BEFORE THE HEARINGS PANEL

IN THE MATTER of hearings on submissions concerning the Proposed One Plan notified by the Manawatu-Wanganui Regional Council

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SECTION 42A REPORT OF MR HISHAM IBRAHIM SABRI ZAROUR ON BEHALF OF HORIZONS REGIONAL COUNCIL

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1. INTRODUCTION

My qualifications/experience

1. My full name is Hisham Ibrahim Sabri Zarour. I hold the degree of Bachelor of Science (BSc) in Applied Earth Sciences, majoring in Hydrogeology, from King Abdulaziz University, Jeddah, Saudi Arabia. I also hold the degree of Master of Science (MSc) in Hydrogeology from the University of Birmingham, Birmingham, United Kingdom. Currently, I am a part-time candidate for the degree of Doctor of Philosophy (PhD) in the Institute of Natural Resources (INR), Massey University, Palmerston North. The title of my PhD research is Characterisation and numerical simulation of the Manawatu Plains hydrogeological system. My MSc thesis was on hydrogeochemical modelling and my BSc graduation project (the equivalent of BSc Honours thesis) was on aquifer characteristics and water well design.

2. I have more than 13 years postgraduate professional experience in groundwater resources assessment and management at various scales.

3. In September 2004 I joined Horizons Regional Council (Horizons) as Environmental Scientist - Groundwater. Since 1 July 2006 I have been Senior Scientist - Groundwater. My main duties in Horizons include maintenance and development of knowledge on the Regional groundwater resource, management of the groundwater database, undertaking and/or overseeing groundwater monitoring and studies, technical assessment of relevant resource consent applications, supporting policy development, and general support to the Consents and Compliance Teams. I also provide specialised support on an as-needed basis to external clients including consultants, drillers, existing and potential resource users, and the general public. I am Horizons' representative to the Regional Groundwater Forum (RGF) of New Zealand council scientists.

4. Overseas, I worked in the Applied Research Institute of Jerusalem (ARIJ), Bethlehem, the West Bank, for three years. I started with ARIJ as Researcher and progressed in positions to finally be appointed Coordinator for the Water Research Unit. After this, I worked for 5½ years as Senior Hydrogeologist and thereafter as Project Coordinator and Team Leader with the United Nations Development Programme (UNDP) in Jerusalem. During my last 2½ years with the UNDP, I was seconded to the Palestinian Water Authority (PWA) where I was appointed Acting Director for the Water Resources and Planning Department in the West Bank. This role involved establishment and overseeing work in three sections: (1) the water databank; (2) the hydrological assessment and monitoring division; and (3) the policy and strategic planning section.

During my work in ARIJ and the UNDP, I provided technical advice to the Palestinian teams to the Middle East peace negotiations. I also represented the PWA at a number of conferences and in multi-national and international joint projects such as the multi-national ME-EXACT initiative, the joint World Bank/World Metrological Organisation (WMO) MEDHYCOS Project, etc. I was a steering committee member for the First Israeli-Palestinian International Academic Conference on Water, held in December 1992 in Zürich, Switzerland. I was also actively involved in development of the Palestinian Water Law of 1996.

5. Over the years outlined above, I participated in a number of multi-national and international conferences and events of various natures.

6. I have authored and co-authored a range of scientific and technical publications relating to water resources management and hydrogeology. I have also written a large number of unpublished reports including assessments of environmental effects (AEEs) and hearing reports for resource consent applications.

7. More recently, I have provided solicited scientific peer review to papers for Hydrological Processes, a prestigious specialised international journal. I also provided a review for a book proposal for Taylor & Francis CRC Press, at their request. The papers and the book that I reviewed have been published last year.

8. I am familiar with Horizons' Region and the regional groundwater resource. I have been living and working in Palmerston North since October 2004 and I have technically assessed and reported on tens of applications for groundwater related activities in the Region. A number of such applications have been decided in hearings. As part of my research on the groundwater in the Region, I undertook a comprehensive survey of all relevant literature. The outcome of this undertaking is summarised in a report that I completed in December 2008 on the regional groundwater resource (Zarour, 2008a)[1].

9. Hence, I believe that I am adequately qualified and experienced to provide technical advice and expert opinion on hydrogeological aspects relating to the regional groundwater resource and its management.

10. I have read the Environment Court's practice note Expert Witnesses – Code of Conduct (Bollard, 2005) and agree to comply with it. The evidence I present here is within my area of expertise, except where I state that I am relying on information provided by

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[1] Report available from Horizons.

another party. I have not knowingly omitted facts or information that might alter or detract from the opinions I express in this evidence.

My role in the Proposed One Plan

11. I have been involved in the Proposed One Plan (POP) since I joined Horizons in 2004. I was tasked with the development of a practical conceptualisation of the regional groundwater resource and a compatible general management framework. This task required me to undertake a comprehensive critical review of all previous work relating to the hydrogeology of the Region. Eventually, I produced a report in December 2008 titled Groundwater resources in the Manawatu–Wanganui Region: technical report to support policy development (Zarour, 2008a). Appendix G of this report summarises the above-mentioned comprehensive literature review. The report describes the regional groundwater resource, provides an account of its general status covering both quantity and quality aspects, and presents a framework for its management in the form of Groundwater Management Zones (GMZs). The report also discusses various available and appropriate technical tools for groundwater resource management. Policies and rules relating to groundwater in the POP are based on the findings of the research presented in this report. In addition, the report describes other groundwater projects which Horizons commissioned recently to enhance knowledge about the regional groundwater resource and establish sound basis for its sustainable management. Most of the subjects covered in the report will be concisely embraced in this evidence. Furthermore, that report constitutes the basis for the work by Pattle Delamore Partners Ltd (PDP) titled Groundwater management options for the Proposed One Plan (PDP, 2009), and the evidence presented to this Hearing by Mr Peter Callander of PDP Ltd.

Scope of evidence

12. My aim in this evidence is to provide a general description of the regional groundwater resource and present a practical framework for its management. I portray the status of the resource in terms of quality and quantity, and briefly describe relevant data gathering systems in the Region. Estimates for groundwater demand and use are given and compared with the resource potential. The evidence also explains the hydrogeological rational for the proposed resource management framework and presents the concept of Groundwater Management Zones (GMZs). The proposed conceptualisation is compared to earlier informal understandings, and the implications for the environment and resource users are discussed. The main features of the various GMZs in the Region are described, and allocation limits are provided for each zone and weighed against current

groundwater use. The compatibility of the proposed groundwater management framework with the surface water management framework is considered in the evidence of Dr Jon Roygard and Ms Maree Clark. My evidence also discusses potential effects of groundwater resource development on the users of the resource and the environment, and provides examples to illustrate this.

13. This evidence will not attempt to respond to submissions relating to groundwater policies and rules in the POP. Responses to such submissions are provided in Mrs Clare Barton's planning report.

14. I recommend reading this evidence in concert with Mr Callander's technical evidence and Mrs Barton's planning evidence. I note here that I totally agree with the opinions expressed by Mr Callander and Mrs Barton and endorse all of the recommendations they present in their evidence.

2. EXECUTIVE SUMMARY OF EVIDENCE

15. My aim in this evidence is to provide a general description of the regional groundwater resource and present the proposed framework for its management in the form of Groundwater Management Zones (GMZs).

16. Many investigators have studied parts of the regional groundwater resource. All such works were reviewed in a recent Horizons report titled Groundwater resources in the Manawatu–Wanganui Region: technical report to support policy development (Zarour, 2008a). Appendix G of that report summarises the main elements in the reviewed studies. In that report I provide a general description of the regional groundwater resource and an assessment of its status in terms of quantity and quality. That report constitutes the basis of this evidence and I recommend referring to it for further information when needed.

17. Zarour (2008a) extensively references other work and contains a comprehensive bibliography of cited and other relevant geological and hydrogeological literature. This evidence also contains several references to other work. These have been included mainly for scholarly purposes and I do not consider them to be required reading for the Hearing Panel. However, I recommend reading this evidence together with Mr Callander's and Mrs Barton's evidence.

18. Groundwater is an important resource in the Region and its sustainable management is fundamental for the Region's socio-economic and environmental wellbeing.

19. Groundwater provides for about half of the Region's demand for water and in some areas it represents the only available reliable resource of good quality water. Almost all of the groundwater that is currently used in the Region comes from drilled wells as the Region's geology does not allow the formation of distinct springs. There are an estimated 9,500 groundwater wells in the Region with the absolute majority of them being less than 100 m deep. Collectively, these wells abstracted an estimated 96 million cubic metres of water in 2008. Approximately half of this volume is taken as a Permitted Activity whereas the other half is abstracted by authority of resource consents (permits).

20. The regional groundwater resource principally consists of Late Quaternary deposits that fill the valleys and cover the floodplains. This hydrogeological system cannot be divided into distinct aquifers. The underlying older Plio-Pleistocene deposits have very limited or no resource potential. However, the Nukumaru strata comprise a productive aquifer in the Whanganui Groundwater Management Zone. The oldest rock in the Region is the greywacke that constitutes its geological 'basement' and crops out to form the axial mountains. These rocks have no potential as a groundwater resource.

21. The groundwater resource is interlinked in many places with surface water bodies. Groundwater and surface water are integral components in the hydrological cycle and in the larger environment. Actions affecting groundwater, surface water and land may have reciprocal effects on each other and may also affect biodiversity. Small changes in the environment may have dramatic effects on some of its various components, especially the most fragile systems.

22. I believe that an explicit conceptualisation of a single, heterogeneous, anisotropic, hydraulically interconnected (ie. leaky) groundwater system that occurs in hydraulic continuity with connected surface water bodies in places represents the most reasonable conceptualisation of the regional groundwater resource.

23. Geological structures (ie. faults and folds) and topography enable the Region to be divided into Groundwater Management Zones. Hydrological balance calculations are technically viable for such management units and, hence, this resource management system can be used to manage cumulative effects of groundwater abstraction within each management unit.

24. It is proposed to subdivide the Region into 10 Groundwater Management Zones. Allocation limits are recommended to be set at 5% of average annual rainfall in seven of these zones where groundwater is a potential resource; namely, the Whanganui,

Whangaehu, Turakina, Rangitikei, Manawatu, Horowhenua and Tararua Groundwater Management Zones. Allocation limits are recommended not to be specified for the North Whanganui, North Rangitikei and East Coast Groundwater Management Zones, because groundwater yield potential there is nonexistent or at best, very limited. These latter units are defined only for completeness purposes and for better compatibility with the [surface] Water Management Zones.

25. The proposed allocation limit (5% of average annual rainfall) is in line with guidelines provided by the Ministry for the Environment (MfE).

26. The outer boundaries of the defined Groundwater Management Zones coincide with topographic highs, which also define the Region's surface Water Management Zones. Therefore, the hydrogeological (groundwater) and the hydrological (surface water) management zones are inherently compatible. This facilitates integrated management of the two interlinked resources.

27. Previous Regional Plans and Policy Statements did not contain a framework for managing the groundwater resource and did not specify allocation limits.

28. Ongoing monitoring of groundwater level and quality, and recent research, generally imply that the resource has not been depleted or spoiled as a result of different human activities. Groundwater levels, as a measure of quantity or resource availability, generally are stable, indicating that abstraction is within sustainable limits. Also, groundwater quality in general has not changed over the length of the monitoring record, indicating minimal human effect. Where groundwater quality can constitute a barrier to water use for different purposes, this generally is due to natural causes, is not a health hazard and can be either tolerated or treated.

29. Throughout the Region and the different Groundwater Management Zones in it, current groundwater abstraction represents a small fraction of what is believed to be the resource yield potential. Additional abstraction should be enabled, but effects on other users of the resource and interlinked components of the environment must be prudently managed.

30. Because the Region as a whole and its various Groundwater Management Zones enjoy a healthy hydrogeological balance, I consider the enabling management approach in the Proposed One Plan (POP) to be appropriate. I also consider the approach to managing individual and cumulative effects of groundwater abstraction as provided in the POP to

be appropriate. I believe that the objectives, policies and rules in the POP are practical and suitable to manage the resource beneficially, efficiently and sustainably. The objectives, policies and rules relating to groundwater in the POP are consistent with those for other regions in New Zealand as well as for other OECD countries.

31. Abundance does not excuse misuse and/or waste. Therefore, I consider Horizons' policies and rules that aim to promoting efficient use of the groundwater resource to be appropriate despite the positive hydrological balance.

32. In my opinion, resource consent conditions are very effective measures to ensure efficient use and protection of the resource. The POP provisions form good foundations for practical resource consent conditions to ensure protection of other users of the resource and the environment.

33. Policies and rules related to other components of the environment, alongside national standards and best practice guides, are also important in effective groundwater resource management. Examples of this include policies and rules relating to discharge to land and land use.

3. EVIDENCE

Introduction

34. Through the development of Horizons' Long Term Community Council Plan (LTCCP) and the Proposed One Plan (POP), the community identified water quality and quantity as priority resource management issues. Groundwater is a valuable resource and an integral component of the water (or hydrological) cycle. It is commonly used in Horizons' Region for a wide spectrum of life maintenance and productive purposes. Sustainable management of this important resource is fundamental for the Region's socio-economic and environmental wellbeing.

35. The status of a groundwater resource is measured in terms of quality and quantity. In general, this is not unconnected to the status of surface water bodies and other components of the environment. For example, groundwater abstraction may affect the quantity and/or quality of a surface water system and, consequently, it may impact on associated biodiversity. Biodiversity is yet another significant environmental issue identified by the community in the LTCCP. Similarly, depletion of a surface water body may affect the quantity and/or quality of interconnected groundwater systems. Pollution of land or surface water bodies may also impact on groundwater quality and land use

changes may affect groundwater quantity and/or quality. For instance, forestation or subdivision of land would potentially reduce recharge to groundwater, leading to lowering of groundwater level. If this takes place in a coastal area, it may result in seawater intrusion[2]. This will be expressed in rising up and/or inland advancement of the seawater-groundwater interface. Section A-10 in Zarour (2008a) presents basic concepts relating to seawater intrusion. Horizons' approach to managing seawater invasion risk is concisely presented in this evidence in the section starting with Paragraph 161 (p 63).

36. It should be noted that even small changes in land use in sensitive areas could result in dramatic environmental effects. For example, if recharge in a certain area is permanently reduced by, say 5 cm/year, the groundwater level in this area would be lowered by 20 cm, assuming the aquifer[3] material is sand with a porosity of 0.25. This is basically because water occupies only the void space in the aquifer material. As explained in Section 7.5.3.1 of Zarour (2008a), the relationship between groundwater level above mean sea level (h_f) and the depth to the groundwater-seawater interface below mean sea level (z) is approximated by what is known as the Ghyben-Herzberg relation as:

$$Z = 40h_f \qquad \text{Equation 1}$$

Figure 1 illustrates the Ghyben-Herzberg relation graphically.

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[2] The terms "seawater intrusion", "seawater invasion" and "seawater encroachment" are used synonymously and interchangeably in Zarour (2008a) and in this evidence.

[3] The term aquifer comes from two Latin words: aqua (water) and ferre (to bear or carry). By definition, an aquifer is an underground bed or layer of earth material that is capable of producing an economically feasible quantity of water to a well or spring. Porous material like sand and gravel and different types of fractured rock like limestone often make good aquifers (Zarour, 2008a).

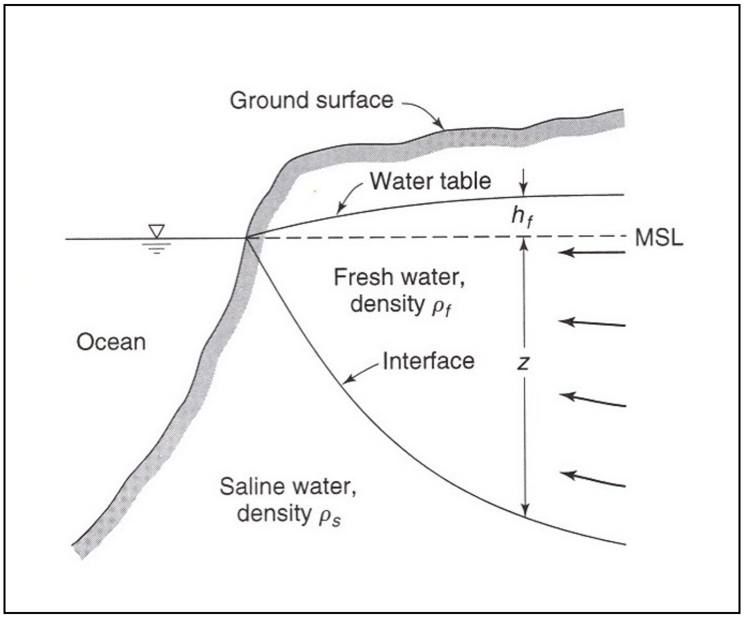

Figure 1. Idealised sketch of occurrence of fresh and saline groundwater in an unconfined coastal aquifer (Source: Todd and Mays, 2005)[4].

37. Hence, a reduction of groundwater level by 20 cm will result in a rise in the groundwater-seawater interface by 8 m (40 x 0.20 m), which would most probably render the resource unusable in coastal areas that depend on groundwater wells.

38. Effective management of groundwater requires a practical framework and appropriate technical tools. The most important element in groundwater management is system conceptualisation. This is particularly important because groundwater is unable to be seen and, therefore, hydrogeological systems can be rather difficult to conceive. Hydrogeologists develop and use groundwater models of different natures to present and test their understanding of groundwater systems. In doing this, they attempt to represent the essential features of a natural hydrogeological system, which requires simplification of the reality by distilling the complexity of a real system down to its essentials. Groundwater models may then be used to evaluate possible water management strategies and make predictions about the behaviour of groundwater systems under various stress scenarios, eg. pumping, recharge, climate change, etc. A conceptual model is a list of “justified assumptions” about the overall nature of the system that enshrines concepts of how the system works. Conceptual modelling may need to be followed by model implementation in the form of mathematical modelling, where concepts are put to the test and the models are used as experimental tools to

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[4] This source is the 3rd edition of a classic hydrogeology textbook.

answer "if-then" questions. However, most cases do not require taking the process of modelling any further than the conceptualisation phase. For example, while I believe that mathematical modelling would be a useful tool for managing groundwater in the Region, I think that it is probably prohibitively expensive to do so for all its Groundwater Management Zones. I believe that a well thought-out conceptual model is quite adequate for the development of the necessary regional-scale general framework for managing the resource. Therefore, in this evidence I will describe the general status of the resource and present my general conceptualisation of the system which constitutes the basis for the general framework for managing the Region's groundwater resource in the form of GMZs, as proposed in Zarour (2008a).

39. The "justified assumptions" on which my proposed groundwater management framework is based are presented in my report on the groundwater resource, titled Groundwater resources in the Manawatu–Wanganui Region: technical report to support policy development (Zarour, 2008a). That report has been externally reviewed by Dr Alan Palmer, Senior Lecturer of soil and earth sciences at Massey University; Dr John Begg, expert geologist at GNS Science; Dr Howard Williams, groundwater scientist at Environment Canterbury; and Mr Wayne Russell, consultant hydrogeologist, GWS, Auckland. The report has been reviewed and accepted at Horizons by Dr Jon Roygard, Science Manager. Hence, I consider the report to have been scrutinised and accepted by experienced academicians and practicing geologists, groundwater resources experts and water resources managers.

40. Principally, this evidence is based on the analysis provided in my above mentioned report, which accounts for all previous relevant hydrogeological work and all relevant geological studies and investigations. The report summarises relevant previous studies in Appendix G. That report is referenced in this evidence as Zarour (2008a).

41. In addition, the evidence is also based on a Horizons-GNS report titled Spatial and temporal variations and trends in groundwater quality in the Manawatu-Wanganui Region, which I co-authored. That report is referenced in this evidence as Daughney *et al.* (2009)[5].

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[5] Report available from Horizons.

Key messages – General

- i. This evidence is based on a Horizons' report which I prepared in 2008 (Zarour, 2008a) and on a Horizons-GNS report which I co-authored (Daughney *et al.*, 2009).
- ii. Groundwater is an important environmental and socio-economic resource in the Region.
- iii. The community has identified water quality and quantity, sustainable [hill country] land use, and biodiversity as priority environmental issues in the Region.
- iv. Groundwater is part of the bigger hydrological cycle and the larger environment.
- v. The status of a groundwater resource is measured in terms of quality and quantity.
- vi. Actions affecting groundwater, surface water and land resources may have reciprocal effects on each other. Such actions may also affect biodiversity.
- vii. Small changes in the environment may have dramatic effects on some of its components.
- viii. Effective groundwater management requires a practical framework and set of tools.
- ix. Robust system conceptualisation is the most important component in groundwater management.
- x. A conceptual model is the mental picture of an unseen object or environment (eg. groundwater) or how a visible or an invisible feature was formed, how it operates and/or its interrelationships with other components in the environment (Dunbar *et al.*, 2001).
- xi. A framework of Groundwater Management Zones is proposed for the Region.

The status of the regional groundwater resource

42. The status of a groundwater resource is determined in terms of quality and quantity. Long-term environmental data records provide the means to assess the status of the monitored resource and the effects on it of policies and management interventions. Hence, long-term monitoring is key to sustainable management and protection of environmental resources. Environmental monitoring entails undertaking observations, measurements, tests and sampling on a regular and/or ongoing basis to track changes in the physical, chemical and biological characteristics and conditions of the monitored resource.

43. Groundwater quality can readily be assessed through field measurements and laboratory analysis of water samples. In general, the fresher the water is and the lower the concentrations of its various chemical constituents, the better its quality. Any increase in the concentration of any of the elements, or combinations of them, indicates worsening water quality. However, this relationship is not always that simple and straightforward. Ion ratios are also important in this assessment. For example, a decrease in the concentrations of calcium and magnesium associated with an increase in the concentration of sodium is alarming as it indicates a drop in the water suitability for irrigation due to rising Sodium Adsorption Ratio (SAR), which is an expression of the ratio of sodium to calcium and magnesium in irrigation water. Suitability of water for irrigation and SAR are discussed in Section 3.3.8 of Zarour (2008a) and in Section 5.3.12.3 in Daughney *et al*. (2009).

44. Suitability of groundwater quality for various uses is judged against appropriate established standards. Daughney *et al*. (2009) undertook a comprehensive analysis of all groundwater quality data that has ever been collected in the Region. They statistically evaluated the groundwater quality and provided an assessment of its suitability for various uses through weighing median field and laboratory groundwater quality testing results against applicable standards, such as the drinking water standards set by the Ministry of Health in 2005 and revised in 2008 (DWSNZ 2005)[6], and the guidelines for irrigation and livestock drinking water that are provided in the Australian and New Zealand guidelines for fresh and marine water quality (ANZECC & ARMCANZ, 2000). Further commentary and reference to the work and report by Daughney *et al*. (2009) is provided in the appropriate sections of this evidence.

45. In contrast, groundwater quantity cannot be directly measured and there are no standards to compare it to. Groundwater levels are an expression of the fullness of groundwater reservoirs (aquifers). The level reached by water in a well that taps an aquifer is taken as a measure of the groundwater level in that aquifer. Everything else being equal, the fuller the aquifer the higher its water level. However, an aquifer cannot be said to be fuller than another aquifer simply because the first aquifer has higher groundwater levels. Sometimes, high head is an expression of low permeability[7], storativity[8] or both. Hence, the degree of aquifer fullness must be assessed through comparison of groundwater observations collected from specific long-term monitored wells.

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[6] Documents are available online from the Ministry of Health website (http://www.moh.govt.nz).
[7] A constant that provides a measure of an aquifer's ability to allow water movement through it.
[8] Storativity is the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area.

46. Under natural conditions, the volume of water in an aquifer reflects a dynamic balance between recharge from rainfall, and losing surface water systems and discharge to the ocean, rivers, streams, lakes, wetlands, springs, other aquifers, and evapotranspiration. Abstraction from wells constitutes an additional artificial output (negative) term in the hydrogeological balance of groundwater systems.

47. For a given aquifer, the general water budget (also known as hydrological balance) can be expressed as:

$$I - O = \Delta S \qquad \text{Equation 2}$$

where

I: sum of water inflows into the aquifer, eg. recharge, inbound throughflow[9], gains from surface waterways, etc;

O: sum of outflows out of the aquifer, eg. outbound throughflow , seepage to the sea, spring discharges, abstraction, evapotranspiration, etc; and

ΔS: change in storage in the aquifer.

48. Groundwater levels provide the easiest and most practical measure of the status of the hydrological balance for an aquifer. The relation between the change in storage and water level can be mathematically expressed as:

$$\Delta S = \Delta h \,.\, A \,.\, S \qquad \text{Equation 3}$$

where

Δh: change in the water level;

A: planar aquifer area; and

S: aquifer storativity (also known as storage coefficient for confined aquifers and specific yield for unconfined aquifers).

49. The relationship is illustrated in Figure 2.

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[9] Flow through an aquifer.

50. Since *A* and *S* are normally constant, it is clear that the change in head is directly proportional to the change in storage, ie. $\Delta h \alpha \Delta S$.

51. Because unconfined aquifers are bound from the top by the water table (ie. the surface of unconfined water level) changes in groundwater level will result in changes in aquifer thickness. In confined aquifers, however, the saturated [aquifer] thickness remains unchanged.

