores adjacent to natural springs, which indicate a higher level of permeability, may also increase the reliability of supply in summer when the water table drops. Most of the basement rocks are indurated and therefore can be readily fractured, which will increase flows into deep boreholes. Water in boreholes is at risk from contaminated from mineralised rocks although this is likely to be low in the Maitai and Richmond groups but increasing in the Brook Street Volcanics and the igneous rocks and rising to an elevated risk in the ultramafic rocks of the "mineral belt", which are rich in magnesium and locally in copper, chromite and nickel. The potential for contamination should be thoroughly assessed before any drilling in the basement rocks is contemplated.

12. CONCLUSIONS

12.1 All but the young (Holocene, Q1) floodplain and marine deposits (Units I and V) have a very low groundwater potential.

12.2 Of the older units, the Moutere Gravel (Unit VI) beneath Stoke and Tahunanui is expected to give yields similar to those already determined from boreholes beneath Stoke and in parts of the Tasman District. As the base of the Moutere Gravel beneath Tahunanui-Stoke has not been reached there is potential for even deeper boreholes to encounter additional minor aquifers similar to those in the upper part of the gravel.

12.3 The Port Hills Gravel (Unit VII) and Jenkins Group and Bishopdale Conglomerate (Unit VIII) consist of rocks that, although they contain planes of weakness, particularly adjacent to the major faults, these are generally not as well defined or as "clean" as those in the basement rocks. Consequently, the groundwater potential in both units is very low.

12.4 The basement rocks (Unit IX) have numerous planes of weakness giving them a low permeability. Yields from appropriately developed boreholes in highly fractured rocks could be similar to or better than those in the Moutere Gravel. Boreholes penetrating deep into rocks containing pyrite and other minerals, including magnesium, chromium, copper and nickel in the "mineral belt" rocks, may be contaminated. However, except in the latter they may not pose a serious health hazard. Nevertheless, the possibility of contamination should be taken into consideration if the groundwater in the basement rocks is to be exploited.

12.5 Of all the units, the basement rocks are the most suited for artificially increasing water flows in deep boreholes by fracturing.

12.6 Because the basement rocks are in hill to mountainous areas there is usually sufficient surface water to meet expected needs other that in some locations during periods of dry weather and low surface flows. Consequently, storage options may be a more economical solution to water shortages.

12.7 The Stoke Fan Gravel (Unit IV) consists largely of platy gravel that, while poorly sorted, contains some permeable lenses, which are more numerous in their stratigraphically upper and younger part (Holocene). The older Stoke Fan Gravel, having been largely deposited during glacial periods, has a greater percentage of fine material, is more weathered where exposed, and is generally less permeable. However, the upper parts of the younger fans (Q1) tend to dry out in summer with the possibility of perched water tables where the creeks flow down the axes of the fans.

12.8 The older terrace gravels (Unit III) were deposited during glacial periods when there was an abundance of fine material. This has resulted in the gravels being both poorly sorted and having a low permeability. Unless there are older interglacial deposits preserved within the gravel in the lowermost Maitai valley, which is considered unlikely, then their groundwater potential is low.

12.9 Holocene marine sands and gravels (Unit V), but excluding estuarine deposits, have generally a higher level of permeability than the other units but the water in them is unconfined, overlies saline water at depth and is recharged by rainwater along with limited surface flows from the Port Hills and Jenkins Creek and from leaking drainage pipes. The freshwater becomes depleted during summer and there is a high risk of contamination from surface land use and leaking pipes.

ACKNOWLEGEMENTS
Figures 3 and 4 were drawn and digitised by Dr Steve Read, Nelson City Council and Ms Jasmine Snowsill prepared figures 2, 5, 6, 7, 8, 9 and 11. Mr Peter Grundy, Nelson City Council, supplied information on shallow wells in the Botanics and Queens Gardens.

LIMITATIONS

This assessment has been prepared solely for the Nelson City Council and is based on existing published geological maps and a limited amount of unpublished data. No site specific investigations have been undertaken for any of the geological units referred to in this report and future work may modify the conclusions reached. Borelogs in the report have been simplified with some generalisations.