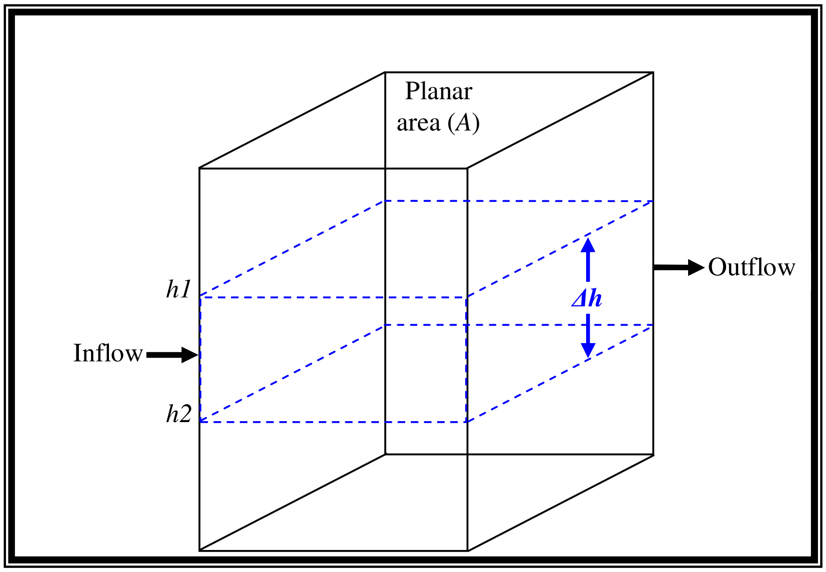

Figure 2. Schematic sketch illustrating the relation between change in head (Δh) and change in storage (ΔS). The parallelepiped represents an aquifer volume which has a planar area of *A*. The difference between inflows and outflows that brings about change is storage (ΔS). As a result, groundwater level will change by Δh, which is proportional to ΔS. Change in storage can be calculated in the form $\Delta S = \Delta h \,.\, A \,.\, S$, where *A* is the planar area and *S* is the aquifer storativity.

52. The incidence of positive (input) terms in the groundwater balance equation is what makes the resource renewable. Sustainable management entails maintaining long-term non-negative (ie. zero or positive) balance between system inputs and outputs. The concept of sustainable management of groundwater resources is discussed in the section starting at Paragraph 270.271, p 135, and in Section in 7.2, p 105, in Zarour (2008a).

Key messages – Groundwater in the environment

i. Groundwater occurs in aquifers.

ii. An aquifer is an underground geological bed or layer capable of producing an economically feasible quantity of water to a well or spring.

iii. Groundwater is a renewable resource.

iv. The status of a groundwater resource is determined in terms of quality and quantity.

v. Long-term monitoring records provide the means to assess the status of the resource and the effects of policies and management interventions on it.

vi. Groundwater quality can readily be assessed through field measurements and laboratory analysis of water samples.

vii. Groundwater level provides a means to assess groundwater quantity and effects of policies, management practices and activities on the resource availability.

Groundwater quality monitoring and results

53. Groundwater quality evolves with residence time of water in the hosting aquifer and with the flow of water from recharge to discharge areas through the hosting aquifer. Residence time is a measure of the time between the entry of water into the aquifer as recharge water and the time the same water exists out of the aquifer naturally or through artificial abstraction from wells. Residence time can be defined for a whole aquifer or a section of an aquifer.

54. The four main processes that control groundwater quality evolution are:

i. Dissolution/precipitation of minerals that compose the aquifer matrix.

ii. Mixing of the aquifer water with other waters like rain water, surface water, seawater, other groundwater, etc.

iii. Oxidation/reduction reactions.

iv. Ion exchange reactions between aquifer matrix and water.

55. Commonly, groundwater is typified in terms of its quality according to the dominant cations[10] and anions[11] it contains.

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[10] A cation is an atom, or group of atoms with a positive charge, eg. the calcium ion (Ca^{2+}).

[11] An anion is an atom, or group of atoms with a negative charge, eg. the sulphate ion (So$_4^{2-}$).

56. Typically, groundwater quality evolves naturally from calcium-bicarbonate type in recharge areas to sodium-chloride type at the end of the flow path in coastal discharge zones. Through this process, the salt content in the water increases.

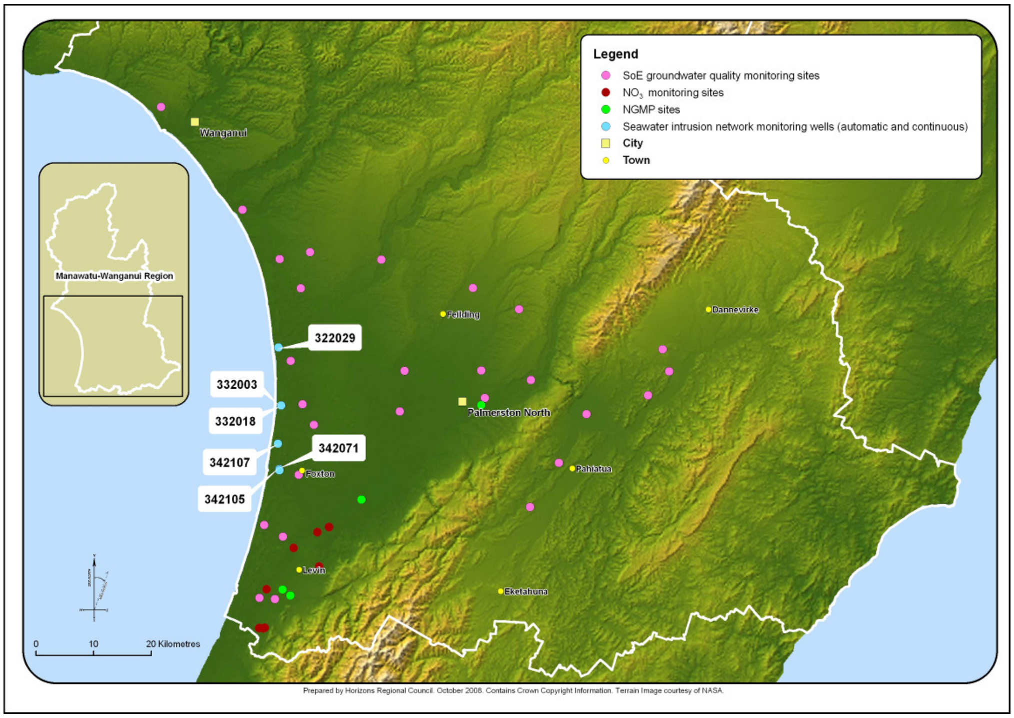
57. In general, groundwater quality is studied and monitored for three purposes:

   i. Assessment of the suitability of the water quality for different uses.
   ii. Evaluation of actual and potential effects of activities on groundwater quality.
   iii. Providing a tool for hydrogeological resource assessment and investigation.

58. Suitability of groundwater quality for various uses is determined according to standards and by methods specific to the particular use. As noted earlier, national drinking water standards (DWSNZ 2005) were set by the Ministry of Health in 2005 and revised in 2008. National guidelines for irrigation and livestock drinking water are provided in the Australian and New Zealand guidelines for fresh and marine water quality document (ANZECC & ARMCANZ, 2000).

59. Figure 3 shows the locations of the wells that comprise the different groundwater quality monitoring networks in the Region. These monitoring networks are described in Zarour (2008a) and include:

   i. Horizons' State of the Environment (SoE) monitoring network, which consists of 28 sites that are sampled once every seven month for laboratory analysis for major constituents in addition to field measurements of temperature, Electrical Conductivity (EC) as a measure of salinity, and pH as a measure of acidity. Analysed parameters include calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), alkalinity or bicarbonate (HCO_3), sulphate (SO_4), and chloride (Cl). In addition, SoE samples are analysed for important secondary constituents like iron (Fe), manganese (Mn) and key nutrients like nitrate (NO_3), nitrite (NO_2), and phosphorus (PO_4). SoE monitoring provides the basis for achieving the main groundwater monitoring objectives outlined in Paragraph 57.
   ii. Nitrate monitoring programme, which consists of quarterly sampling and laboratory analysis only for nitrate from nine wells in the Horowhenua area.
   iii. GNS-operated National Groundwater Monitoring Programme (NGMP), which includes four wells in the Region that are sampled quarterly. Field measurements and laboratory analysis undertaken are similar to those of Horizons' SoE monitoring programme.



Prepared by Horizons Regional Council. October 2008. Contains Crown Copyright Information. Terrain Image courtesy of NASA.

Figure 3. Regional groundwater quality monitoring networks (Source: Zarour, 2008a).

60. In addition to the monitoring programmes summarised in Paragraph 59, Horizons has recently established a network of six wells to monitor groundwater level and Electrical Conductivity (EC) to protect against potential seawater invasion into the Rangitikei/Manawatu coastal plains. Electrical Conductivity is considered a water quality parameter.

61. Occasionally, groundwater quality samples and/or measurements are collected in the Region for specific academic or science research, compliance monitoring or incident investigation purposes. Data from such investigations complement the regular groundwater quality monitoring database.

62. In 2008, Horizons commissioned a project to GNS to analyse all available groundwater quality data. That project is described in Section 8.4 in Zarour (2008a). The project (Daughney *et al.*, 2009) investigated trends in groundwater quality and assessed fitness of groundwater in the Region for various uses. This assessment was based only on major parameters and did not include microbial indicators, arsenic, heavy metals or organic compounds, because this data does not exist. Pesticides were not included in the analysis because there is a special national programme for this, as briefly clarified in this evidence in the section starting with Paragraph 146 (p 58). The main conclusions reached by Daughney *et al.* (2009) can be summarised as follows:

i. Horizons long-term groundwater quality records allow for a high level of interpretation with respect to the status and spatial variation of groundwater quality across the Region. However, there are limitations relating to the length and continuity of historical records. As a result, assessment of temporal groundwater trends can only be made for a subset of the studied sites.

ii. Trend tests for the sites that have sufficient data indicate that most parameters at most sites have remained constant with time. While it appears that groundwater quality in the Region has not been changing, there is a need to commit to long-term, regular groundwater quality monitoring at a core set of sites to confirm this assessment.

iii. Groundwater quality across the Region is similar to the average expectation for aquifers around the world. It is mostly oxygen-poor, resulting from natural chemical and biological reactions that take place as groundwater moves through an aquifer. These natural processes also typically lead to the accumulation of dissolved iron (Fe), manganese (Mn) and ammonia (NH_4) in the groundwater, and the concomitant depletion of nitrate and sometimes also sulphate.

iv. There are pronounced spatial variations in groundwater quality across the Region, which appear to reflect differences in hydrogeological conditions in different groundwater catchments (ie. management zones). The analysis indicates strong statistical relationship between water quality and the Groundwater Management Zones presented in the Proposed One Plan.

v. Human activities have little detectable influence on groundwater quality in the Region. There is no evidence of seawater intrusion into the coastal aquifers and only about 10% of the sites considered in the investigation display nitrate concentrations in excess of the natural background. Elevated nitrate predominantly occurs in the Horowhenua, in wells screened in the Otaki Formation. This is a low permeability fine sand geological unit that was deposited during the Last Interglacial period (Oxygen Isotope Stage 5; OIS 5).

vi. In general, groundwater in the Region is of suitable quality for livestock consumption.

vii. Groundwater quality may act as a barrier to some other uses in certain areas in the Region.

viii. Two-thirds of the sites investigated have at least one parameter with a median level of concentration that exceeds the relevant maximum Guideline Value (GV) for human consumption. Attention is drawn here to the fact that the possible consequences of exceeding Guideline Values are not as serious as the possible consequences of exceeding Maximum Allowable Values (MAV). The parameters most commonly found in excess of the drinking water thresholds are iron (Fe), manganese (Mn), ammonia (NH_4), hardness and pH. I emphasis here that all of these are naturally occurring, can be treated, and not harmful.

ix. About one-third of the sites investigated were found to have at least one parameter that exceeds the recommended guideline for irrigation water. However, I have previously assessed that the Region's groundwater is generally suitable for irrigation, according to the U.S. Department of Agriculture method (the Wilcox diagram), with low sodium hazard and mainly low to medium salinity hazard (Section 3.3.8 in Zarour, 2008a). Again, it should be noted that these represent a harmless natural phenomenon.

63. The suitability of water for different industrial uses is determined by the specific requirements for those types of activities. Hence, assessment of the suitability of groundwater for various industrial uses has not been attempted in either Zarour (2008a) or in Daughney *et al*. (2009) and is left to be undertaken on a case-by-case basis when needed.

64. Reliability and usability of available groundwater quality data is first and foremost assessed in terms of ionic balance error, which is termed Charge Balance Error (CBE) in Daughney *et al*. (2009). The ionic balance error is defined as the difference between cations and anions divided over the sum of the two terms (Equation 4). The ionic balance error for an analysis is normally reported as a percentage value. The United Nations Environment Programme (UNEP) and the World Health Organization (WHO) regard the ionic balance check as one of the basic tests of the quality of groundwater quality data, and recommend acceptable limits between -5% and +5% to enable qualified interpretation of the data (Zarour, 2008a). It should be noted that some references define the ionic balance error differently and, correspondingly, define different acceptable ranges. Both Zarour (2008a) and Daughney *et al*. (2009) assess that only about 30% of the available regional groundwater quality records pass this test.

$$Error\ in\ ionic\ balance\ (\%) = 100\ x \left[\frac{\left(\sum cations - \sum anions\right)}{\left(\sum cations + \sum anions\right)}\right] \qquad \text{Equation 4}$$

65. To ensure robustness of groundwater quality data that will be collected in the future, Zarour (2008a) and Daughney et al. (2009) recommend that in the future all samples be analysed for the full suite of major constituents as a minimum, and that field and laboratory procedures comply with national and international best-practice guidelines (eg. Ministry for the Environment, 2006)[12]. In addition, I believe it is important to expand

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[12] Document available online from the website of the Ministry for the Environment.

the groundwater quality monitoring network to provide more coverage in space and more frequent monitoring to meet the objectives identified in Paragraph 57.

Key messages – Groundwater quality monitoring

i. Groundwater quality evolves naturally as water resides in and flows through aquifers.
ii. Human activities can influence groundwater quality.
iii. Long-term groundwater quality monitoring is required for resource management purposes.
iv. Regional groundwater quality monitoring networks are described in Zarour (2008a).
v. Groundwater quality studies and monitoring enable: (1) assessment of the suitability of the water for different uses; (2) evaluation of actual and potential effects of policies, management practices and activities on groundwater quality; and (3) they provide an additional tool for resource assessment and investigation.
vi. GNS (ie. Daughney *et al.*, 2009) has undertaken comprehensive analysis of Horizons' groundwater quality records.
vii. Reliability and usability of the Region's historical groundwater quality records have been identified as issues that need to be addressed. Nonetheless, available data allows for a high level of interpretation with respect to the status and spatial variation of groundwater quality across the Region.
viii. Generally, groundwater quality in the Region has not changed over the length of available record.
ix. Human activities have little detectable influence on groundwater quality in the Region.
x. There is a notable statistical relationship between water quality and the GMZs presented in the POP, and Zarour (2008a).
xi. There are methods and standards to assess groundwater quality fitness for various uses.
xii. In general, all groundwater in the Region is of suitable quality for livestock consumption.
xiii. Mainly for natural reasons, most groundwater in the Region requires some form of treatment to completely comply with drinking water standards.
xiv. Groundwater in the Region is generally suitable for irrigation purposes with some limitations and exceptions that relate to natural reasons.
xv. Regional groundwater quality monitoring needs to be enhanced and standardised.

Special groundwater quality issues

66. The statistical synthesis of groundwater quality data and the subsequent report by Daughney *et al*. (2009) pinpoint and discuss a number of special groundwater quality issues like possible causes and potential effects of detected levels of various groundwater quality parameters and suitability of groundwater for various uses. Zarour (2008a) discussed the seawater intrusion hazard in the Region and Horizons' approach to managing it. A series of reports on pesticides in groundwater are available (see Paragraph 150, p 58). In the following sections of this evidence I will concisely depict the status of the Region's groundwater resource from a quality perspective, based on the aforementioned reports.

67. The analysis presented in Daughney *et al*. (2009) and the opinions expressed in this evidence are based on available information. Hence, there is a possibility that some aspects may have been overlooked, but I believe that important issues are sufficiently covered.

Groundwater quality fluctuations and trends

68. Similar to groundwater levels, long-term groundwater quality trends provide a measure of the healthiness, or otherwise, of groundwater systems. This is important because heads in a system may remain unchanged while the resource is being spoiled due to pollution. The main purpose of Horizons' SoE groundwater quality monitoring is to provide an alert in the event that quality deteriorates.

69. Daughney and Wall (2007) statistically analysed groundwater quality data from 119 NGMP[13] sites and 871 SoE[14] sites throughout New Zealand. These sites included four NGMP sites and 28 SoE sites in Horizons' Region (Figure 3). National and regional data did not show a noticeable trend.

70. The basic analysis presented in Zarour (2008a) and the advanced comprehensive statistical analysis undertaken by Daughney *et al*. (2009) indicate the general absence of trend in groundwater quality in the Region, ie. there have not been measurable changes with time. Therefore, I deduce in Zarour (2008a) that "*groundwater quality in the Region is as good, or as bad, as it has always been*". According to Daughney *et al*.

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[13] NGMP: GNS operated National Groundwater [quality] Monitoring Programme.
[14] SoE: State of the Environment [monitoring].

(2009), most parameters remain constant with time at most monitoring sites in the Region at which trend tests can be performed (Table 1).

Table 1. Number (#) and percentage (%) of sites where (1) the Median Absolute Deviation (MAD) could be determined for various parameters, assuming a required minimum of two results above the detection limit, and (2) the MAD exceeds 10% of the corresponding median. Note that 1,522 were sites considered in the study (Source: Daughney *et al.*, 2009).

Class	Parameter	#	%N	%INCR	%DECR
Major Constituents	Ca	250	95.6	2.0	2.4
	Cl	331	94.2	2.1	3.6
	HCO_3	301	94.4	3.3	2.3
	K	209	92.3	4.8	2.9
	Mg	246	95.9	1.2	2.9
	Na	218	95.0	2.8	2.3
	SO_4	170	94.1	2.9	2.9
	TDS	53	96.5	3.8	0.0
	Cal TDS	Not determined			
Minor Constituents	B	17	100.0	0.0	0.0
	Br	24	87.5	0.0	12.5
	F	64	96.8	1.6	1.6
	Fe	310	94.8	1.0	4.2
	Mn	171	97.0	1.2	1.8
	NH_4	132	88.6	6.8	4.5
	NO_3	203	84.7	7.4	7.9
	PO_4-P	35	76.5	20.6	2.9
Trace	NO_2	44	100.0	0.0	0.0
Other Parameters	EC	390	93.6	1.5	4.9
	pH	323	91.0	3.7	5.3
	Temp	192	98.4	1.6	0.0
	Eh	10	100.0	0.0	0.0
	Turb	24	82.6	13.0	4.3

Key messages – Groundwater quality fluctuations and trends

i. Long-term groundwater quality trends provide a measure of the healthiness of groundwater systems.

ii. The main purpose of Horizons' SoE groundwater quality monitoring is to provide an alert in the event that quality deteriorates.

iii. Groundwater quality in New Zealand in general and in the Region does not show noticeable changing trends.

iv. In simple terms, groundwater quality in the Region continues to be as good, or as bad, as it has always been.

Salinity – Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

71. Pure water does not contain ions (charged atoms[15] or molecules[16]), making it a covalent compound, ie. it cannot share electrons with other compounds. Hence, pure water is a good insulator (dielectric, not conductive) because it cannot carry an electrical current effectively. However, water is the universal solvent that can dissolve a large range of other substances, forming solutions. When rock-forming minerals such as calcite (calcium carbonate, $CaCO_3$) dissolve in water, the dissolved compound is broken into positive and negative charged ions (cations[17] and anions[18], respectively) and, thus, free ions become available in the solution and the solution becomes conductive to electricity in proportion with the amount of free electrons in it. Electrical Conductivity (EC), also known as specific conductance, is a measure of a material's ability to conduct an electric current.

72. Because Electrical Conductivity (EC) is directly proportional to the Total Dissolved Solid (TDS) contents of a solution, EC is used as a proxy measurement of groundwater salinity. However, some dissolved solids in water are not charged, eg. silica (SiO_2). Understandably, such substances are counted in TDS, but they do not contribute to EC.

73. The SI (*Système International d'Unités*)[19] unit of conductivity is Siemens per metre (S/m), but hydrogeologists traditionally use milliSiemens per metre (mS/m) or microSiemens per centimetre (µS/cm). To convert between various EC units, the following relations apply:

$$1\ \text{S/m} = 1{,}000\ \text{mS/m} \qquad \text{Equation 5}$$

$$1\ \text{S/m} = 1{,}000{,}000\ \mu\text{S/m} \qquad \text{Equation 6}$$

$$1\ \text{mS/m} = 10\ \mu\text{S/cm} \qquad \text{Equation 7}$$

74. The analysis presented in this evidence uses mS/m to express groundwater Electrical Conductivity to maintain consistency with the recent report by Daughney *et al.* (2009).

75. TDS can be determined in the laboratory by either: (1) summing the results of separate analyses for all major ions (calculation or summation method), or (2) directly by weight (gravimetric method).

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[15] Atom: A unit of matter; the smallest unit of an element, having all the characteristics of that element and consisting of a dense, central, positively charged nucleus surrounded by a system of electrons.

[16] Molecule: a group of like or different atoms held together by chemical forces.

[17] A cation is an atom, or group of atoms with a positive charge, eg. the calcium ion (Ca^{2+}).

[18] An anion is an atom, or group of atoms with a negative charge, eg. the sulphate ion (So_4^{2-}).

[19] The current international form of the metric system.

76. Typically, EC is converted to TDS assuming that the solid dissolved in water is sodium chloride (NaCl, table salt, halite). 1 mS/m of Electrical Conductivity is equivalent of about 6 mg of NaCl per kg of water. However, not all the dissolved solid content in groundwater is NaCl, so this relationship can only provide a first approximation of TDS from EC. When better data is available for an area, it is possible to derive an area-specific empirical relationship between TDS and EC. Daughney *et al*. (2009) established that the relationship between TDS and EC in Horizons' Region is:

TDS [mg/l] = 6.90 EC [mS/m] for measured TDS Equation 8

Whereas

TDS [mg/l] = 7.38 EC [mS/m] for calculated TDS Equation 9

77. Hence, TDS (expressed in mg/l) can generally be approximated in the Region as 7 x EC (measured in mS/m).

78. The above relationship is important as it enables quick estimation of groundwater salinity from EC measurements in the absence of more expensive and onerous laboratory analysis. Electrical Conductivity can easily be measured in the field using special meters.

79. Daughney *et al*. (2009) note that rainwater has TDS of about 10 mg/l, the global average for rivers is about 120 mg/l, the average for recently recharged groundwater is 160 mg/l, and the global average for groundwater is 350 mg/l, whereas older and/or more chemically evolved groundwater can have TDS greater than 1,000 mg/l. They also note that seawater has TDS of 34,500 mg/l.

80. Salinity (assessed as EC or TDS) is an important factor in determining: (1) the usability of water for various purposes, and (2) the status of the water in terms of pollution, eg. salinisation due to seawater intrusion, which is discussed in this evidence in Paragraphs 161-177.

81. Because of the direct proportional relationship between TDS and EC, as described in the previous paragraphs, they are discussed collectively in Daughney *et al*. (2009) and this evidence.

82. The drinking water standards (DWSNZ 2005) do not provide a maximum allowable value (MAV) for either TDS or EC, but they do provide an aesthetic Guideline Value of 1,000 mg/l for TDS, because above this level the water generally tastes unpleasant. ANZECC & ARMCANZ (2000) establish Guideline Values (GV) for EC so that it should be less than 60 mS/m for sensitive crops in poorly draining soil, whereas more tolerant crops in well drained soil may withstand EC above 1,200 mS/m. ANZECC & ARMCANZ (2000) also provide GV for TDS as a range between 2,000-5,000 mg/l for livestock consumption, because different animals have different tolerance levels to water salinity.

83. The recent study by Daughney *et al*. (2009) indicates that TDS and/or EC are unlikely to represent barriers to use of the Region's groundwater for various purposes. They were able to calculate median TDS values for 623 wells across the Region. They found that only 3% of these wells exceed the drinking water standard GV of 1,000 mg/l and fewer than 1% of the wells exceed the lowest Trigger Value (TV) for livestock consumption of 2,000 mg/l (Figure 4).

84. Similarly, Daughney *et al*. (2009) were able to calculate median EC for 1,212 wells across the Region. They found that fewer than 1% of the wells exceed 200 mS/m, the TV for relatively sensitive crops in moderately drained soil (Figure 5).

85. Daughney *et al*. (2009) note that there are a few wells with median TDS and/or EC above GV that are scattered around the Region (Figure 4 and Figure 5). Most of such wells also have elevated median sodium (Na) and chloride (Cl) concentrations. Sodium and chloride in regional groundwater are discussed in the section starting with Paragraph 94. According to Daughney *et al*. (2009), the noticeable relation between elevated salinity and elevated Na and Cl indicates that these ions constitute the majority of the dissolved ions in the concerned groundwater. For example, Well 352271 has the highest median TDS value (3,808 mg/l) and also the highest median Na and Cl concentrations (750 and 1,843 mg/l, respectively). This particular well is located on the Porotawhao basement high in the Horowhenua GMZ, and the lithology of the site is characterised by low water yield from greywacke, which has been encountered in this well from about 17 metres below ground level (mbgl) to the bottom of the well at about 93 mbgl. This groundwater is not considered to be representative of the Region's groundwater resource and the penetrated greywacke rock is part of the geological basement that is not classified as a groundwater resource as explained in Paragraph 219, p 99.

Key messages – Salinity

i. Electrical Conductivity (EC) of water is directly proportional to the Total Dissolved Solid (TDS) contents, ie. salinity.
ii. Salinity can be measures in the laboratory by summing the results of separate analyses or directly by weight (gravimetric method).
iii. EC is used as a proxy to TDS, using empirical equations. In the Region, the relationship is approximated to: TDS [mg/l] = 7 EC [mS/m].
iv. New Zealand drinking water standards (DWSNZ 2005) do not provide a Maximum Allowable Value (MAV) for TDS and EC, but there is an aesthetic Guideline Value (GV) of 1,000 mg/l for TDS.
v. ANZECC & ARMCANZ (2000) contain Guideline Values (GV) for EC, which correspond to the different levels of tolerance of crops and animals water salinity.
vi. Salinity is unlikely to represent barriers to use of the Region’s groundwater for various purposes.

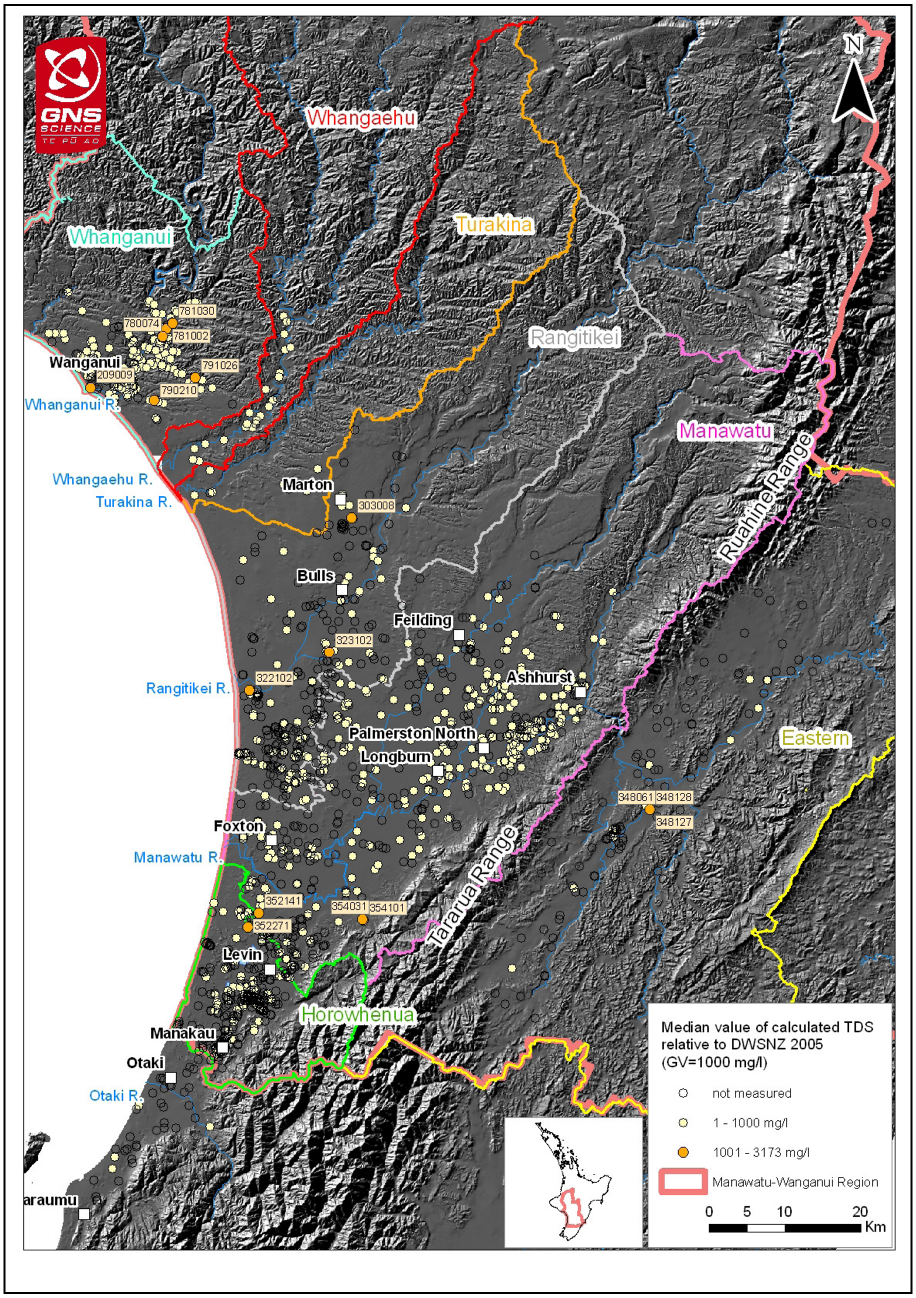

Figure 4. Median values of Total Dissolved Solids (TDS) concentration relative to Drinking Water Standards New Zealand guidelines (GV = 1,000 mg/l). Orange circle for sites where GV is exceeded, yellow circle where GV is not exceeded and empty circle where median concentrations cannot be determined. For clarity of presentation, only sites with median concentration above GV are labelled (Source: Daughney *et al.*, 2009).

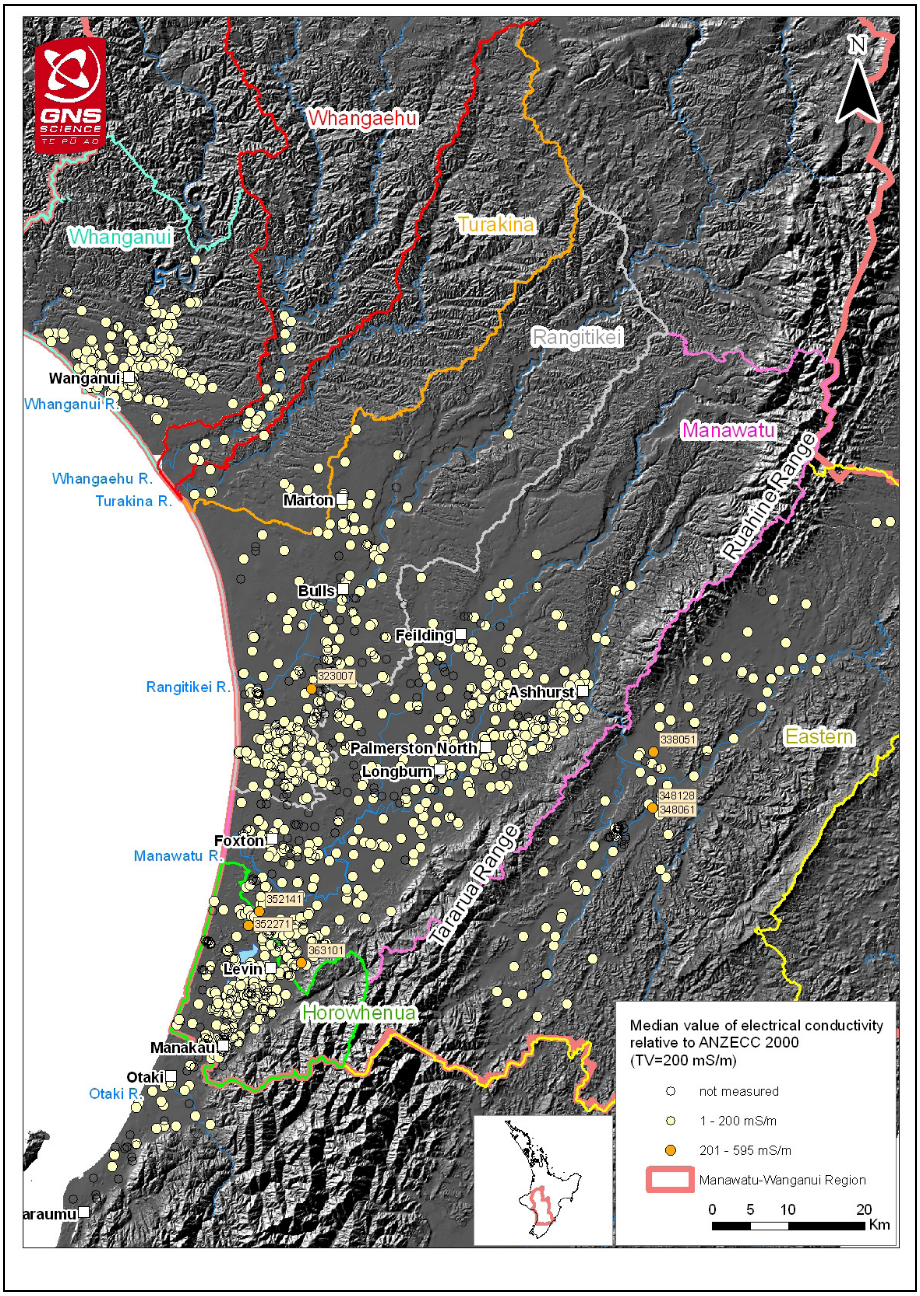

Figure 5. Median values of Electrical Conductivity (EC) relative to ANZECC & ARMCANZ (2000) irrigation guidelines (TV = 200 mS/m). Orange circle for sites where TV is exceeded, yellow circle where TV is not exceeded and empty circle where median Electrical Conductivity cannot be determined. For clarity of presentation, only sites with median concentration above TV are labeled (Source: Daughney *et al*., 2009).

Hardness

86. Water is called hard where it contains mineral salts of calcium (Ca) and magnesium (Mg) that form hard, adherent scale on appliances and fittings which come into contact with the water. Scale on boiler plates increases energy consumption and leads to deterioration of the heater through overheating. Hardness can clog small diameter pipes and emitters in irrigation systems and affect industrial apparatuses. Hardness also affects walls and fittings in bathrooms and kitchens.

87. There are two types of hardness: temporary and permanent. Temporary hardness is caused by a combination of calcium and/or magnesium ions and bicarbonate (HCO_3) ions in the water. It can be removed by boiling the water or by the addition of lime (calcium hydroxide).

88. Permanent hardness cannot be removed by boiling. It is usually caused by the presence of calcium (Ca) and magnesium (Mg) sulphates (SO_4) and/or chlorides (Cl) in the water. These compounds become more soluble as the temperature rises and, hence, they do not precipitate with boiling. Despite the name, permanent hardness can be removed through ion exchange, where calcium and magnesium ions in the water are exchanged with sodium ions in a “water softener”.

89. Normally, hardness occurs in water due to natural causes and is not a result of human interference with the environment.

90. Hardness is normally measured in milligram of calcium carbonate per litre of water (mg/l $CaCO_3$). It is a calculated parameter and is evaluated as follows (all concentration units in mg/l):

$$\text{Hardness as } CaCO_3 = (Ca \times 2.5) + (Mg \times 4.1) \qquad \text{Equation 10}$$

91. Hard water generally is not a health hazard. Hence, the drinking water standards (DWSNZ 2005) do not specify a Maximum Allowable Value (MAV) and the stock water guidelines (ANZECC & ARMCANZ, 2000) do not provide a Trigger Value (TV) for it. However, DWSNZ 2005 establishes an aesthetic Guideline Value (GV) of 200 mg/l $CaCO_3$ for hardness, to minimise household appliance scaling problems. To protect irrigation systems against scaling, ANZECC & ARMCANZ (2000) guidelines for irrigation water include a hardness TV of 350 mg/l $CaCO_3$. However, ANZECC & ARMCANZ

(2000) guidelines indicate that hardness should be at least 60 mg/l $CaCO_3$ in order to minimise the risks of corrosion of metal pipes and fittings.

92. In the recent study by Daughney *et al*. (2009) median hardness values could be determined for 959 wells across the Region. Of these, 27% were found to exceed the drinking water standard GV of 200 mg/l $CaCO_3$, 15% have median hardness below 60 mg/l $CaCO_3$, and 7% have median Hardness above 350 mg/l $CaCO_3$ (Figure 6).

93. It is acknowledged that hardness outside the recommended ranges represents a potential barrier to use of the Region’s groundwater for certain purposes. However, this is a natural phenomenon which can be tolerated or dealt with in the absence of alternative sources of water. The most important consideration here is that hardness is not a health hazard or a serious environmental problem. In addition, hardness in the underground environment is controlled not only by the composition of the aquifer material, but also aquifer conditions and the degree of evolution of the water. Aquifer hydraulic conditions (ie. degree of confinement) also play an important role in this. In brief, hardness in groundwater is an expression of the thermodynamic status in the specific hydrochemical zone of the aquifer in which it occurs.

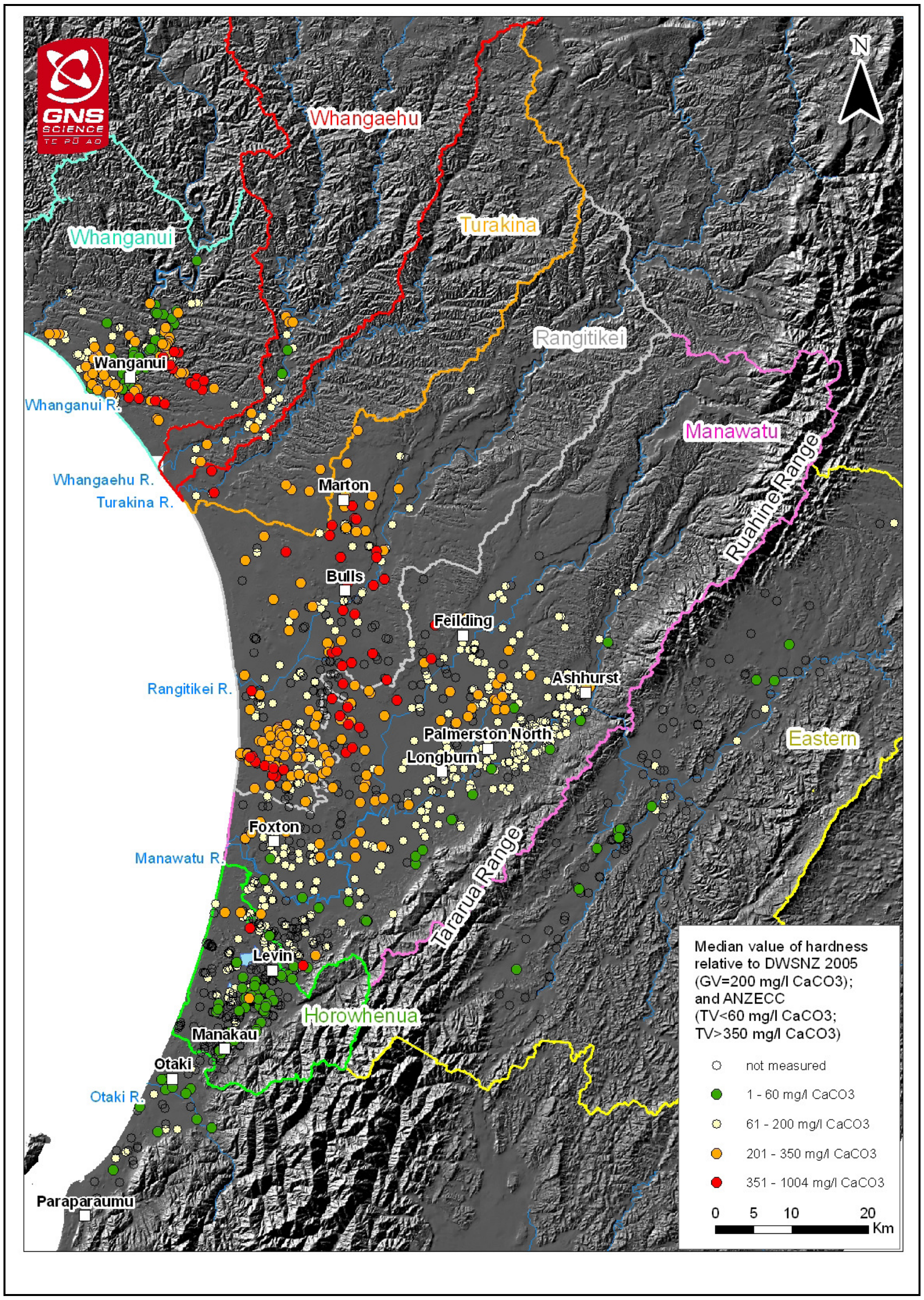

Figure 6. Median values of hardness relative to Drinking Water Standards New Zealand guidelines (GV = 200 mg/l $CaCO_3$) and ANZECC & ARMCANZ (2000) (TV < 60 mg/l $CaCO_3$; TV > 350 mg/l $CaCO_3$). Red circle for sites where DWSNZ 2005 and highest ANZECC & ARMCANZ (2000) values are exceeded, orange circle where DWSNZ 2005 is exceeded, green circle where median values are below the lowest ANZECC & ARMCANZ (2000) TV, yellow circle where neither standard is exceeded, and empty circle where median values cannot be determined. For clarity of presentation, sites are not labeled (Source: Daughney *et al*., 2009).

Key messages – Hardness

i. Hardness occurs in water due to natural causes and is not a result of human impact on the environment.
ii. Hard water generally is not a health hazard.
iii. Above standard hardness can clog small diameter pipes and emitters in irrigation systems and affect industrial apparatuses. It can also cause scale to form on household appliances and affect walls and fittings in bathrooms and kitchens.
iv. Below standard hardness can result in corrosion of metal pipes and fittings.
v. Hardness outside the recommended ranges represents a potential barrier to use of the Region's groundwater for certain purposes. However, this is a natural phenomenon that can either be tolerated or treated.

Sodium and chloride

94. Commonly, sodium (Na) and chloride (Cl) co-occur in comparable concentrations in groundwater. It should be noted that comparability of concentrations of Na and Cl applies only for measurements expressed in equivalent units, eg. milliequivalent per litre (meq/l). The following relationships apply for conversion between mg/l and meq/l concentration units:

For Na: Concentration in mg/l ÷ 22.99 = Concentration in meq/l Equation 11

For Cl: Concentration in mg/l ÷ 35.45 = Concentration in meq/l Equation 12

95. In theory, the ratio between Na and Cl in meq/l should be equal or very close to one (ie. Na:Cl = 1). After all, Na and Cl co-occur in seawater and rainwater at 1:1 ratio. Also, Na and Cl combine to produce NaCl (table salt, halite) in 1:1 ratio.

96. Elevated concentrations of Na and Cl in drinking water do not constitute a health risk. Therefore, the drinking water standards DWSNZ 2005 do not contain Maximum Allowable Values (MAV) for these two constituents. The DWSNZ 2005 contains aesthetic Guideline Values (GV) for Na and Cl of 200 mg/l and 250 mg/l, respectively. Daughney *et al*. (2009) indicate that the ANZECC & ARMCANZ (2000) guidelines for irrigation water indicate that Na and Cl concentrations should be less than 115 mg/l and 175 mg/l, respectively, to avoid foliar damage in sensitive crops. However, this increases for highly tolerant crops to up to, and even in excess of, 460 mg/l and 700 mg/l of Na and Cl, respectively.

97. Zarour (2008a) and Daughney *et al*. (2009) report that there is no evidence of elevated Na and/or Cl in the Region's groundwater that might be caused by seawater intrusion into coastal aquifers due to over-abstraction from wells. Daughney *et al*. (2009) also note that there is no evidence of elevated Na and/or Cl in groundwater due to contamination from septic tanks or land disposal of dairy shed effluent.

98. Daughney *et al*. (2009) note that high levels of Cl in irrigation water can also increase cadmium (Cd) concentration in crops. They explain that the risk of increasing crop cadmium concentrations is low when the irrigation water has up to 350 mg/l Cl, medium for Cl between 350 and 750 mg/l, and high for Cl above 750 mg/l.

99. Daughney *et al*. (2009) also note that the ANZECC & ARMCANZ (2000) guidelines for irrigation water also specify Trigger Values (TVs) for sodicity, defined as a high concentration of Na relative to calcium (Ca) and magnesium (Mg). This risk is expressed in terms of Sodium Adsorption Ratio (SAR)[20], which is a dimensionless[21] parameter. Extremely sensitive crops can tolerate SAR of up to 8, sensitive crops tolerate SAR of up to 18, crops with medium tolerance up to 46, and highly tolerant crops up to 102. The ANZECC & ARMCANZ (2000) guidelines for Na and Cl are also intended to minimise the risk of damage to soil structure and infiltration capacity.

100. SAR is calculated from the following equation (all concentration units in mg/l):

$$SAR = \frac{(Na/23)}{\sqrt{\frac{(2 \times Ca/40.1) + (2 \times Mg/24.5)}{2}}} \qquad \text{Equation 13}$$

101. Division of concentrations in the above equation by respective atomic weights for various ions is necessary to convert them from mg/l into equivalent units (meq/l).

102. According to Daughney *et al*. (2009), elevated concentrations of Na and/or Cl are rare in the Region and they pose little barrier to use of groundwater for most purposes. They also note that the risk of toxicity arising from sodicity is generally low throughout the Region, except perhaps for the most sensitive crop types.

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[20] Erroneously termed Sodium A**b**sorption Ratio in Daughney *et al.* (2009).
[21] Dimensionless: has no units.

Key messages – Sodium and chloride in groundwater

i. Commonly, sodium (Na) and chloride (Cl) co-occur in comparable concentrations in groundwater.
ii. Elevated concentrations of Na and Cl in drinking water do not constitute a health risk.
iii. DWSNZ 2005 contains aesthetic Guideline Values (GV) for Na and Cl
iv. ANZECC & ARMCANZ (2000) guidelines contain limits for Na and Cl in irrigation water.
v. Elevated concentrations of Na and/or Cl in regional groundwater are rare and they do not pose a barrier to use of the resource.

Nitrogen

103. Nitrogen occurs in various organic and inorganic forms in the environment. It constitutes approximately 79% by volume of Earth's atmosphere. The biogeochemical transformation of nitrogen and nitrogen-containing compounds in nature from one form to another is described by the nitrogen cycle (Figure 7). The nitrogen cycle is complicated. In it, atmospheric nitrogen is transferred in the soil into forms usable by living organisms, in a process that is called fixation. Nitrogen fixation is mostly done by free-living or symbiotic bacteria and algae, which combine gaseous nitrogen (N) with hydrogen (H) to produce ammonia (NH_3), which occurs in water as ammonium ion (NH_4^+). This process is called ammonification. The ammonia is further converted by other bacteria, first into nitrite ions (NO_2^-) and then into nitrate ions (NO_3^-), which plants utilise to grow. This part of the nitrogen cycle is known as nitrification. The cycle is completed in the soil through the conversion of nitrate back to nitrogen gas by other bacteria, in a process known as denitrification. Nitrogen in the soil also can emanate from fertilisers, urine, manure, septic tanks and landfills.

104. Regardless of its source, nitrate (NO_3^-) is highly soluble and, therefore, it is the form of nitrogen that is most used by plants for growth and development. For the same reason, it is the form of nitrogen that can easily leach into aquifers with recharge water.

105. Fresh groundwater recharge is usually oxygen-rich (ie. oxic water, oxidising conditions) due to contact with the atmosphere. As water flows under the ground, its oxygen content becomes depleted because of isolation from the atmosphere and microbial respiration (ie. anoxic water, reducing conditions). Under reduced conditions, ammonia (NH_4^+) becomes the dominant form of nitrogen in the water. Thus, the dominant nitrogen

species in groundwater is nitrate (NO_3^-), then to a lesser extent ammonium ion (NH_4^+). Daughney *et al.* (2009) discuss the changes in the oxidation-reduction conditions in groundwater and explain that:

i. Oxidised groundwater might contain nitrate (NO_3), but the concentrations of elements or compounds that only accumulate in groundwater in their reduced forms, such as iron (Fe), manganese (Mn) and ammonia (NH_4), should be near or below their analytical detection limits (typically 0.05 mg/l or less);
ii. Reduced (oxygen poor) groundwater might contain concentrations of Fe, Mn, and/or NH_4 well above their analytical detection limits (potentially several mg/l or more), but would not contain detectable oxygen or NO_3 (ie. substantially elevated concentrations of NO_3 and NH_4 are mutually exclusive in most groundwaters).

106. Daughney *et al.* (2009) explain that nitrite (NO_2^-) is generally unstable in groundwater as it is formed primarily as a short-lived intermediate form of nitrogen between NH_4 and NO_3 or nitrogen gas (N). It only accumulates in groundwater when the rate of its production exceeds the rate of its conversion to nitrogen gas (N), nitrate (NO_3) or ammonia (NH_4).

107. Daughney *et al.* (2009) note that there are no specific water use quality guidelines pertaining to total nitrogen, ie. the sum of all nitrogen species such as nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+) and other forms of nitrogen that might be present in water. Daughney *et al.* (2009) argue that because nitrogen is typically present in groundwater almost entirely in the form of nitrate (NO_3^-) or ammonia (NH_4^+), comparisons to water quality guidelines are best performed on the basis of the individual forms of nitrogen rather than on the basis of total nitrogen. They further argue that an assessment of total nitrogen concentration provides very little information that is not already conveyed by independent assessment of the concentrations of NO_3^- and NH_4^+. They note that Horizons' groundwater quality dataset includes only 10 sites at which the median concentrations of NO_3^- and NH_4^+ are both above 1 mg/l, and even for these sites one form of nitrogen has much higher concentration than the other.

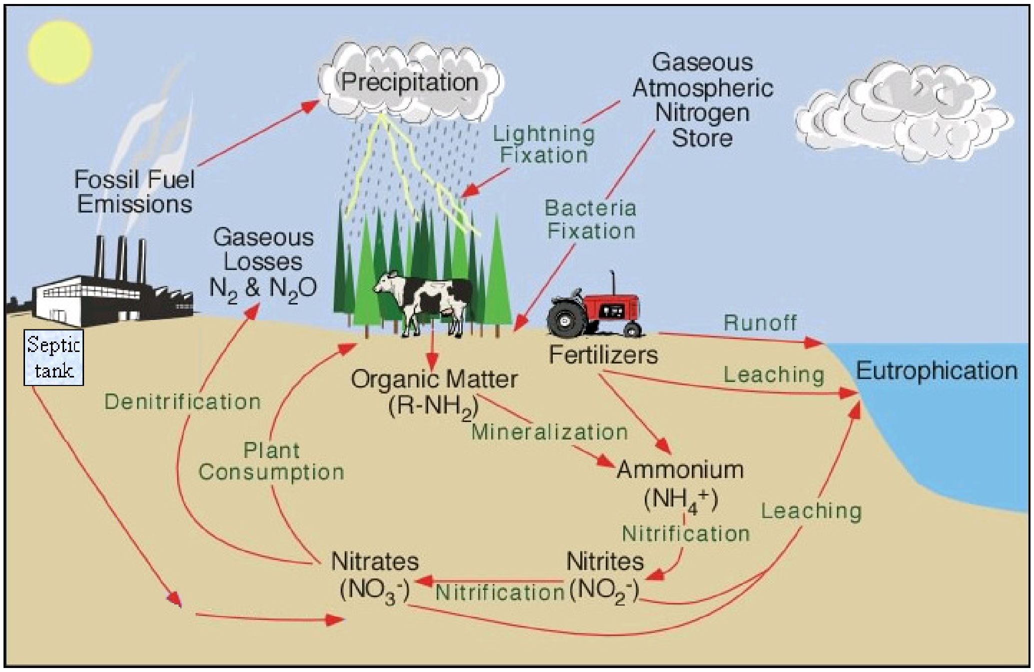

Figure 7. The nitrogen cycle (Modified after a diagram in PhysicalGeography.net[22]).

Nitrate

108. Nitrate (NO_3^-) can be found in pristine groundwater in low concentrations. Elevated nitrate concentration in groundwater is a general indicator of possible pollution. However, low nitrate levels in groundwater do not necessarily mean that the resource is not impacted by human activities (Daughney *et al.*, 2009).

109. Unlike ammonia, nitrate (NO_3) is not directly toxic to aquatic life. However, high nitrate levels in groundwater can indirectly affect aquatic life if it contributes to eutrophication in ecosystems that are groundwater dependent. Eutrophication is a process that results in high algal in surface water bodies and the consequent death of aquatic life due to excessive demand for oxygen. More information on eutrophication is provided in the evidence by Mrs Kate McArthur and Mr Max Gibbs.

110. The public is normally more concerned with the possibility of blue baby syndrome (methemoglobinemia), which can occur when nitrate contaminated water is consumed by breastfeeding mothers or used to prepare infant formula. This condition can rapidly progress to cause coma and death.

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[22] http://www.physicalgeography.net

111. Drinking water standards for New Zealand specify the Maximum Allowable Value (MAV) for nitrate as 50 mg/l NO_3, which is the equivalent of 11.5 mg/l nitrate-nitrogen (NO_3-N). This standard is adopted from the World Health Organisation (WHO, 1998) as it is believed that in excess of this concentration, nitrate can interfere with the transport of oxygen through the blood (ie. methemoglobinemia or blue baby syndrome), particularly in infants under six months of age.

112. Nitrate (NO_3) concentrations in excess of New Zealand drinking water standards have been noticed in the Region since the mid 1990s in wells in the Horowhenua District, particularly around Manakau (Bekesi, 1996). Hence, Horizons established a special monitoring programme to deal with this issue (Figure 8). Long-term monitoring results from this network are presented in Figure 9.

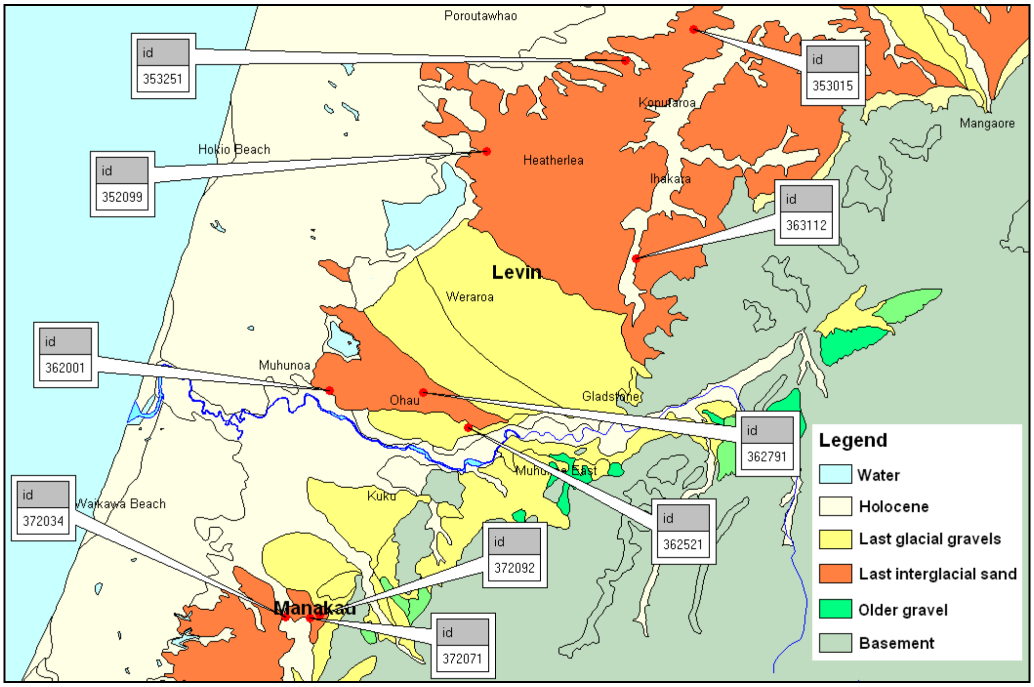

Figure 8. Location map for long-term nitrate (NO_3) monitoring sites in the Horowhenua District showing associated geology (Source: Zarour, 2008a).

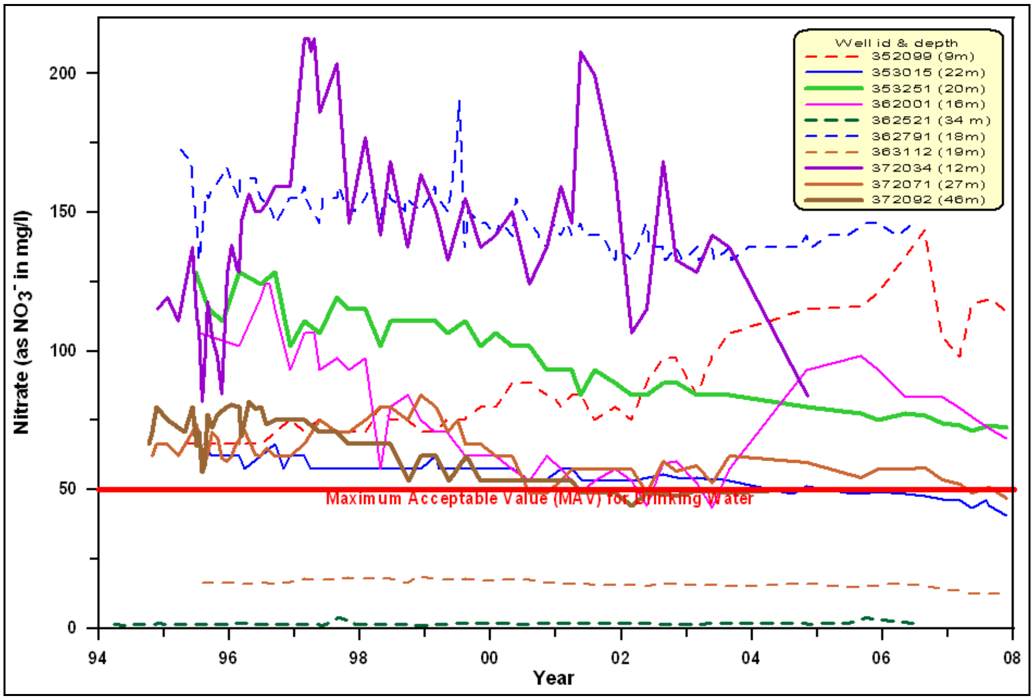

Figure 9. Long-term nitrate (NO_3) in groundwater monitoring results in the Horowhenua District (Source: Zarour, 2008a). For well locations, see Figure 8.

113. Daughney *et al*. (2009) note that the Australia New Zealand Environment Conservation Council guidelines (ANZECC & ARMCANZ, 2000) for livestock consumption indicate that NO_3^- concentrations below 400 mg/l should not be harmful to animal health, and that stock may tolerate higher NO_3 concentrations in drinking water provided NO_3 concentrations in feed are not high. Daughney *et al*. (2009) also note that water containing more than 1,500 mg/l NO_3^- is likely to be toxic to animals.

114. Daughney *et al*. (2009) also note that in order to minimise nutrient leaching into aquifers and surface water systems, the ANZECC & ARMCANZ (2000) guidelines for irrigation water specify a long-term maximum (for periods of up to 100 years) of 22 mg/l for NO_3 and a short-term maximum (for up to 20 years) of between 110 and 550 mg/l, depending on site characteristics and crop type.

115. The recent analysis of regional groundwater quality data by Daughney *et al*. (2009) reports that of the 605 sites that have sufficient records to enable determination of median NO_3 concentrations, only 10% exceed the health-related Maximum Allowable Value (MAV) for human consumption, whereas 30% of the sites have median NO_3 concentrations above the long-term Trigger Value (TV) for irrigation water. Only 2% of the sites have median NO_3 above the lowest short-term TV for irrigation water (110 mg/l),

and no sites exceed the Guideline Value (GV) for livestock consumption. It should be noted that nitrate monitoring is biased to concentrate in the Horowhenua area, so site numbers and percentages reported in Daughney *et al*. (2009) should not be taken to be representative of the Region. By plotting median NO_3 concentration relative to MAV specified in DWSNZ 2005, Daughney *et al*. (2009) demonstrate that the Horowhenua District is the only part of Horizons' Region containing a density of wells with above MAV nitrate levels (Figure 10).

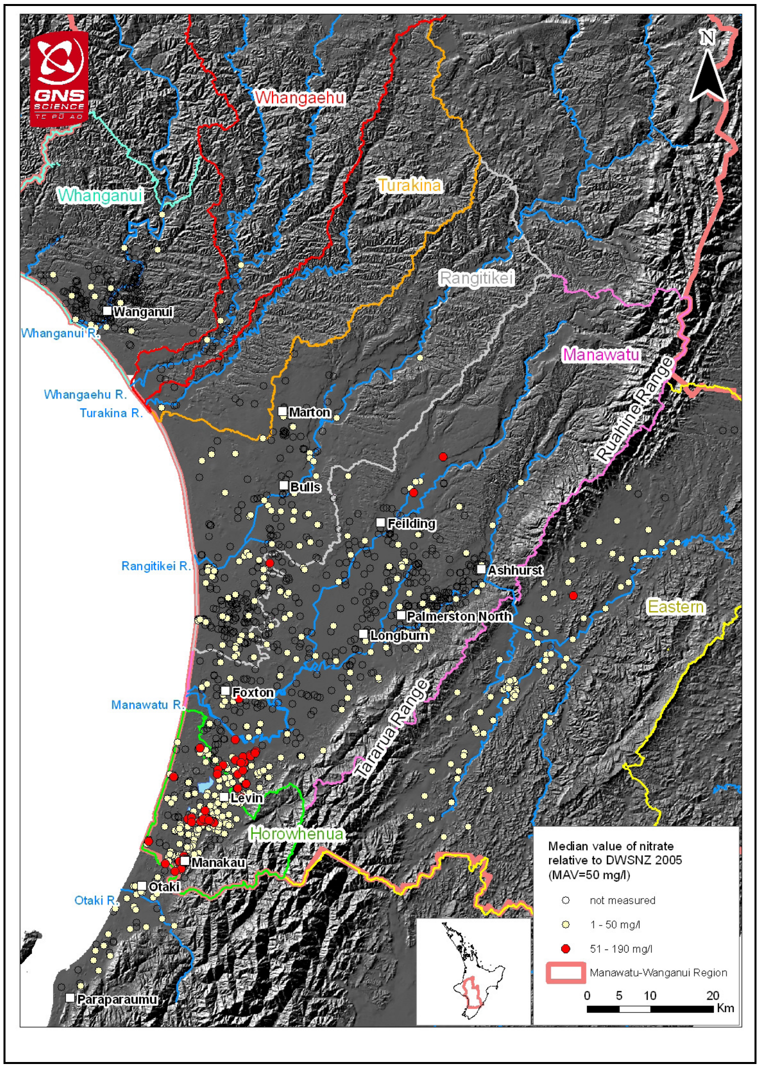

Figure 10. Median values of nitrate (NO_3) concentration relative to Drinking Water Standards New Zealand guidelines (MAV = 50 mg/l). Red circle for sites where MAV is exceeded, yellow circle where MAV is not exceeded and empty circle where median concentrations cannot be determined. For clarity of presentation, sites are not labelled. Blue lines rivers and coloured lines boundaries for groundwater management zones (Source: Daughney *et al*., 2009).

116. Zarour (2008a) notes that many investigators have looked into the problem of high nitrate concentrations in some wells in the Horowhenua District (eg. Bekesi, 1996; Bramwell, 2000; Bruns, 2000; McLarin *et al*., 1999; McLarin, 1996). All such investigators recognise that this problem is limited to wells in the District that are screened in the low permeability Otaki Formation. They also all agree that the problem is highly localised, meaning that elevated nitrate is not continuous and cannot be interpolated between wells. However, different investigators have different opinions in relation to the reason for this problem. While it goes without saying that this problem is a result of human activity, exactly what kind of activity is responsible largely remains unknown. Personally, I am of the opinion that the problem is essentially related to non-diffuse sources like septic tanks and piggeries, rather than diffuse contamination sources such as application of fertilisers to agricultural land.

117. Basic examination of long-term monitoring suggests the nitrate problem in the affected area is not worsening (Figure 9). The recent statistical analysis of the data by Daughney *et al*. (2009) indicates that there is a decreasing trend in 7.9%, and an increasing trend in 7.4%, of the 203 sampled wells at which trend tests can be performed for NO_3^-. The remaining 84.7% of such wells do not show detectable trend, ie. the situation is constant (Figure 11). Daughney *et al*. (2009) conclude that their analysis shows that there are wells where nitrate (NO_3) concentrations are changing, but nitrate levels are not systematically increasing or decreasing across the Region. In my opinion, this suggests that existing policies relating to discharge to land and surface water are adequate to protect against diffuse nitrate pollution. The new septic tanks policies are believed to be adequate to protect against non-diffuse sources of contamination.

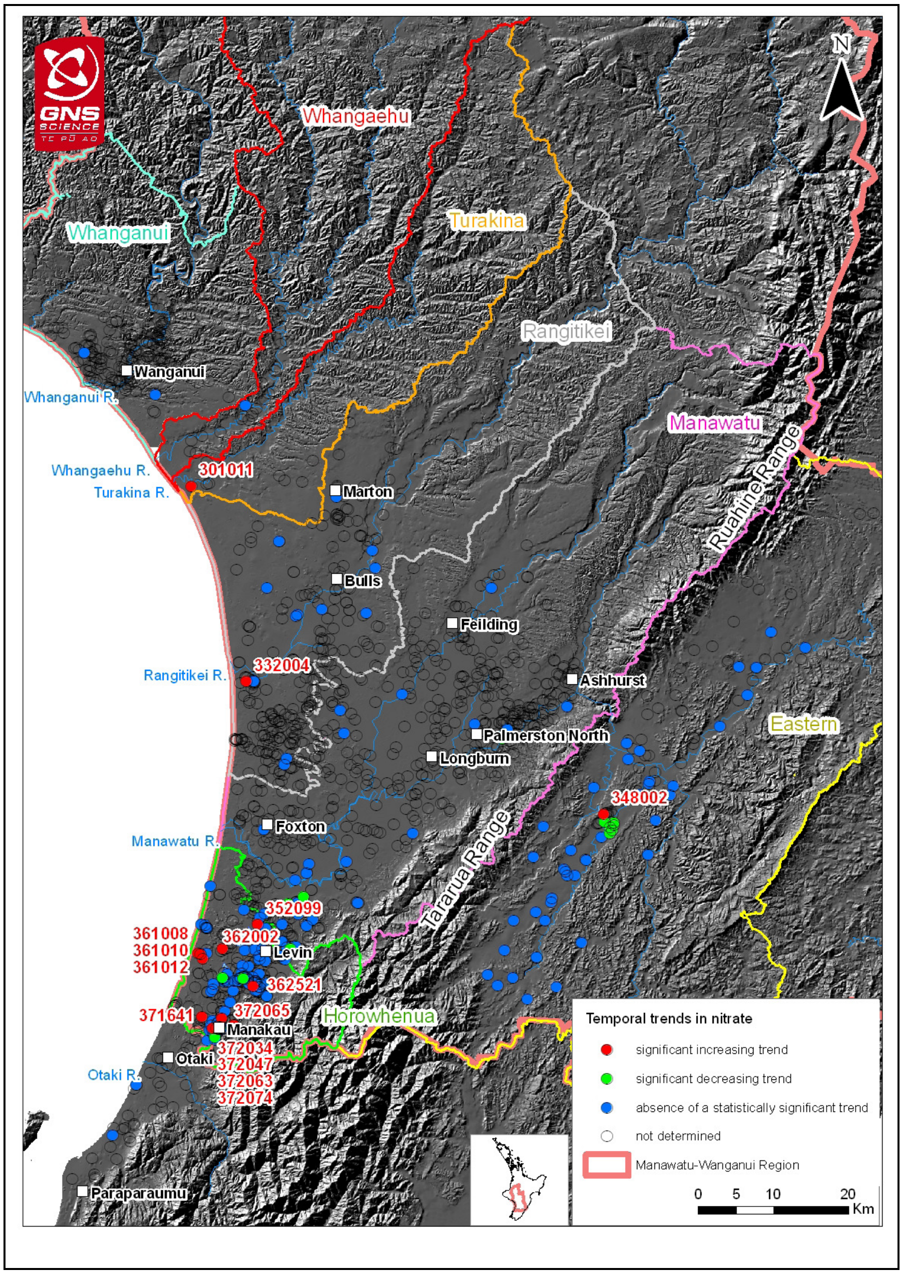

Figure 11. Spatial distribution of temporal trends in nitrate (NO_3^-). Red, green, blue and empty circles for sampled sites with a significant increasing trend, a significant decreasing trend, absence of a statistically significant trend and where the trend test is "not determined" due to lack of data, respectively. For clarity of presentation, only sites with a significant increasing trend are labelled (Source: Daughney *et al.*, 2009).

Ammonia

118. When dissolved in water, ammonia (NH_3) is ionised into ammonium (NH_4^+). Traditionally, hydrological literature used the two terms, ammonia and ammonium, indifferently. There is no Maximum Allowable Value (MAV) for NH_4 in the drinking water standards (DWSNZ 2005). This may be a reflection of the fact that the human body produces much higher levels of ammonia than are usually found in the environment. New Zealand drinking water standards (DWSNZ 2005) specify an aesthetic Guideline Value (GV) of 1.5 mg/l of NH_4 to minimise odour.

119. Public water supply is often treated by addition of hypochlorous acid (ie. chlorinated) to control disease-causing organisms and provide protection until water is consumed. Chlorination of water containing NH_4 can result in the formation of chloramine (NH_2Cl), which is toxic in large quantities. Therefore, the maximum allowable NH_4 concentration is 0.3 mg/l for drinking water that requires chlorination.

120. Daughney *et al*. (2009) found that about one third of the 366 sites which have enough information to enable calculation of the median ammonia concentration have ammonia in excess of the DWSNZ 2005 GV of 1.5 mg/l, and two thirds of the 366 sites have median NH_4 concentration above the threshold of 0.3 mg/l set for chlorine-treated drinking water. Daughney *et al*. (2009) note that wells with ammonia concentrations above the aesthetic GV of 1.5 mg/l are distributed across the Region, particularly in the Whanganui and Whangaehu GMZs (Figure 12).

121. ANZECC & ARMCANZ (2000) guidelines do not provide thresholds for ammonia in stock water or irrigation water. Hence, ammonia in groundwater is not considered an issue for these uses in the Region.

122. Removal or reduction of ammonia levels (treatment) is possible and relatively easy through aeration of water to allow ammonia to transform into nitrate (nitrification). As ammonia is usually found in low levels in comparison to nitrate, and ammonia rich water is usually nitrate free, the treated water should have acceptable levels of both ammonia and nitrate, within the drinking water standards. Treatment for ammonia is not necessary for stock water and irrigation water.

123. As discussed in the section starting with Paragraph 270.286 (p 142) of this evidence, many surface water bodies receive replenishment from groundwater. Although ammonia is highly toxic to aquatic life, ammonia-rich groundwater seeping into surface water

bodies is not a hazard to aquatic life because ammonia will be converted into nitrite (NO_2) or nitrate (NO_3) upon entering the receiving surface water body, which is normally relatively richer in oxygen. Lusby *et al*. (1998) indicate that more than 95% of the ammonia load into a monitored recipient wetland was removed by nitrification and subsequent denitrification. Mr Max Gibbs is the corresponding author for that paper and will provide further information on this matter in his evidence.

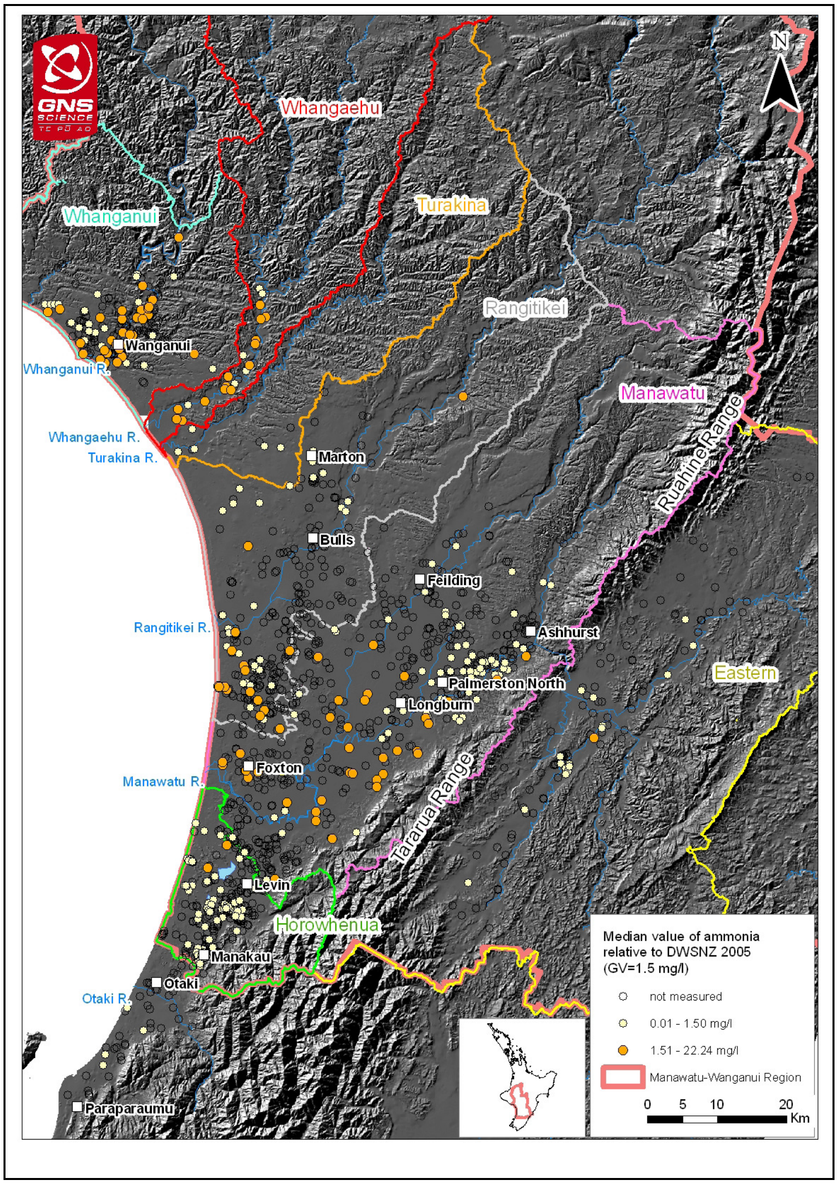

Figure 12. Median values of ammonia (NH_4) concentration relative to Drinking Water Standards New Zealand guidelines (GV = 1.5 mg/l). Orange circle for sites where GV is exceeded, yellow circle where GV is not exceeded and empty circle where median concentrations cannot be determined. For clarity of presentation, sites are not labelled (Source: Daughney *et al*., 2009).

Nitrate

124. Daughney *et al*. (2009) note that nitrite (NO_2^-) concentrations poses little risk to the use of the Region's groundwater for various purposes. They were able to calculate the median nitrite (NO_2^-) concentration at 282 wells in the Region and found out that none have median nitrite concentration above the short-term Maximum Allowable Value (MAV) of 3 mg/l provided in the drinking water standards (DWSNZ 2005) and that only 12 wells have median nitrite concentrations above the long-term MAV of 0.2 mg/l. In addition, they note that there are no sites at which the median nitrite concentration exceeds the trigger value (TV) for livestock consumption as provided in ANZECC & ARMCANZ (2000) guidelines.

Key messages – Nitrogen species in groundwater

i. Nitrogen occurs in various organic and inorganic forms in the environment. The dominant nitrogen species in groundwater is nitrate (NO_3^-), then to a lesser extent ammonium ion (NH_4^+).

ii. Nitrate (NO_3^-) concentration in groundwater above background levels is a general indicator of human influence on groundwater quality, ie. pollution.

iii. There are national standards for NO_3 in drinking water, stock water and irrigation water.

iv. The Maximum Allowable Value (MAV) for nitrate (NO_3) in drinking water is established in New Zealand and internationally at 50 mg/l NO_3, which is the equivalent of 11.5 mg/l nitrate-nitrogen (NO_3-N). The drinking water standard is set to protect against methemoglobinemia (blue baby syndrome).

v. Nitrate concentrations in groundwater in the Region are within the stock water standards and generally within irrigation water standards.

vi. Some wells in the Horowhenua District have nitrate levels above the MAV for drinking water.

vii. Nitrate in groundwater in the Horowhenua District is a problem specific to wells that tap a particular low permeability geological formation (the Otaki sand, ie. Q5b QMAP unit).

viii. A number of investigators have looked at the problem with nitrate in groundwater in the Horowhenua District, but results are diverse and inconclusive.

ix. Horizons has an ongoing monitoring programme that does not suggest that the situation is generally changing for the better or for the worse.

x. Policies for discharges to land and surface water are adequate to protect the groundwater resource from diffuse nitrate pollution, and the new septic tanks policies are adequate to protect against non-diffuse sources.

xi. Ammonia (NH_4^+) in the drinking water is not a health hazard and there is no Maximum Allowable Value (MAV) for it. There is an aesthetic Guideline Value (GV) for NH_4^+ in drinking water to minimise odour.

xii. Ammonia in groundwater is not considered a potential hazard in stock water or irrigation water.

xiii. Ammonia concentrations above 0.3 mg/l in drinking water that requires chlorination may be a health hazard.

xiv. Removal or reduction of ammonia levels is possible and relatively easy.

xv. Nitrite (NO_2^-) is generally unstable in groundwater and is formed primarily as a short-lived intermediate form of nitrogen between NH_4 and NO_3 or nitrogen gas.

xvi. Nitrite (NO_2^-) poses little risk to the use of the Region’s groundwater for various purposes.

xvii. Assessment of total nitrogen concentration in groundwater does not add value to independent assessment of the concentrations of various nitrogen species, eg. of NO_3^-, NH_4^+ and NO_2^-.

Phosphorus (P) and phosphate (PO_4^{3-})

125. Phosphorus exists in the environment in different chemical organic and inorganic forms. It occurs naturally in rock-forming minerals. Weathering of rocks gradually releases phosphorus as phosphate ions (PO_4^{3-}) into the wider environment. Phosphate ions are soluble in water. Phosphates are found in the environment as free ions or weakly chemically bounded in aqueous systems, chemically bounded to sediments and soils, or as mineralised compounds in soil, rocks and sediments. Phosphorus is a key element necessary for growth of plants and animals, which take it from the soil and water. The phosphate cycle describes the biogeochemical transformation of phosphorus-containing compounds in the environment from one form to another (Figure 13).

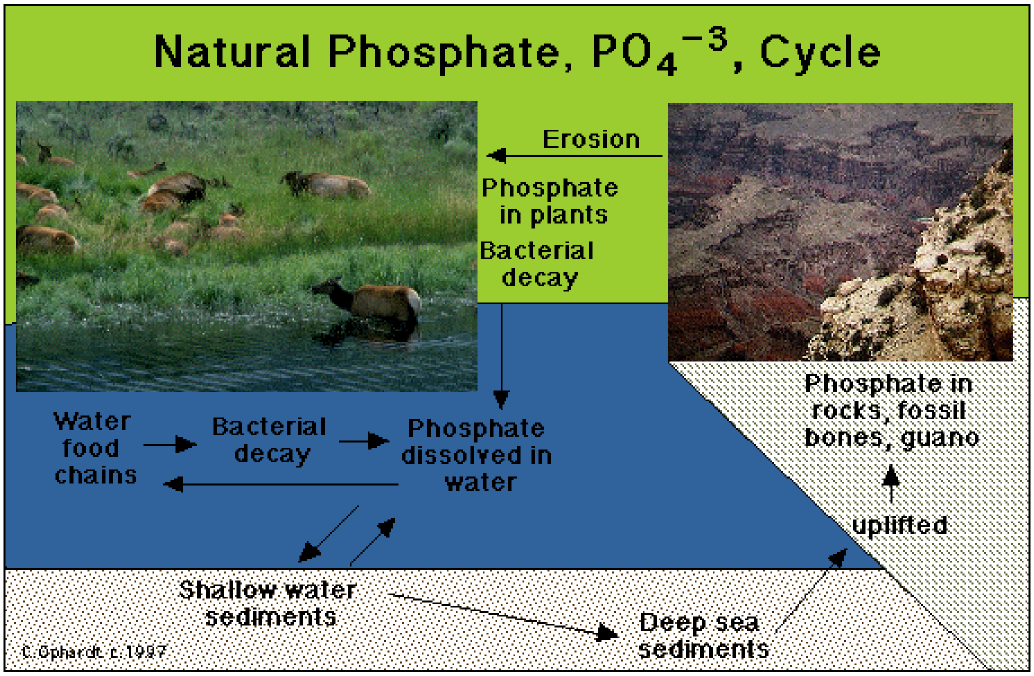

Figure 13. The phosphate cycle (Adopted from the website of the Centre for Environmental Quality, Environmental Engineering and Earth Sciences of Wilkes University[23]).

126. Phosphorus is often scarce in the aerobic (well-oxygenated) waters. The soluble form of phosphorus (phosphates) is typically found in very low concentrations in unpolluted waters, but they can increase as a consequence of human activities. Sources of phosphates related to human activity include partially treated and untreated sewage, run-off from agricultural sites and fertilisers.

127. During storm events, phosphates applied to land as fertilisers are washed from agricultural fields and carried into the draining surface water body in dissolved form and/or attached to eroded particles of soil or manure. Recharge from rain can cause phosphates to migrate downwards into the groundwater. However, phosphates have little potential to leach through soil into groundwater because soil particles have a large capacity to fix phosphorus in forms that are immobile in soil. Because soil particles strip soluble phosphorus compounds from the water as it leaches through the soil, phosphorus levels in soil leachate can be as little as 10% of surface run-off concentrations. Hence, I consider phosphorus to be a potential surface water quality issue rather than a groundwater problem.

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[23] http://www.water-research.net/phosphate.htm

128. According to Daughney *et al*. (2009), phosphates are not toxic to people or animals unless they are present in very high levels and, hence, the Ministry of Health Drinking Water Standards (2005 & 2008) do not specify limits for phosphorus for human consumption and ANZECC & ARMCANZ (2000) guidelines do not specify limits for stock water. It should be noted that the United Kingdom Drinking Water Standard is set at 2.2 mg P /l. Phosphorus concentrations above this limit have been noticed only in one well in the Region, in the Wanganui area (Well 209005).

129. The ANZECC & ARMCANZ (2000) guidelines for irrigation water specify short-term and long-term Trigger Values (TV) of 0.05 mg PO_4-P /l and 0.8-12 mg PO_4-P /l, respectively. The long- term TV is set to minimise algal growth in the irrigation water itself over a period of 100 years, whereas the short-term TV is intended to minimise phosphorus loss to receiving water bodies for periods of up to 20 years. Daughney *et al*. (2009) were able to calculate median PO_4-P concentration at 242 wells across the Region. They found that 58% of the wells have PO_4-P concentrations above the long-term TV of 0.05 mg/l and 4% of the wells have median PO_4-P concentration above the more lowest short-term TV of 0.8 mg/l.

130. Daughney *et al*. (2009) note that sites with median PO_4-P concentration above Trigger Values for irrigation water are scattered across the Region (Figure 14). They also note that elevated concentrations of PO_4-P co-occur with elevated concentrations of Fe, Mn and/or NH_4. This is expected to happen in underground oxygen-poor (anoxic, reduced) environments. I believe that the presence of peat[24] and other organic deposits may contribute to this phenomenon.

131. As phosphorus concentrations in surface run-off are expected to be higher than phosphorus concentrations in groundwater, phosphorus in groundwater feeding into surface water bodies is not considered a potential problem for the receiving ecosystem. This matter will be further addressed in the evidence presented by Mr Max Gibbs.

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[24] Buried, partly decomposed plant material.

Key messages – Phosphorus and phosphate

i. Phosphorus occurs in the environment in different forms.
ii. The phosphate cycle describes the biogeochemical transformation of phosphorus-containing compounds in nature from one form to another.
iii. Phosphate ions (PO_4^{3-}) are soluble in water.
iv. Phosphate is often scarce in aerobic (well-oxygenated) waters.
v. Phosphates are not toxic to people or animals unless they are excessive.
vi. Elevated concentrations of phosphates in the Region co-occur with elevated concentrations of Fe, Mn and/or NH_4.
vii. About half of the Region’s wells have phosphate concentration in excess of the long-term (100 years) Trigger Value (TV) for phosphates in irrigation water and only very few exceed the short term (20 years) TV.
viii. Phosphates concentrations in surface run-off are expected to be much higher than in groundwater.
ix. Phosphorus in groundwater feeding surface water systems is not considered a problem.

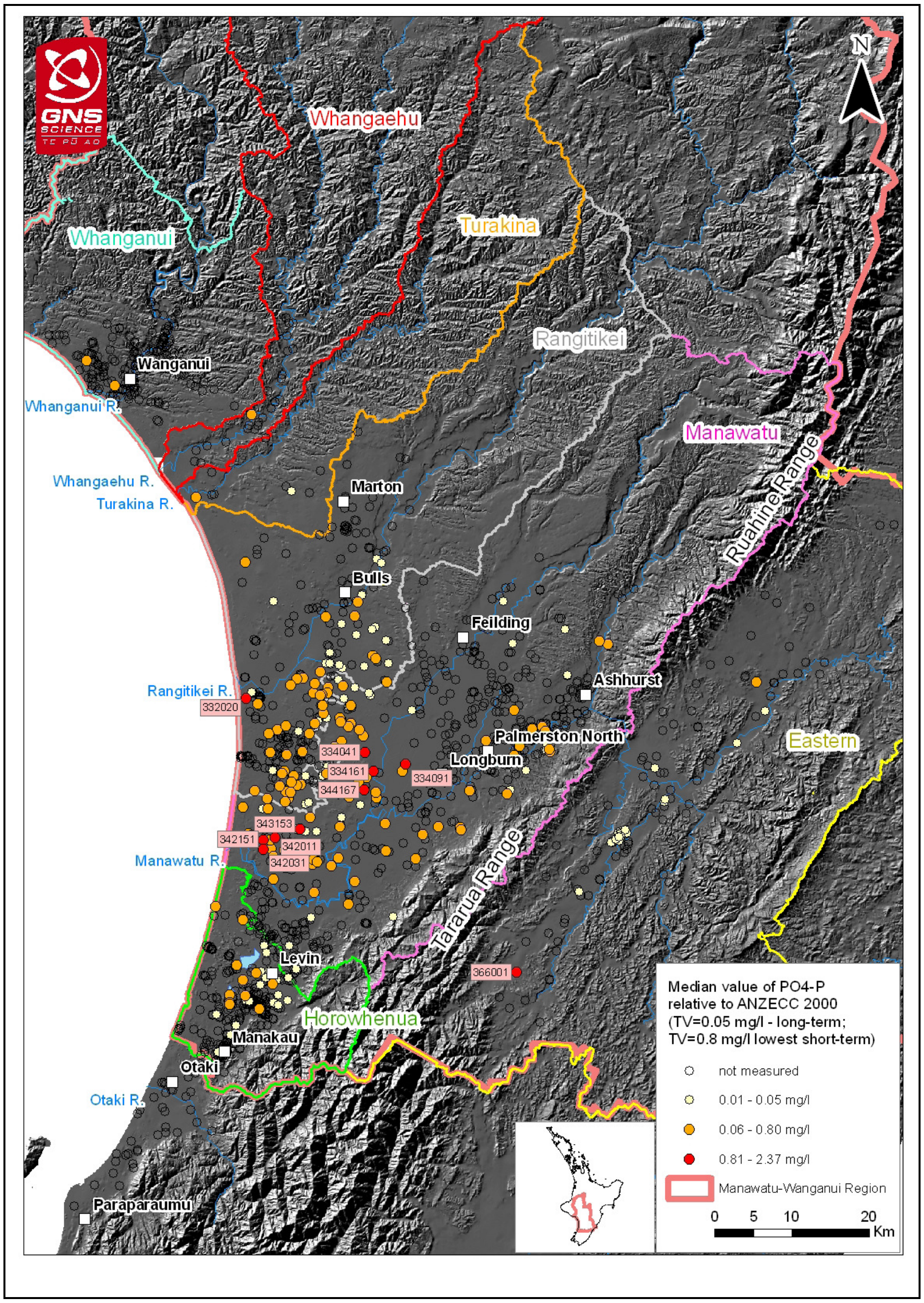

Figure 14. Median values of phosphate-phosphorus (PO_4-P) concentration relative to ANZECC & ARMCANZ (2000) irrigation guidelines (long-term TV = 0.05 mg/l, lowest short-term TV = 0.8 mg/l). Red circle for sites where both TVs are exceeded, orange circle where long-term TV is exceeded, yellow circle where TVs are not exceeded and empty circle where median concentrations cannot be determined. For clarity of presentation, only sites exceeding both TV are labelled (Source: Daughney *et al.*, 2009).

Iron (Fe) and Manganese (Mn)

132. Daughney *et al*. (2009) note that dissolved iron (Fe) and manganese (Mn) often co-occur and accumulate naturally in anoxic (oxygen-poor, reduced) groundwater and, therefore, they discuss them together.

133. Commonly, Fe and Mn accumulate in groundwater naturally, where they are sourced from weathering of iron and manganese bearing rocks. They may also reach groundwater from industrial effluent, acid-mine drainage, sewage, and landfill leachate.

134. Both Fe and Mn have more than just one oxidation state (or number). Iron may occur in solution as Fe^{2+} or Fe^{3+} ions and manganese may occur as Mn^{2+} or Mn^{3+}.

135. Iron exists as Fe^{2+} only in anoxic (reduced) waters (oxygen levels < 1 mg/l). This form of iron is water soluble and reduced waters can contain up to several mg/l of Fe^{2+}. Where oxygen levels increase, the water becomes oxic and Fe^{2+} ions change to Fe^{3+} ions, which is much less water soluble. The same applies to manganese (Mn^{2+} and Mn^{3+} ions). Hence, when reduced groundwater containing dissolved iron and manganese in the form of Fe^{2+} and Mn^{2+} is extracted from an aquifer, contact with air leads to oxidation, and the iron and manganese precipitate. Daughney *et al*. (2009) note that these precipitates often form stains on surfaces and may lead to clogging of pipes and/or well screens, which may in turn reduce well yields and the efficiency of water reticulation systems. They further note that the precipitation of Fe and/or Mn from solution is often associated with increased growth of unwanted bacteria, which form a slimy coating on surfaces and can further reduce well yields and reticulation efficiency (eg. Figure 15). Hence, the ANZECC & ARMCANZ (2000) guidelines for irrigation specify Trigger Values (TVs) of 10 mg/l for both Fe and Mn.

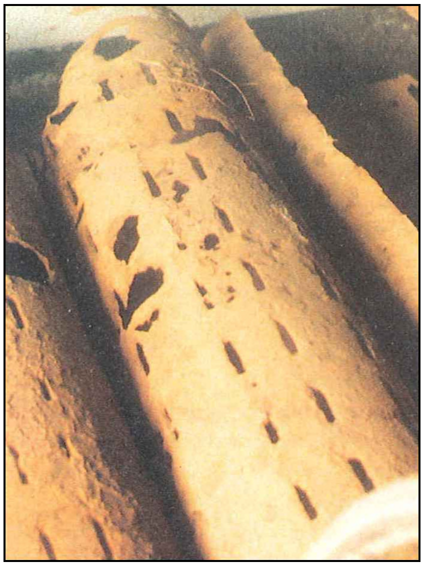

Figure 15. Example of erosion causing damage to screen and eventual failure of the well as a result of incrustation and corrosion due to iron precipitation and bacteria growth (Photo from: Driscoll, 1986)[25].

136. According to Daughney *et al.* (2009), elevated concentrations of dissolved Fe and/or Mn can also impart an unpleasant taste to drinking water. For these reasons, DWSNZ 2005 includes aesthetic Guideline Values (GVs) of 0.2 and 0.04 mg/l for Fe and Mn, respectively. Due to risks to human health, Mn also has a Maximum Allowable Value (MAV) of 0.4 mg/l. There are no recognised health risks associated with elevated Fe and, hence, there is no MAV defined for it.

137. Daughney *et al.* (2009) note that elevated Fe and Mn concentrations are common in groundwater across the Region. They were able to determine median concentrations of Fe for 1,090 wells. Of these, 773 wells (71%) have median Fe concentration above the aesthetic GV of 0.2 mg/l, reaching a maximum of 40 mg/l. They were also able to determine median Mn concentration for 709 wells. They report that 28% of these wells have median Mn above the health-related MAV of 0.4 mg/l and 71% have median Mn above the aesthetic GV of 0.04 mg/l, reaching a maximum of 13 mg/l. Daughney *et al.* (2009) were able to determine the median concentrations for both Fe and Mn for 695 wells, of which 419 (60%) have median values that exceed the corresponding aesthetic GVs for both elements. They articulate that very few sites (3%) have median concentrations of Fe or Mn in excess of the ANZECC & ARMCANZ (2000) TV for irrigation water.

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[25] This is the second edition of a classical industry reference book. The third edition was released in July 2008, but is on back order.

138. Daughney *et al*. (2009) note that wells with above-threshold concentrations of Fe and/or Mn are distributed across the Region (Figure 16 and Figure 17, respectively), which suggests that the majority of the Region's groundwater is anoxic (oxygen-deprived, reduced).

139. Iron and manganese concentrations in groundwater in the Region can fluctuate seasonally and vary with the depth, location and geological setting of wells. As iron and manganese occur in groundwater that has little or no oxygen, they are typically (but not always) found in deeper wells, in areas where groundwater flow is slow. Elevated concentrations of Fe and Mn are usually associated with aquifer material rich in organic matter, like peat, which is also the situation with other chemical constituents such as phosphate (see Paragraph 130, p 47). Concentrations in excess of standard values can occur locally anywhere in the Region and are not predictable.

140. If needed, groundwater can be treated to remove iron and manganese or reduce their concentrations. Normally, both constituents are treated at the same time. Boiling water does not remove Fe and Mn. Treatment methods largely depend on scale, and include using carbon filters, chlorine or ozone. Ion exchange, oxidising filters and reverse osmosis can also be used but these vary in effectiveness and may be expensive for households and small communities.

141. Elevated iron (Fe) and manganese (Mn) in groundwater is not perceived as an ecological problem in surface water systems that are dependent on groundwater.

Key messages – Iron (Fe) and manganese (Mn)

i. Iron (Fe) and Manganese (Fe) in groundwater can stain surfaces and may lead to clogging of reticulation system pipes and/or well screens.
ii. Elevated iron (Fe) and manganese (Mn) concentrations are common in groundwater across the Region.
iii. Iron and manganese often co-occur in groundwater.
iv. They are natural constituents and widespread in the Region's groundwater.
v. Their existence and distribution in the Region's groundwater suggest predominance of oxygen-poor (reduced) hydrogeochemical conditions.
vi. There are no recognised health risks associated with elevated Fe.
vii. Mn > 0.4 mg/l may be a human health risk.
viii. Elevated concentrations of dissolved Fe and/or Mn can impart an unpleasant taste to drinking water.
ix. If desired, groundwater can be treated to remove or reduce iron and manganese.
x. Iron and manganese in groundwater is not perceived as an ecological problem in surface water systems that are dependent on groundwater.

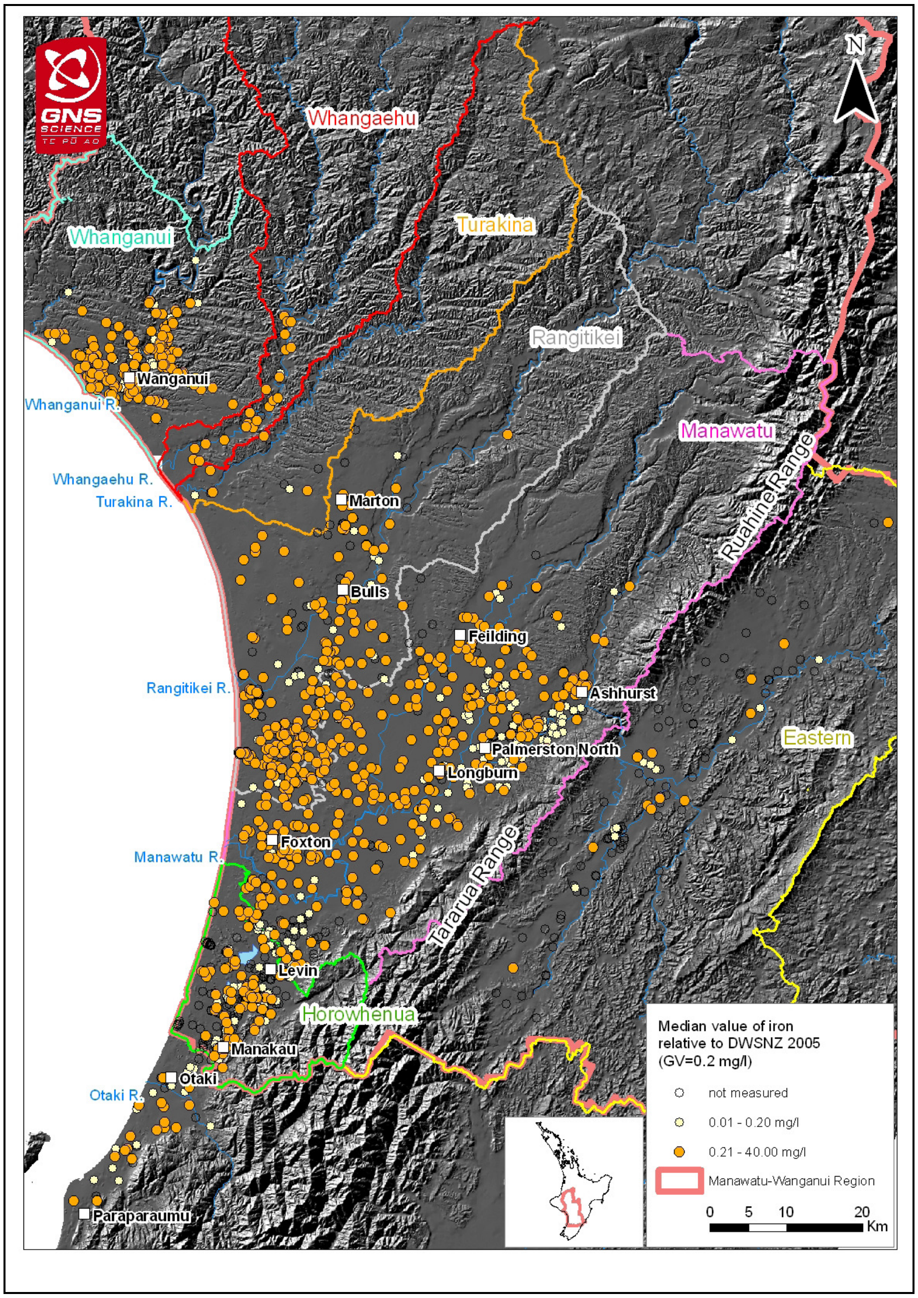

Figure 16. Median values of iron (Fe) concentration relative to Drinking Water Standards New Zealand guidelines (GV = 0.2 mg/l). Orange circle for sites where GV is exceeded, yellow circle where GV is not exceeded and empty circle where median concentrations cannot be determined. For clarity of presentation, sites are not labelled (Source: Daughney *et al.*, 2009).

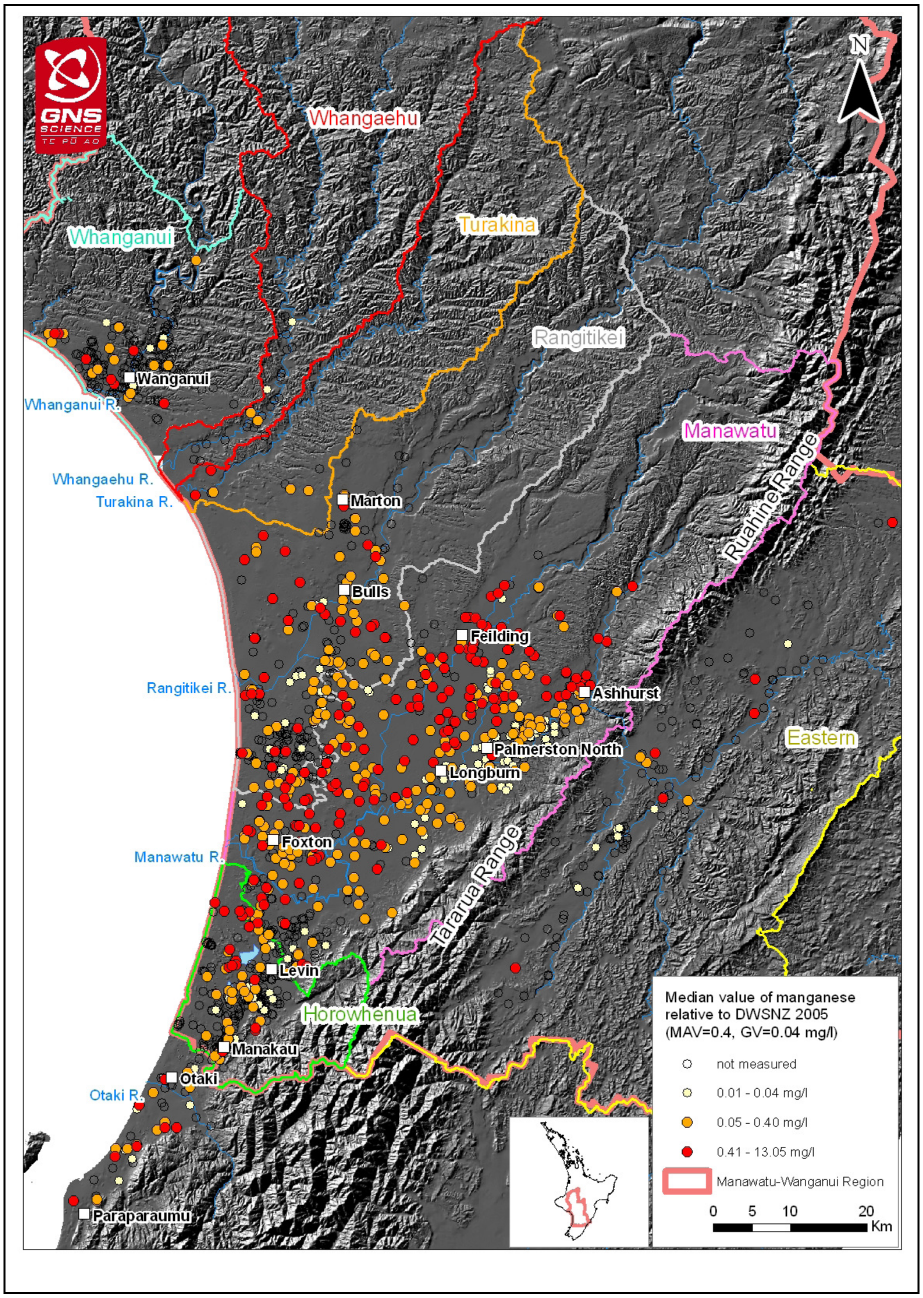

Figure 17. Median values of manganese (Mn) concentration relative to Drinking Water Standards New Zealand guidelines (MAV = 0.4 mg/l, GV = 0.04 mg/l). Red circle for sites where MAV and GV are exceeded, orange circle where GV is exceeded, yellow circle where MAV and GV are not exceeded and empty circle where median concentrations cannot be determined. For clarity of presentation, sites are not labelled (Source: Daughney *et al.*, 2009).

pH

142. pH (ie. **p**otential of **H**ydrogen) is a measure of the acidity or alkalinity of a solution, measured at a scale from 0 to 14, with a value of 7 for neutral solutions. Acids have pH < 7 and bases have pH > 7.

143. Daughney *et al*. (2009) note that the drinking water standards (DWSNZ 2005) and the guidelines for irrigation and livestock drinking water (ANZECC & ARMCANZ, 2000) recommend pH ranges of 7.0-8.5 for human consumption and 6.0-8.5 for irrigation water. They also note that ANZECC & ARMCANZ (2000) recommended ranges are intended to limit corrosion and fouling of reticulation, irrigation and stock watering systems, and that pH values outside these ranges can also lead to solubilisation and accumulation of metals such as copper, lead, zinc, etc, which have their own associated health risks.

144. Daughney *et al*. (2009) were able to determine median pH for 1,091 wells in the Region. They found that median pH in 24% of these wells falls outside the recommended range for drinking water and 4% are outside the range for irrigation use. They articulate that 254 wells have median pH below 7, 32 sites below 6, and eight sites above 8.5. They conclude that pH outside of the recommended range is a common occurrence in the Region (Figure 18).

145. Daughney *et al*. (2009) note that wells with median pH below 7 (acidic) are found throughout the Region, but with greatest spatial density in the Horowhenua and Tararua Groundwater Management Zones. The few wells with median pH above 8.5 (basic) are almost all found in the Whanganui Groundwater Management Zone adjacent to the Whanganui River and about 10 km from the coast.

Key messages – pH

i. pH (potential of Hydrogen) is a measure of the acidity or alkalinity of a solution.
ii. Acids have pH < 7, neutral solutions have pH = 7 and bases have pH > 7.
iii. Recommended guideline ranges are intended to limit corrosion and fouling of reticulation, irrigation and stock watering systems
iv. pH outside recommended ranges may lead to solubilisation and accumulation of metals, which have their own associated health risks.
v. pH outside of the recommended range is a common occurrence in the Region.
vi. Acidic water wells are found throughout the Region, but with greatest concentration in the Horowhenua and Tararua Groundwater Management Zones.
vii. The few wells that have basic water are almost all found in the Whanganui Groundwater Management Zone.

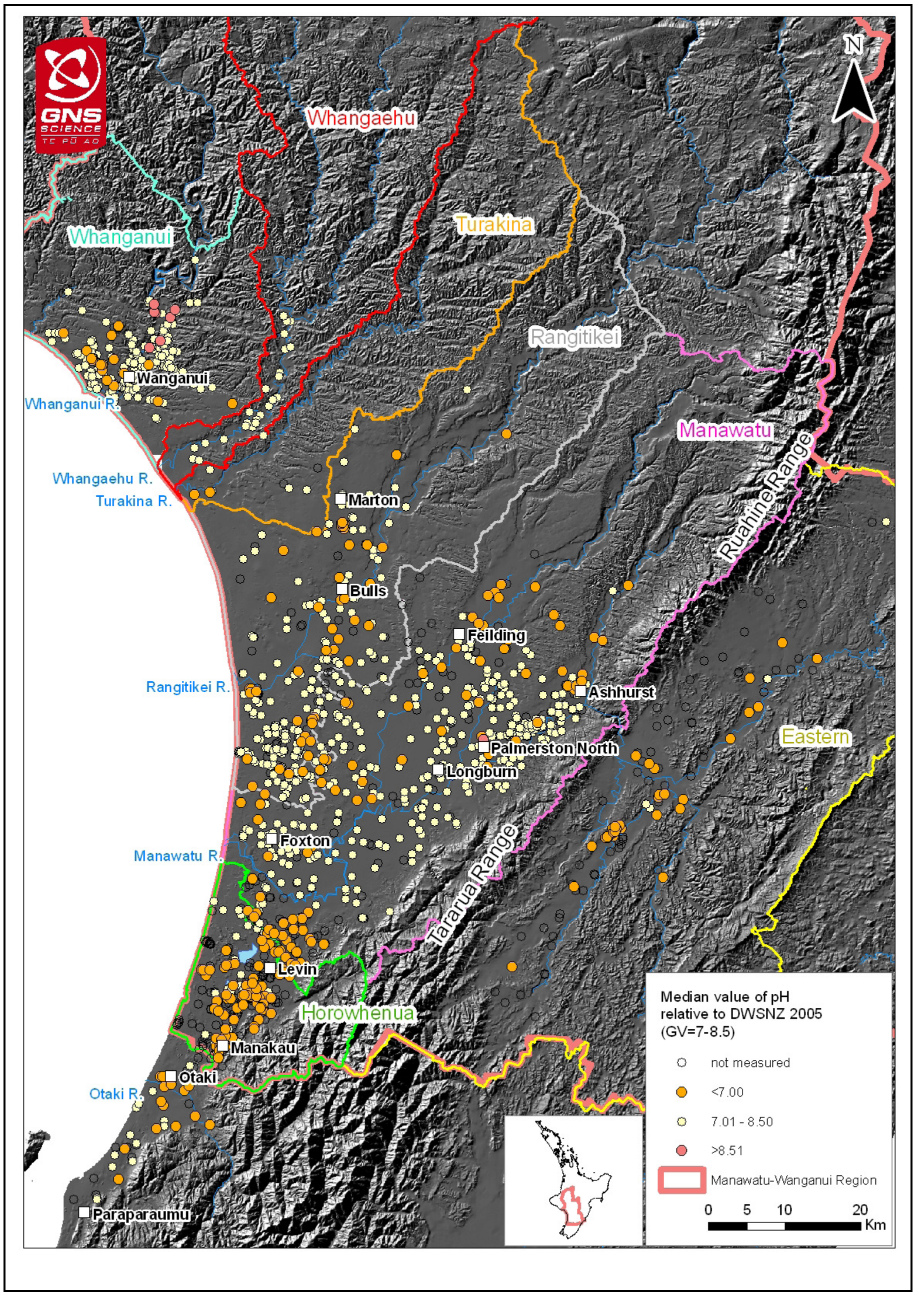

Figure 18. Median values of pH relative to Drinking Water Standards New Zealand guidelines (GV = 7-8.5). Orange circle for sites where pH is below GV (ie. more acidic), red circle for pH above GV (ie. more basic), yellow circle where pH is between 7 and 8.5 and empty circle where median pH cannot be determined. For clarity of presentation, sites are not labelled (Source: Daughney *et al*., 2009).

Pesticides

146. Pesticides help to increase agricultural production, but can be a health and environmental hazard due to their general toxic nature. For example, pesticides can leach through the soil into underlying aquifers, affecting groundwater quality. The possibility of this happening, and the time required for it to happen, depend on many factors including the properties of the pesticide, the properties of the soil, site conditions including climate, depth to groundwater, land use, etc, and management practices.

147. Different pesticides have different degradation rates (ie. chemical breakdown). Obviously, the longer the time before the chemical compound is broken down, the longer it is available to act against the target weed or insect pest. On the other hand, the longer the life of the chemical compound, the higher the possibility for it to infiltrate into aquifers. Fortunately, modern pesticides are generally designed so that they have a high rate of degradation so they do not last for long periods in the receiving environment.

148. Pesticides degrade mainly through three major processes: (1) exposure to sunlight (photolysis); (2) reaction with water (hydrolysis); and (3) oxidation and other reactions mediated by microorganisms in the soil. These processes become less effective with depth because as sunlight diminishes, hydrolysis rates slow down, the soil micro-organism population drops and oxygen becomes less abundant. Hence, when pesticides do get into groundwater, cleanup of the contamination usually is impossible. Pesticide contamination in groundwater can last many years and spread over a large area before dilution and chemical decay eventually reduce the pesticide concentrations to acceptable levels.

149. Because of the rural nature of the Region, there is a potential risk of groundwater contamination by pesticides. As a precaution, Horizons regularly participates in the national pesticides in groundwater surveys. This programme is an initiative of the Institute of Environmental Science and Research Limited (ESR)[26], in which surveys have been carried out at four-yearly intervals since 1990.

150. No pesticides in groundwater in the Region were found in the fourth and third surveys, which took place in 2002 and 1998-1999, respectively (Close and Flintoft, 2004; Close and Rosen, 2001). In the 1998-1999 survey, only two samples from the Region were investigated and in the 2002 survey, samples from 40 wells (Figure 19) were investigated. Sampled wells provide a reasonably good spatial coverage and, therefore,

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[26] http://www.esr.cri.nz

could be considered to be representative of conditions in the Region. In that survey, however, Horizons used a different laboratory from the one used by other participating councils. As a result, regional samples were analysed at higher detection limit than those from other regions (Close and Flintoft, 2004).

151. In the latest national pesticide survey (2006), Horizons included the same wells that were studied in the fourth survey (2002) to allow for comparability of results. In this survey, Horizons sent the samples to the same laboratory (AsureQuality Ltd, Lower Hutt) used by other regional and district councils, to provide for methodological and reporting consistency.

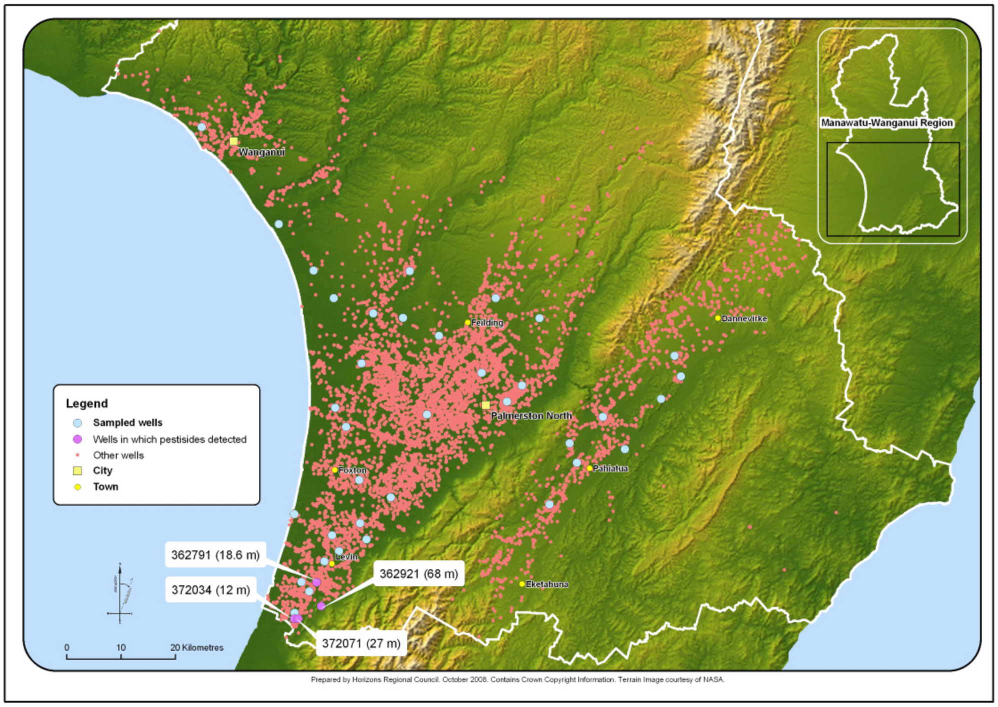

Figure 19. Location map showing wells sampled in the last two national pesticides surveys (2002 and 2006). Identification numbers and depths of wells in which pesticides were detected in the 2006 survey are indicated on the map. Information on detected pesticides is provided in Table 2 (Source: Zarour, 2008a).

Table 2. Positive pesticides detection in wells in Horizons' Region in the 2006 national survey (Source: Zarour, 2008a). For well locations see Figure 19.

WELL	PESTICIDE DETECTED	MEASURED CONCENTRATION (MG/M³)	MAV[27] (MG/M³)
362921	Terbuthylazine	0.012	40
362791	Atrazine	0.011	2
372034	Alachlor	34.000	20
	Metalaxyl	0.085	100
	Metribuzin	0.088	70
372071	Simazine	0.012	2

152. In the 2006 survey, pesticides were detected in four wells in the Region, mainly in the Horowhenua District (Table 2 and Figure 19). With the exception of alachlor[28] in Well 372034, measured concentrations of detected pesticides in these wells are well below the Maximum Allowable Values (MAV) established by the Ministry of Health (2005).

153. A repeat sample from the same well contained an alachlor concentration of 18 mg/m³, confirming the original detection of alachlor (Close *et al.*, 2007). The detected high alachlor concentration also exceeded the New South Wales' general limit of 10 mg/m³ for herbicide residues in irrigation water (ANZECC & ARMCANZ, 2000).

154. The well in which alachlor concentrations above MAV were detected is old and no lithological log is available for it. Nonetheless, examination of QMAP[29] Wellington Sheet (Begg and Johnston, 2000) suggests that the well is screened in Last Interglacial deposits, ie. in the low permeability Otaki sand formation. Hence, low dilution may contribute to the repeated detection of the herbicide. Inadequate dilution in this geological material is also believed to contribute to the observed elevated levels of nitrate in the Horowhenua District (see section on nitrate, starting with Paragraph 108, p 36).

155. According to Close *et al.* (2007), concentrations for the majority of the detected pesticides on the national scale were less than 1% of the MAV. This also applies to Horizons' Region (Table 2). These results indicate that there should be no significant

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[27] MAV: maximum allowable value as established by the Ministry of Health (2005)

[28] A chloroacetanilide herbicide, marketed under the trade name Lasso, used mainly to control weeds in corn fields. Exposure to alachlor for relatively short periods of time at concentrations above MAV can cause slight skin and eye irritation. Lifetime exposure to alachlor at concentrations above MAV can cause damage to liver, kidney, and spleen, lining of nose and eyelids, and cancer.

[29] GNS's ***Q****uarter million* ***Map*** Project. The QMAP programme is intended to improve knowledge of the geology of New Zealand by mapping and exploring relationships between rock types and their geological origins. Additional information on this project is available from GNS's website (http://www.gns.cri.nz).

health risk from drinking from the wells sampled in the survey, except perhaps for Well 372034. In my opinion, this also indicates that pesticides in groundwater are not a problem in the Region. I believe that there should be no specific policies to protect groundwater in the Region from pesticides and that relevant best practices have been and continue to be adequate to protect the environment from pesticides.

156. Horizons is planning to resample Well 372034 and other neighbouring wells in August 2009 for low level pesticides, which include alachlor. An agreement has recently been signed with AsureQuality Ltd for this purpose. ERS has expressed readiness to help Horizons with interpretation of the results.

157. Horizons intends to participate in the next national survey of pesticides in groundwater, which is planned for next year.

Key messages – Pesticides in groundwater

i. Pesticides can be a health and environmental hazard due to their general toxic nature.
ii. Because of the rural nature of the Region, groundwater contamination by pesticides is a potential risk.
iii. Management practices and the properties of the used pesticides and the application site determine the possibility for groundwater contamination by pesticides.
iv. Cleanup of groundwater pesticides contamination usually is impossible and a long time may be needed for remedy.
v. Horizons regularly participates in the national pesticides in groundwater surveys.
vi. Pesticides in groundwater are not considered a problem in the Region.
vii. Relevant best practices have been and continue to be adequate to protect the environment from pesticides.
viii. Continuing monitoring pesticides in groundwater through participating in the national surveys every four years is important to safeguard the Region's groundwater resource.

Potentially important, non-monitored parameters (eg. silica and arsenic)

158. Some parameters are not regularly monitored as part of the regional groundwater State of the Environment (SoE) monitoring programme. This has been noted by Daughney *et al.* (2009). In my opinion, future monitoring must not overlook important parameters such

as silica (SiO_2), arsenic (As) and other biological, inorganic and organic parameters as may be necessary.

159. Universally, silica (SiO_2) is a major constituent of most groundwaters because it is a main constituent in rocks. It is a neutral (ie. uncharged compound), so it does not affect the ionic balance error (Paragraph 64) or Electrical Conductivity (EC), but must be counted as part of the Total Dissolved Solids (TDS) (Paragraph 72) and in hydrogeochemical interpretation. Hence, it would be useful to incorporate SiO_2 in Horizons' routine SoE groundwater monitoring.

160. Daughney *et al*. (2009) note that arsenic is a naturally occurring substance that can accumulate in groundwater under reduced (ie. oxygen-poor) conditions to concentration levels that pose a threat to human health. I believe that elevated arsenic is a real possibility in Quaternary aquifers such as those in the Region. Daughney *et al*. (2009) recommend that arsenic concentrations be measured in oxygen-poor groundwaters on quarterly basis for one year, in order to determine whether or not a health risk exists. If this one-year regional survey reveals that arsenic in groundwater might pose a threat to human health, then continued monitoring would be prudent and resource management options will need to be investigated. This matter will be considered in the review of the regional SoE groundwater monitoring programme that is planned following the One Plan Water Chapter hearings (also see Paragraph 186, p 81).

Key messages – Other non-monitored parameters

i. There is a need to include silica in Horizons' SoE groundwater quality monitoring programme.

ii. The geological nature of the Region's aquifers and the prevalent anoxic (ie. oxygen-poor) hydrogeochemical conditions necessitate monitoring of arsenic to investigate this potential problem, which may require further monitoring and intervention.

iii. Inclusion of other biological, inorganic and organic parameters in the SoE groundwater quality monitoring programme may be necessary and will be decided upon in the monitoring programme review which is planned following the One Plan Water Chapter hearings.

Seawater intrusion hazard

Definition and concepts

161. Seawater intrusion can be perceived as a water quality problem. However, it usually results from over-exploitation of the subsurface water resource in coastal areas, ie. it is a water quantity problem with water quality implications (Zarour, 2008a).

162. Under natural conditions, the higher density of saline seawater makes it tend to sink beneath fresh groundwater and, hence, a fresh groundwater-saline seawater interface develops with a steep inland slope (Figure 1).

163. In reality, the fresh–saline seawater interface is not a sharp boundary as depicted in Figure 1 but rather takes the shape of a transition zone due to diffusion, mixing and other physical and chemical processes. Hence, Figure 20 is a more realistic schematic representation of the fresh groundwater-saline seawater interface in coastal settings. It illustrates typical supratidal, intratidal and submarine groundwater discharge zones. The extent of each zone depends very much on local geological conditions and tidal amplitude. Generally speaking, the zone of submarine groundwater discharge does not normally extend more than a few hundred metres from the low tide line.

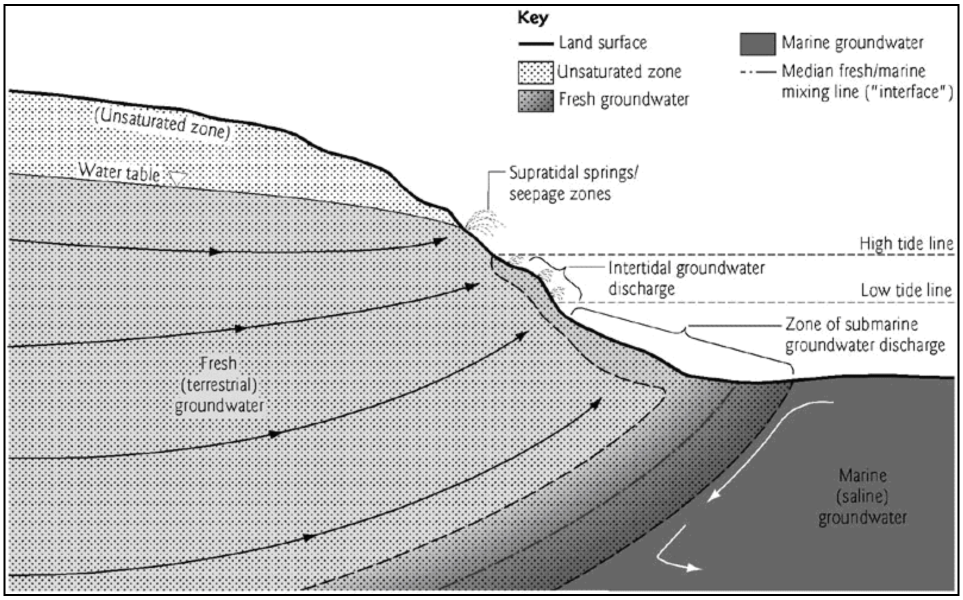

Figure 20. Schematic cross-section through a coastal groundwater discharge area (Source: Younger, 2007)[30].

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[30] This is an introduction level text book.

164. Over-exploitation of the groundwater resource can result in lowering the groundwater level at the coast; that in turn will result in upward and inland advancement of the seawater-fresh groundwater interface into the formerly freshwater aquifer. This process is known as "seawater intrusion" Figure 21b). Under such circumstances, fresh groundwater will mix with saline seawater in the aquifer until eventually the proportion of saline water entering wells may be sufficiently high that the wells, and perhaps even entire sections of the aquifer, become unusable for water supply purposes. Only 10% sea water will typically make groundwater in a well unusable for most common purposes due to elevated sodium (Na), chloride (Cl), and sulphate (SO_4) concentrations.

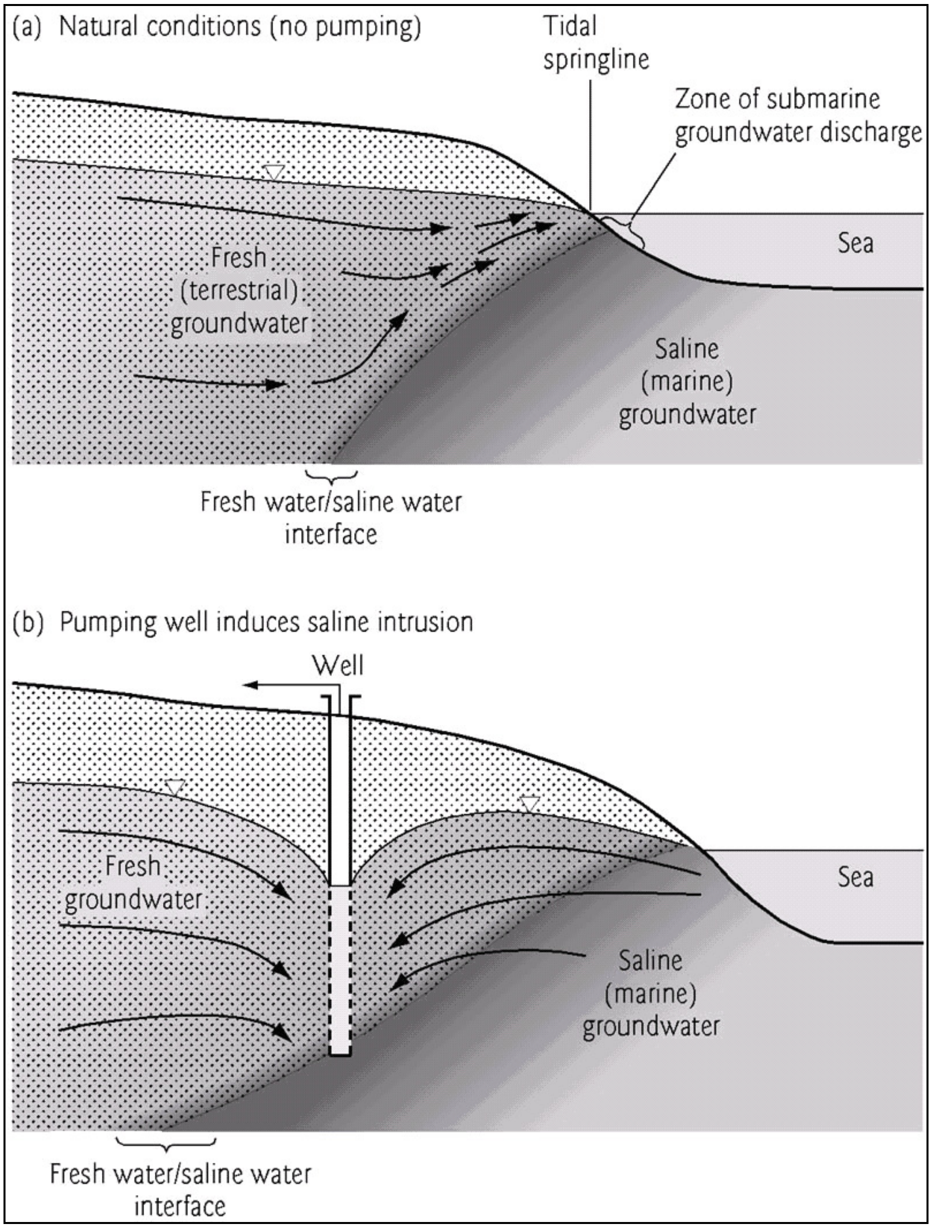

Figure 21. The seawater invasion process (Source: Younger, 2007).

165. Zarour (2008a) discusses the hazard of seawater intrusion in the Region and concisely presents related concepts (eg. Sections 3.3.7, p 42; 7.5.3, p 123; and A-10, p165). The regional situation in relation to seawater invasion risk is also discussed in Daughney *et al*. (2009) and in the evidence to this hearing by Mr Callander. In addition, seawater invasion risk in the Region was studied by Gyopari (2005)[31] and Craig (2008)[32]. The studies by Daughney *et al*. (2009) and Gyopari (2005) were commissioned by Horizons, which also provided financial and technical support to the thesis by Craig (2008).

166. All the above mentioned research agrees that there is no evidence of seawater intrusion into coastal aquifers in the Region.

167. Recent research commissioned and supported by Horizons, and the establishment of a special monitoring network to protect against seawater invasion risk as described in the section starting with Paragraph 170 (p 69), demonstrate Horizons' awareness of this potential hazard and commitment to proactively protect the Region's groundwater resource from it. In most places around the world, resource management authorities intervene only in the wake of actual intrusion of seawater into coastal aquifer, when the problem in many situations has become irreparable.

Risk areas in the Region

168. Most large sources of fresh groundwater throughout the world are in close proximity to the sea. New Zealand and Horizons Region are no exception. Encroachment of seawater in coastal areas is a potential risk associated with the development of coastal groundwater resources.

169. Seawater intrusion is a potential risk only in coastal areas where the groundwater resource is, or could become, extensively developed. Hence, it is not considered a risk in the eastern coastal areas of the Region, where the resource is only lightly developed due to unfavourable hydrogeological conditions. The eastern coastal area has few wells and no consented groundwater abstractions (Figure 22). In contrast, the groundwater system in the western coastal areas of the Region has good potential and, therefore, is fairly well developed and is expected to be further developed in the future. There are a large number of wells in this part of the Region (Figure 23) and there are also a considerable number of large consented abstractions (Figure 24). The demand on the

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[31] Report available from Horizons.

[32] Thesis available online from Victoria University Library's website (http://researcharchive.vuw.ac.nz/bitstream/handle/10063/569/thesis.pdf?sequence=1)

groundwater resource in the western coastal area is increasing (Zarour, 2008a; Chapter 6) and, hence, seawater intrusion is identified as a risk there.

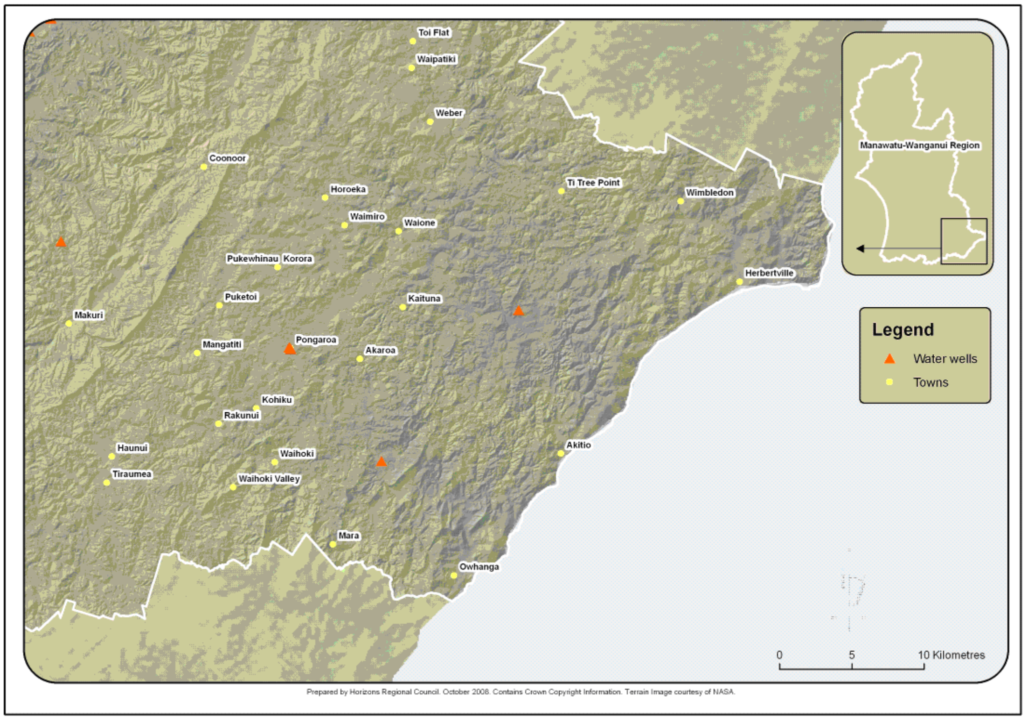

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Figure 22. Map of the eastern coast of the Region showing very few wells (red triangles) and no consented groundwater abstractions. The regional boundary is demarcated by the white line (Source: Zarour, 2008a).

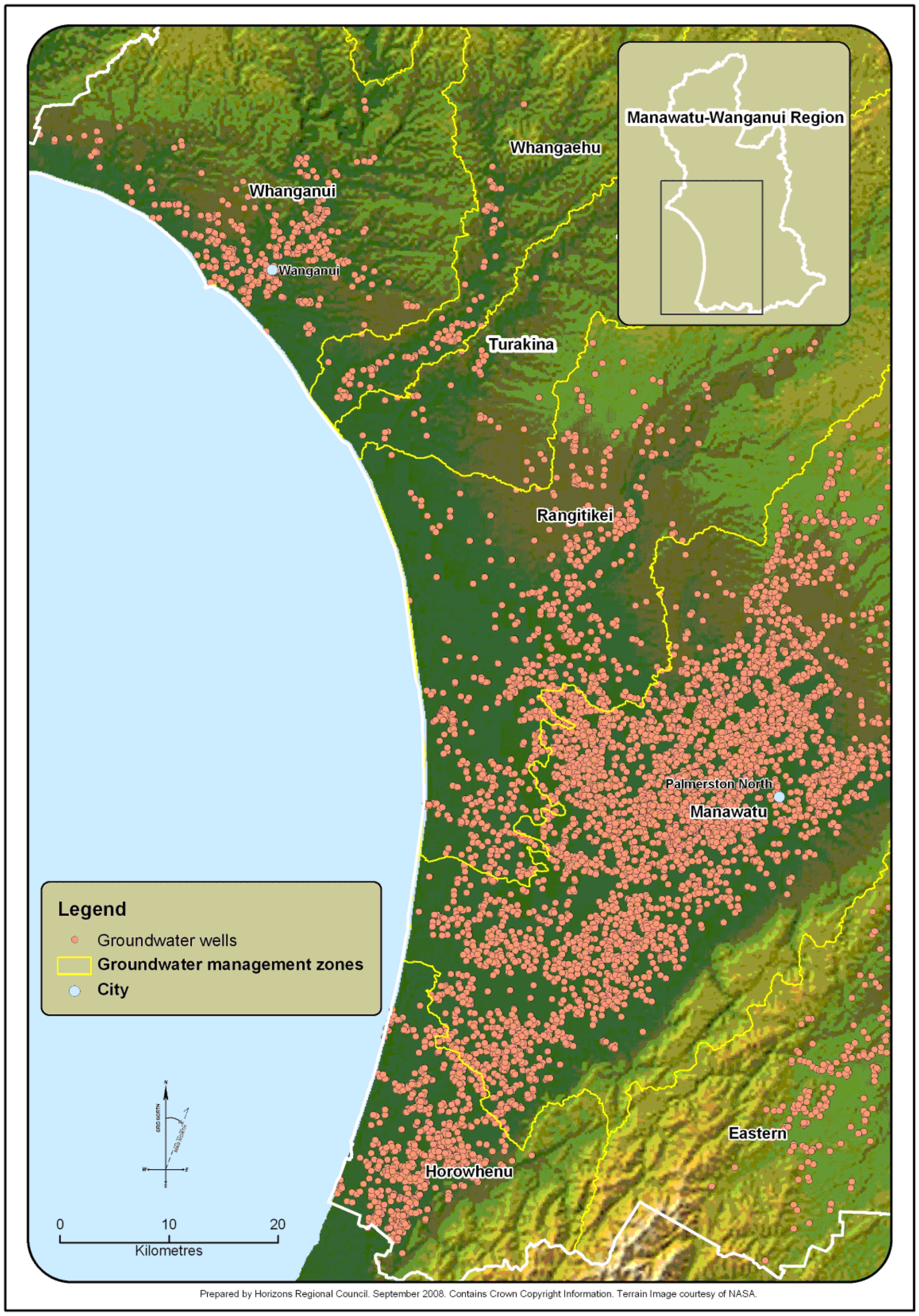

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Figure 23. Groundwater wells (pink dots) in the western part of Horizons' Region. The regional boundary is demarcated by the white line. Groundwater Management Zones are indicated on the map (Source: Zarour, 2008a).

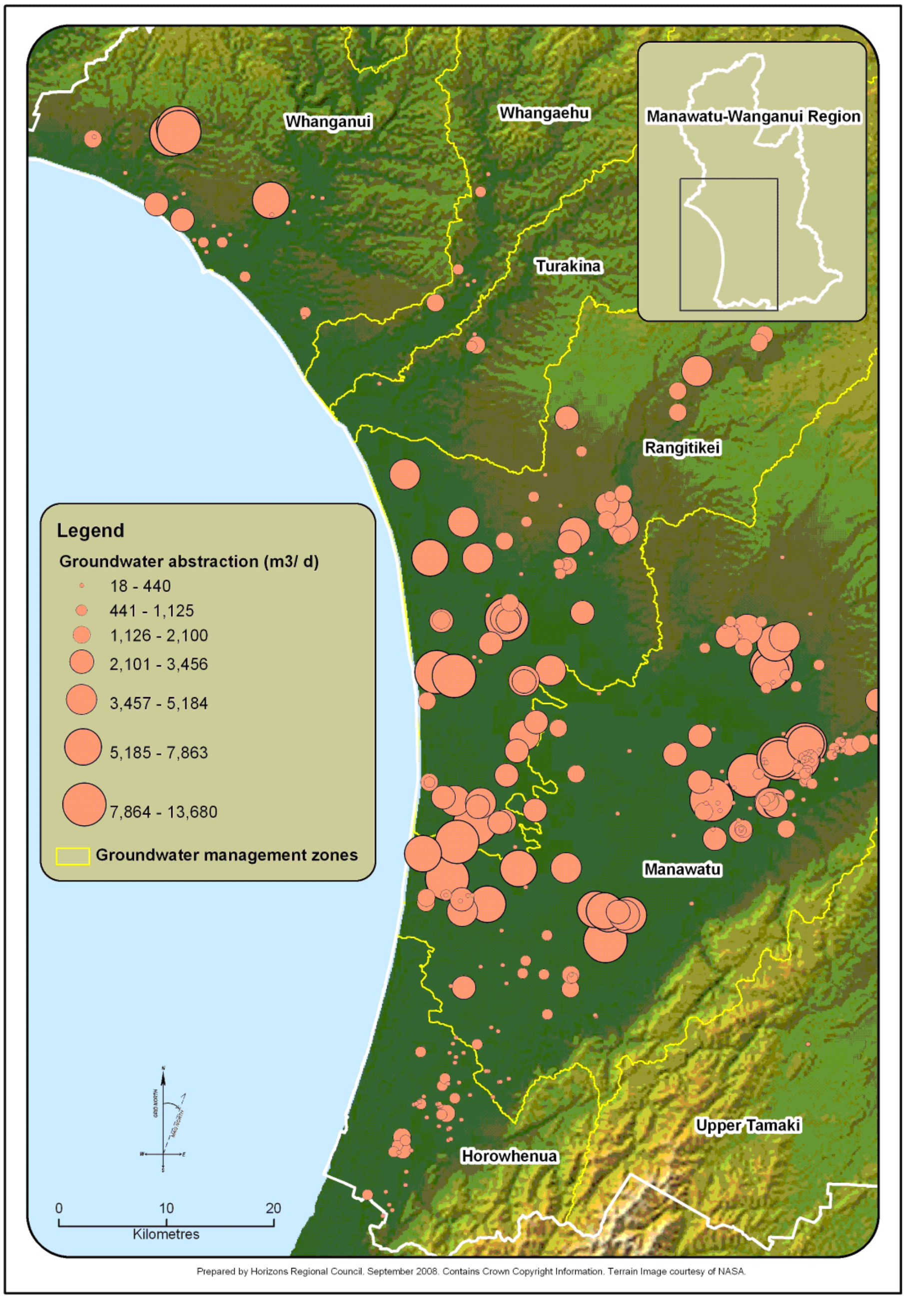

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Figure 24. Groundwater abstraction consents in the western part of Horizons' Region. The size of the pink circle is proportional to the consented maximum daily abstraction. The regional boundary is demarcated by the yellow line. Groundwater Management Zones are indicated on the map (Source: Zarour, 2008a).

Resource management interventions

170. Seawater intrusion, invasion or encroachment into fresh groundwater aquifers is not a natural phenomenon. It is a special case of groundwater contamination that results inadvertently from human activities. Prudent management and careful monitoring of the resource are the only practical means for safeguarding against seawater intrusion.

171. In 2006 Horizons established an automated monitoring network to provide advanced warning against seawater intrusion risk in the coastal area on the Tasman Sea, which is the part of the Region that has been identified as a high-risk area. This network is intended to provide a regional-scale point of reference dataset for managing the groundwater resource and abstractions in the western coastal area of the Region. Horizons' seawater invasion monitoring network consists of six operational wells in which Electrical Conductivity (EC) and groundwater level measurements are taken automatically every 15 minutes and transmitted to Horizons via telemetry (for well locations, see Figure 3). The network design is based on the recommendations by Gyopari (2005) (Figure 25). Here, I would like to emphasise that none of these six wells in this network is purpose-built for monitoring, ie. they are regular pumping wells. The seawater invasion monitoring network has been deliberately designed to use operational pumped wells, to make sure water in the monitored wells is flushed regularly. Because groundwater moves slowly (Zarour, 2008a; p 102), monitoring unpumped wells may mean monitoring stagnant water, which is not representative of the aquifer conditions.

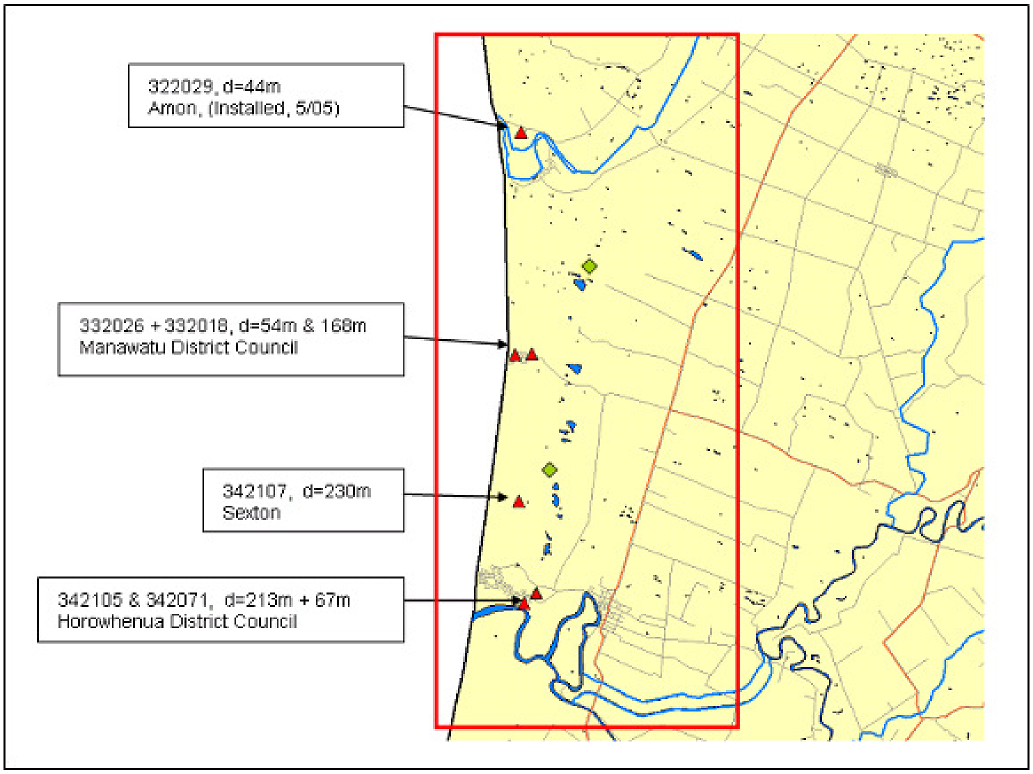

Figure 25. Initial design of Horizons' seawater intrusion monitoring network (Adopted from Gyopari, 2005). Well ID number, depth (d) and name of owner are noted for the wells incorporated in the monitoring network. Manawatu District Council's 54 m deep Well 332026 was not found and, hence, was substituted for by another Manawatu District Council's (ID: 332003, depth 62 m) (Source: Zarour, 2008a).

172. In addition to monitoring, Horizons has embarked on using consent conditions to actively manage the risk of seawater intrusion in the western coastal area of the Region by including conditions to monitor groundwater levels and quality in groundwater abstraction permits (consents) in this area. Conditions on such permits may also include a requirement to reduce or stop pumping if seawater intrusion is detected. In this context, the Proposed One Plan provides that groundwater abstraction resource consent applicants within 5 km from the coastline (Figure 26) are generally required to include an assessment of seawater intrusion hazard as an integral part of the required assessment of environmental effects (AEE). This is less than the 10 km coastal sector suggested by Gyopari (2005), which I believe to be excessive. Attention is drawn here to the fact that drawdown effects resulting from pumping are only circular in shape when pumping none-flowing aquifers (Figure 27, upper left diagram). In reality, they are elliptically shaped (Figure 27, right diagram) due to existing gradients (Figure 27, lower left

diagram). The situation is also schematically represented in 3-D in Figure 28. Accordingly, it is expected that drawdown effects resulting from pumping in coastal aquifers would extend inland more than they would extend seawards. Wells farther inland than 5 km will not potentially enhance the risk of seawater invasion.

173. In his evidence to the Hearings, Mr Callander will discuss appropriate policies and rules to manage groundwater abstraction in the Region, including aspects specific to coastal settings.

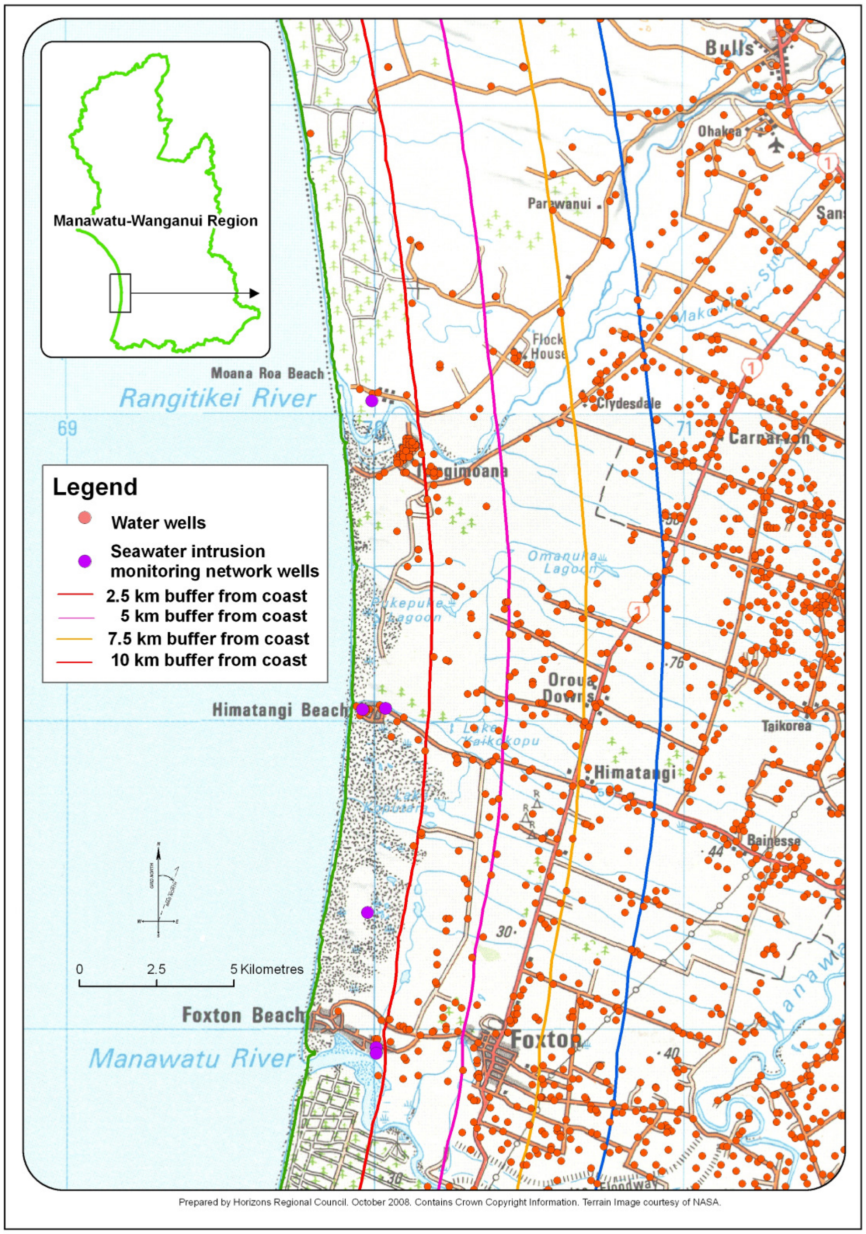

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Figure 26. Location map showing the coastal area on the Tasman Sea between the mouths of the Rangitikei River to the north and the Manawatu River to the south, which is considered at high risk of seawater invasion. Water wells are indicated as orange points and seawater intrusion monitoring wells are marked as violet dots. Limits for buffer zones of various widths (2.5 km, 5 km, 7.5 km, and 10 km) are drawn to help with the map scale. The Proposed One Plan requires undertaking seawater invasion risk assessment for all proposed groundwater takes within 5 km from the shoreline (ie. the zone between the coastline and the violet line) (Source: Zarour, 2008a).

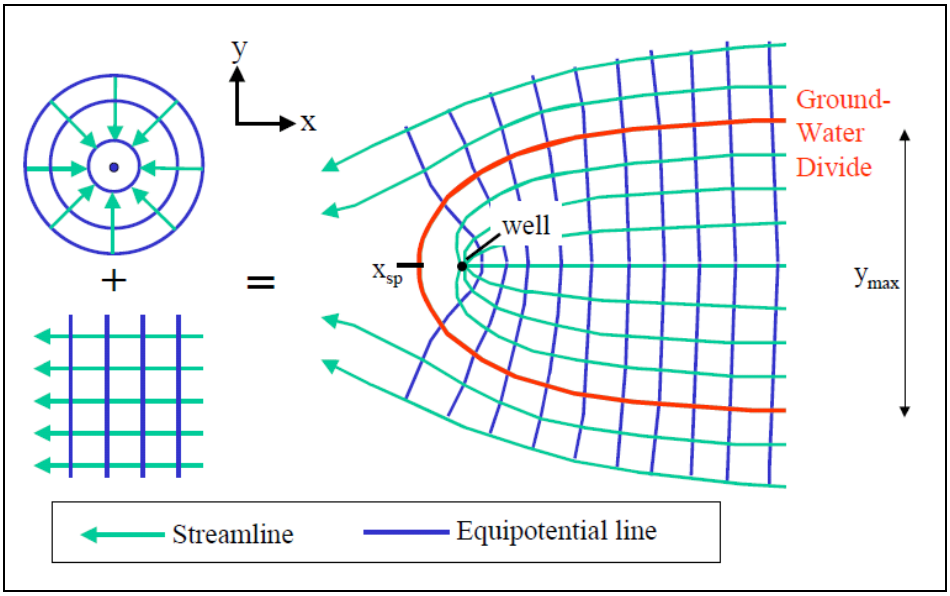

Figure 27. Plan view of dimensional superposition of uniform (lower left) and radial flow (upper left) indicating larger drawdown effect upstream of the abstracting well (Source: Ahern, 2005).

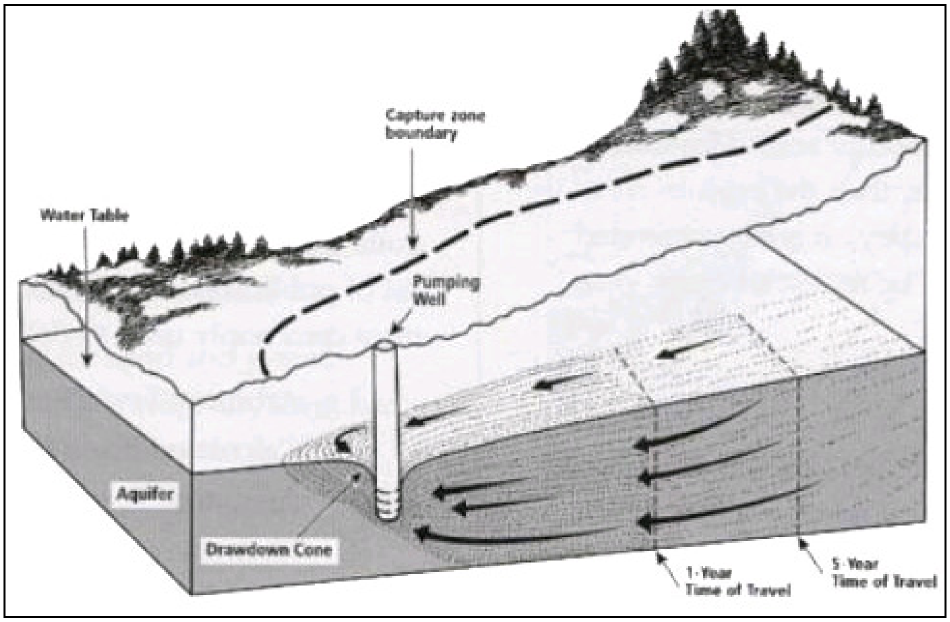

Figure 28: Three dimensional (3-D) representation of natural groundwater flow intercepted by pumping (Source: Website of the Canadian Ground Water Association; CGWA [33]).

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[33] http://www.cgwa.org

Monitoring results and status assessment

174. There is no evidence of mixing between fresh groundwater and seawater anywhere in the Region, ie. no indication of inland seawater invasion into coastal aquifers (Section 3.3.7.3 p 44 in Zarour, 2008; pp 115-6 in Craig, 2008; Section 6.5 p 71 in Daughney *et al*., 2009). Zarour (2008a) note that groundwater mixed with seawater due to seawater invasion would have a distinct “signature” on trilinear plots conventionally used to interpret groundwater quality data such as the Piper and Durov diagrams. For example, such water will plot on the lower right corner box in the Durov diagram (Figure 29). The fact that no groundwater samples in the Region plot in that area of the Durov diagram indicates that none of the plotted samples are mixed with saline water as a result of seawater intrusion.

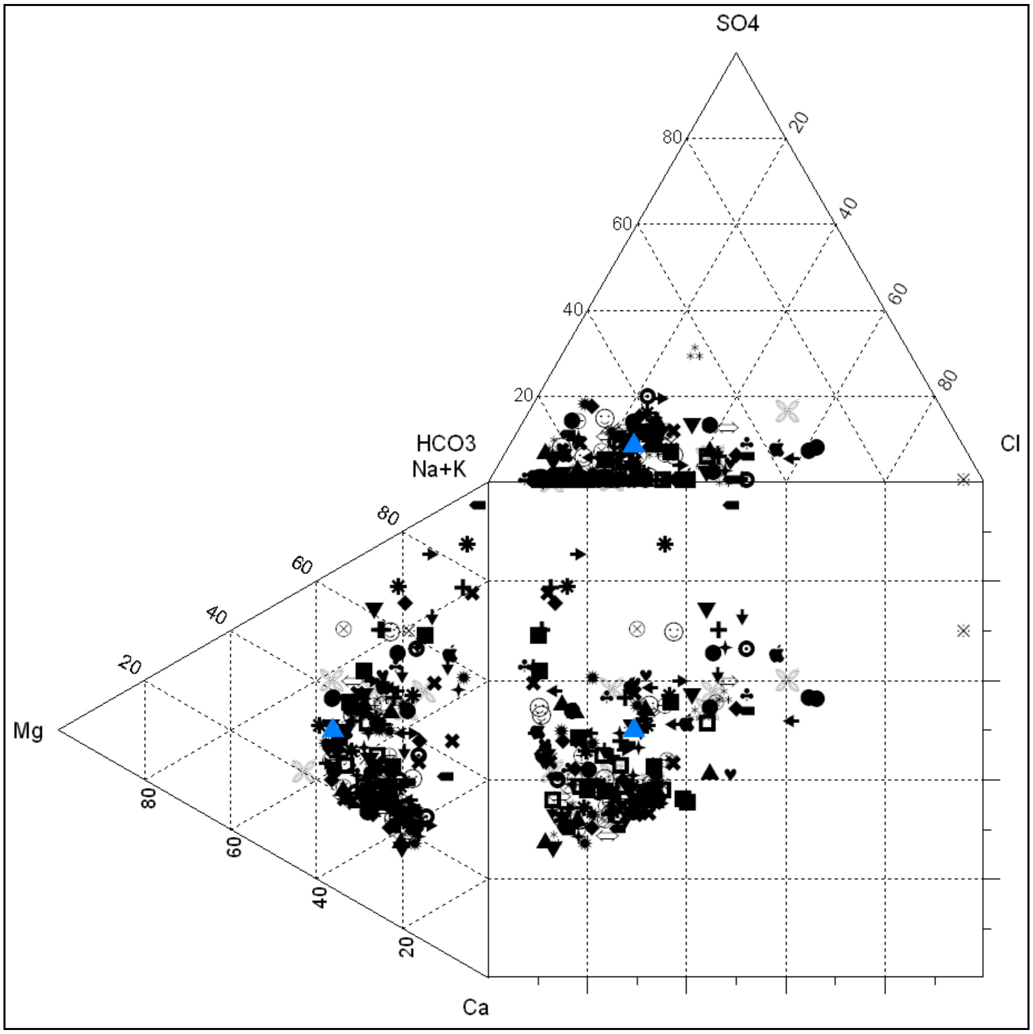

Figure 29. Durov diagram for groundwater samples collected from around the Region in 1989 (Source: Zarour, 2008a).

175. Data from the seawater invasion monitoring network supports this opinion. For instance, Electrical Conductivity (EC), an indicator of salinity as discussed in the section starting with Paragraph 71 (p 23), has been noticed to be proportional to the water level in the monitored wells in the Region, ie. when groundwater level drops due to pumping, water salinity in the monitored pumped well drops too (eg. Well 342107; Figure 30). Electrical Conductivity and groundwater level data started to show positive correlation in Well 342107 from October 2006, when the equipment had been satisfactorily calibrated. This positive correlation is continuing. However, longer records are needed to establish the real relationship between pumping, groundwater level and salinity (Zarour, 2008b).

176. Positive correlation between groundwater level and Electrical Conductivity (EC) in the monitored coastal wells was not expected by earlier investigators (eg. Gyopari, 2005). Before monitoring began, they expected that EC would increase with the lowering of groundwater level due to pumping, or at least it would stay unchanged. Now, it appears that pumping is inducing recharge from inland rather from the coastal downstream area. Water from this source is supposed to have lower salinity than the water around Well 342107. This interpretation is compatible with the conceptualisation by Russell (1989), who described the Manawatu plains as a major discharge zone. The interpretation is also consistent with the general conceptualisation shown in Figure 27 (p 73) and Figure 28 (p 73) to represent superpositioning of pumping effects on a naturally flowing system, where the well is expected to intercept more water from the upstream area than water withdrawn from the downstream area.

177. Even though available groundwater quality data are comforting, the Region's groundwater resource, especially in the coastal area, needs to be developed prudently to ensure its long-term sustainability (Zarour, 2008a; Zarour, 2008b).

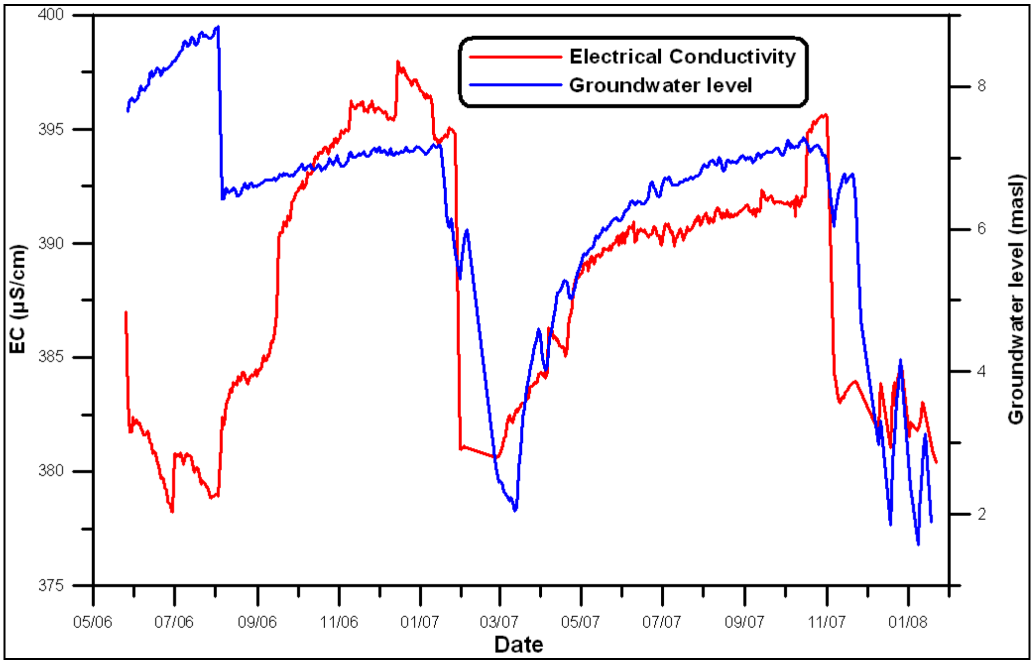

Figure 30. Groundwater level and Electrical Conductivity plots for data from Well 342107: an example of information provided by the regional seawater intrusion monitoring network (Source: Zarour, 2008a).

Key messages – Seawater invasion risk

i. Generally, seawater invasion into aquifers is a perceived risk in all coastal areas.

ii. In most places around the world, authorities intervene only in the wake of actual intrusion of seawater into coastal aquifer, when the problem in many situations has become irreparable.

iii. Seawater invasion is considered a potential risk only in the Region's western coastal area on the Tasman Sea, but not in the eastern coastal area on the Pacific Ocean.

iv. The highest risk area on the western coast is confined to the coastal strip that extends between the Rangitikei River in the north and the Manawatu River in the south along the Tasman Sea with an assumed width of 5 km.

v. There is no indication of seawater invasion into groundwater aquifers anywhere in the Region.

vi. Environmental authorities need to manage the coastal groundwater resource prudently and proactively to ensure its long-term sustainability.

vii. Proactive management of abstractions, land use and careful monitoring are the most feasible safeguards against seawater intrusion. Precautionary consent conditions are effective in this process.

Suitability of regional groundwater for various uses

178. Groundwater in the Region is an important resource and is used for life maintenance and productive purposes. Hence, it is important to assess the suitability of groundwater quality for various uses. Assessment of the suitability of the water quality for different uses is one of the principle objectives of groundwater quality monitoring and studies (Paragraph 57).

179. Suitability of groundwater quality for various uses is judged by comparison of its composition against appropriate standards, such as the drinking water standards set by the Ministry of Health in 2005 and revised in 2008 (DWSNZ 2005)[34], and the guidelines for irrigation and livestock drinking water in the Australian and New Zealand guidelines for fresh and marine water quality document (ANZECC & ARMCANZ, 2000). Daughney *et al*. (2009) summarise applicable water quality guidelines for parameters commonly monitored in Horizons' Region (Table 3).

180. Daughney *et al*. (2009) undertook comprehensive statistical assessment of groundwater quality data available for the Region, which included assessment of the fitness of the groundwater for various uses (Section 6.1, p 69). Zarour (2008a) also commented on this matter (Section 3.3.8, p 49). Both studies conclude that groundwater quality in the Region is suitable for livestock consumption and is also generally suitable for irrigation.

181. Nonetheless, the latest study (Daughney *et al*., 2009; Section 6.1, p 69) reaches the general conclusion that "*poor groundwater quality is prevalent across the Region and may act as a barrier to its use for human consumption or irrigation*". This was based on fact that 68% of the sites considered in that study have been found to have at least one parameter with a median value that exceeds the relevant threshold for drinking water specified in DWSNZ 2005.

182. Daughney *et al*. (2009) note that the parameters that are most commonly found to be in excess of the DWSNZ 2005 thresholds are iron (Fe), manganese (Mn), ammonia (NH_4), [carbonate] hardness and/or pH. It should be noted that this fundamentally is a natural phenomenon, ie. it is not a result of human intervention with the environment. Also, iron (Fe), ammonia (NH_4) and hardness do not represent human health risks. It is also noted here that groundwater in many wells in the Region exceed the health related Maximum Allowable Value (MAV) for manganese (Mn) (Figure 17). Again, this is a natural occurrence, not all of these wells are used for potable supplies, and treatment of water

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[34] Document is available on line from the Ministry of Health website (http://www.moh.govt.nz).

to reduce manganese is possible. On the other hand, elevated nitrate (NO_3^-) levels are not natural and, most probably, result from human activities (see section in this evidence on nitrogen, starting with Paragraph 103 on p 34). As mentioned earlier in this evidence (Paragraph 116, p 40), this problem is specific to wells in the Horowhenua District that tap low permeability Last Interglacial deposits (Q5b unit in GNS's QMAP sheets). The situation is not worsening or improving (Paragraph 116, p 40) and the reasons are not well understood (Paragraph 117, p 40). Further studies are needed to understand the situation and explore practical management options. The two projects that Horizons has recently commissioned to GNS (Zarour, 2008a; Sections 8.5 and 8.6, pp 133-4) will lay a solid foundation for the required additional research to properly address the nitrate problem in the Horowhenua District.

183. Daughney *et al*. (2009) also note that 37% of the wells considered in their study have at least one parameter that exceeds the recommended guidelines for irrigation water as specified in ANZECC & ARMCANZ (2000). According to them, nitrate (NO_3), phosphate-phosphorus (PO_4-P) and hardness exceed the irrigation guideline values at the greatest proportion of sites. However, I have previously assessed that the Region's groundwater is generally suitable for irrigation according to the US Department of Agriculture method (the Wilcox diagram), with low sodium hazard and mainly low to medium salinity hazard (Zarour, 2008a; Section 3.3.8, p 49). Here, I would like to emphasise that I believe that the occurrence of phosphate (PO_4) and hardness in groundwater that may be used for irrigation in the Region is natural and, hence, is unavoidable. As for nitrate (NO_3), I reiterate that this problem is specific to wells that tap low permeability Last Glaciation sand deposits in the Horowhenua area. The low permeability of these geological deposits means that wells in them cannot yield enough water to allow for irrigation. Hence, I do not consider nitrate (NO_3) in groundwater to be a problem for the irrigation sector.

184. The suitability of water for different industrial uses is determined by the specific requirements for those types of activities. Hence, assessment of the suitability of groundwater for various industrial uses has not been attempted in Zarour (2008a) or Daughney *et al*. (2009) and is left to be undertaken on case-by-case basis as and when needed.

185. From the above discussion of specific groundwater quality issues (Paragraphs 66-177), it appears to me that the potential for groundwater quality to affect the quality of linked dependent surface water bodies is limited. Nonetheless, I remind the Panel that this matter is outside my area of expertise.

Table 3. Summary of water quality guideline values relevant to monitored parameters in Horizons' Region (Source: Daughney *et al.*, 2009).

		DWSNZ 2005		ANZECC 2000	
Parameter	**Units**	**MAV [1]**	**GV [2]**	**Irrigation TV [3]**	**Irrigation TV [3]**
EC	mS/m	-	-	60-1,280 [4]	-
TDS	mg/L	-	1,000	-	2,000-5,000
pH	pH units	-	7.0-8.5	6-8.5	-
Turbidity	NTU	-	2.5	-	-
Ca	mg/L	-	See Hardness	-	1,000
Mg	mg/L	-	See Hardness	-	-
Hardness	mg/L $CaCO_3$	-	200	>60 and <350 [5]	-
Na	mg/L	-	200	<115 to <460 [6]	-
Cl	mg/L	-	250	<175 to <700 [6]	-
Fe	mg/L	-	0.2	10	Not sufficiently toxic
Mn	mg/L	0.4	0.04	10	Not sufficiently toxic
B	mg/L	1.4	-	<0.5-15	5
SO_4	mg/L	-	250	-	1,000
F	mg/L	1.5 [7]	-	2	2
NH_4	mg/L	-	1.5 [8]	-	-
NO_2	mg/L	3 [8]	-	22 or 110-550 [10]	30
NO_3	mg/L	50 [9]	-		400
PO_4-P	mg/L	-	-	0.5 or 0.8-12 [11]	-
SAR					
extremely sensitive	-	-	-	<2-8	-
sensitive	-	-	-	<8-18	-
medium	-	-	-	<18-46	-
high	-	-	-	<46-102	-

Notes:

i. Maximum Allowable Value (MAV) for parameters of significance to human health.

ii. Guideline Value (GV) for parameters of aesthetic significance.

iii. Trigger Value (TV) for short-term exposure and/or long-term range of higher values that may be tolerated, depending on the type of crops or livestock.

iv. General guide for Electrical Conductivity (EC) of irrigation water at the threshold level for a range of plants and soil types: for sensitive crops in poorly draining soil, EC should be less than 60 mS/m (milliSemins per metre), whereas more tolerant crop types in well drained soil may withstand EC above 1,200 mS/m.

v. Hardness < 60 mg/l $CaCO_3$ has an increased corrosion potential, > 350 mg/l CaCO3 has an increased fouling potential. DWSNZ 2005 does not specify a health-related MAV for hardness.

vi. Concentration causing foliar injury depends on crop sensitivity: < 115 mg/l Na and < 175 mg/l Cl for sensitive crops, up to > 460 mg/l Na and > 700 mg/l Cl for tolerant crops. High levels of chloride in irrigation water trigger the risk of increasing cadmium concentrations in crops: < 350 mg/l risk is low.

vii. For oral health reasons, the Ministry of Health recommends that the fluoride content for drinking water in New Zealand be in the range of 0.7-1.0 mg/l; this is not a MAV.

viii. A GV of 1.5 mg/l is specified as an odour threshold, and in addition, NH_4 concentration should be less than 0.3 mg/l in cases where treatment for use as drinking water requires addition of chlorine.

ix. Short-term only. The short-term exposure MAVs for nitrate and nitrite have been established to protect against methaemoglobinaemia in infants.

x. TVs are set for minimisation of nitrogen leaching into aquifers and surface water bodies: long-term TV (maximum recommended average over periods of up to 100 years) is 22 mg/l for NO_3 as a generic guide, whereas short-term TV (maximum recommended average over periods of up to 20 years) is 110-550 mg/l, is site-specific, and considers the crop being grown.

xi. The long-term TV (maximum recommended average over periods of up to 100 years) is 0.05 mg/l for PO_4-P is set to minimise algal growth in irrigation water. The short-term TV (maximum recommended average over periods of up to 20 years) is 0.8-12 mg/l PO_4-P to minimise phosphorus leaching to aquifers and surface waters, and is site-specific depending on fertiliser input and the fraction of phosphorus taken up by plants and soils.

Key messages – fitness of Regional groundwater for various purposes

i. Groundwater in the Region is an important resource and is used for life maintenance and productive purposes.

ii. It is important to assess the suitability of groundwater quality for various uses.

iii. Suitability of groundwater quality for various uses is assessed through comparison of its composition against appropriate standards, such as DWSNZ 2005 and ANZECC & ARMCANZ (2000).

iv. Zarour (2008a) and Daughney *et al*. (2009) considered the suitability of groundwater quality in the Region for different purposes.

v. Groundwater quality in the Region is suitable for livestock consumption and is also generally suitable for irrigation.

vi. Concentrations in excess of drinking and irrigation water standards are common in the Region for iron (Fe), manganese (Mn), ammonia (NH_4), hardness and/or pH. This is a natural phenomenon.

vii. Nitrate (NO_3) levels in excess of drinking standards are noted only in wells in the Last Interglacial sand deposits in the Horowhenua District.

viii. Elevated nitrate in some wells in the Horowhenua District may be a health hazard (ie. can cause methemoglobinemia, blue baby syndrome).

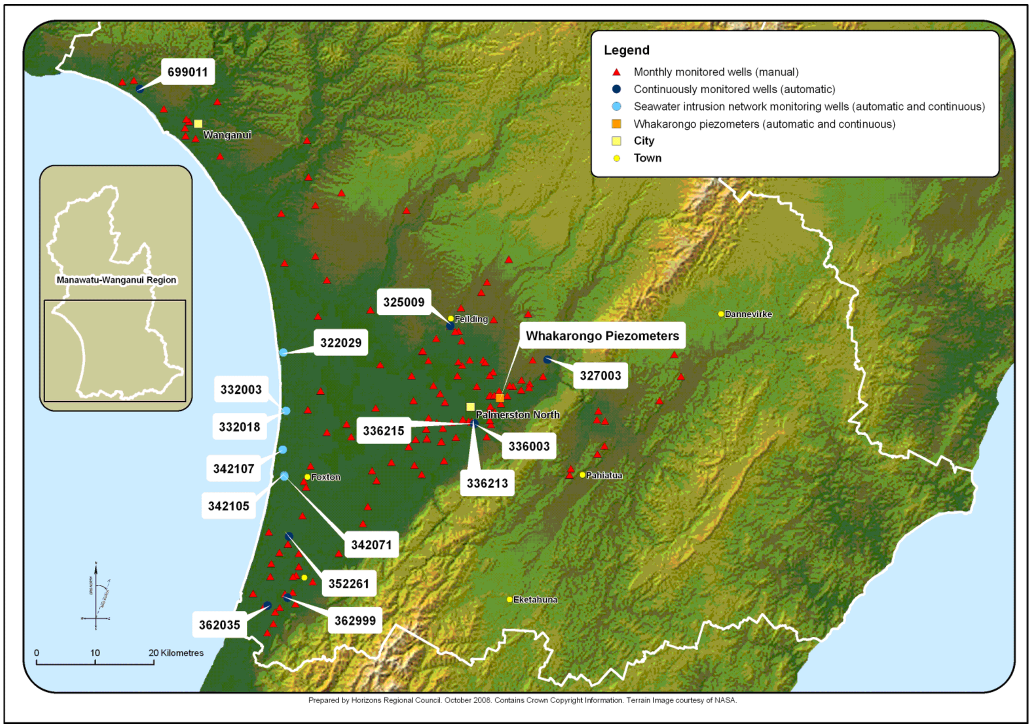
ix. I do not consider that elevated nitrate (NO_3) in some wells in the Horowhenua District is a problem for the irrigation sector.

x. The suitability of water for different industrial uses is determined by the specific requirements for those types of activities and, therefore, can only be considered on case-by-case basis.

Groundwater level monitoring and results

Regional groundwater level monitoring network

186. Groundwater level monitoring is the most practical and useful way to assess the healthiness of the resource (Paragraph 45, p 12). Horizons operates an extensive groundwater level monitoring network in the Region, which has developed over a number of years (Figure 31). In Zarour (2008a) I concisely describe the groundwater level monitoring programmes in the Region (Section 3.2.1, p 12). I also note there that a review of the programme is planned following the One Plan hearings.



Prepared by Horizons Regional Council. October 2008. Contains Crown Copyright Information. Terrain Image courtesy of NASA.

Figure 31. Groundwater level monitoring networks in Horizons' Region (Source: Zarour, 2008a).

187. As articulated in Zarour (2008a), Horizons' groundwater level monitoring network is built around monthly groundwater level measurements done manually in about 140 wells spread out across the Region (red triangles in Figure 31). None of the manually monitored wells are purpose-built and almost all of them are operational production wells. This is considered to be the most cost-efficient arrangement for regional-scale resource management purposes. However, the usefulness of intermittent groundwater

level monitoring in operational wells may be limited for some local scale and specific purpose studies.

188. Since 1986, Horizons has initiated continuous groundwater level monitoring in a number of wells across the Region (Figure 31). Groundwater levels are automatically measured in these wells and transmitted to Horizons via telemetry every 15 minutes. The purpose of this monitoring is to collect data frequently for general SoE assessment purposes and future water resource assessments, which may include modelling.

189. In 1996, Horizons enhanced the groundwater monitoring network by adding a multi-level piezometer system to monitor groundwater levels at various depths in the Whakarongo area, in the Lower Manawatu Valley about 2 km from the eastern outskirts of Palmerston North (for location, see Figure 31). In this system, groundwater levels are automatically measured and transmitted to Horizons via telemetry every 15 minutes.

190. In 2006, Horizons further enhanced the hydrogeological monitoring network by establishing automated monitoring of groundwater level and Electrical Conductivity (EC) in six coastal bores, to provide early warning in the event of commencement of seawater invasion into coastal aquifers. Figure 31 shows the locations of these wells. As explained in Paragraph 171 (p 69), none of these six wells is purpose-built for hydrogeological monitoring.

191. In addition to the above, groundwater levels are monitored for compliance purposes. This is normally the responsibility of resource consent holders and monitoring is either manual or automatic. Where monitoring is undertaken automatically, measurements are recorded at 15 minute intervals and the equipment is linked to Horizons' telemetry network. Groundwater levels are also measured by drillers in most wells upon their completion. Occasionally, special studies and surveys include collection of groundwater level data. For example, Horizons completed a well inventory in the Horowhenua area in 2008, which involved an extensive groundwater level survey. The data from that project is being incorporated in the ongoing work on the Horowhenua water resources which Horizons commissioned to GNS.

192. Groundwater level data from various sources enables Horizons to assess the status of the resource. This data is also used by Horizons and applicants in environmental effects assessments (AEEs) that are required for resource consent applications. In addition, this data is used to measure the actual effects of groundwater takes on the environment and other users, as part of compliance monitoring of groundwater permits.

Key messages – Regional groundwater level monitoring network

i. Regional groundwater level monitoring programmes are described in Zarour (2008a).
ii. Horizons operates an extensive groundwater level monitoring programme.
iii. The groundwater level monitoring programme developed over a significant period of time.
iv. Groundwater level monitoring is mainly undertaken manually on a monthly basis in operational wells where pumping effects can mask measurements.
v. Groundwater level monitoring is undertaken automatically at 15 minute intervals in some wells.
vi. Horizons has one automatic purpose-built multi-level dedicated groundwater level monitoring piezometer, located in the Whakarongo area, about 2 km to the east of Palmerston North.
vii. Additional groundwater level data is provided by drillers upon completion of new wells, consent holders as part of compliance monitoring, and from one-off studies and investigations.
viii. Horizons plans to review the groundwater monitoring network following the One Plan hearings.

Groundwater level fluctuations and trends

193. I explained in Zarour (2008a) that the groundwater level is never at rest, because it is subject to the influences of a variety of natural factors and human-induced stresses. At any point in time, a groundwater level is the cumulative result of the superposition of several different types of fluctuations. Interpreting groundwater level trends requires consideration of the time frames involved. Short-term fluctuations, seasonal trends and long-term trends are all recorded in a long-term record. Short-term (ie. diurnal time-scale or shorter) water level fluctuations are caused by Earth and ocean tides, surface loading, barometric pressure changes, evapotranspiration[35] by phreatophytes[36], earthquakes, and also by abstraction. Long-term fluctuations can result from changes in recharge as well as extensive pumping. If the intensity of abstractions in time and/or space increases, localised drawdowns can accumulate into a long-term, aquifer-scale groundwater level reduction.

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[35] The release of water vapour from the Earth's surface by evaporation and transpiration.
[36] Deep-rooted plants that obtain water from a permanent ground supply or from the water table.

194. I note in Zarour (2008a) that groundwater level data from the Whakarongo multi-level piezometer setup (Section 189) provides the best indicator to the situation of groundwater resources in the Region in general and in the Manawatu Catchment in particular. This setup is especially important because these piezometers measure heads at various depths in a single location, are not pumped, and monitoring is continuous and frequent. Long-term monitoring by the Whakarongo multi-level piezometer setup shows general stability and consistent parallel fluctuation across all monitored depths (Figure 32). It also shows direct correlation between depth and head, ie. head increases with depth. The upward vertical hydraulic gradient in the area is estimated at 1:5 Figure 33).

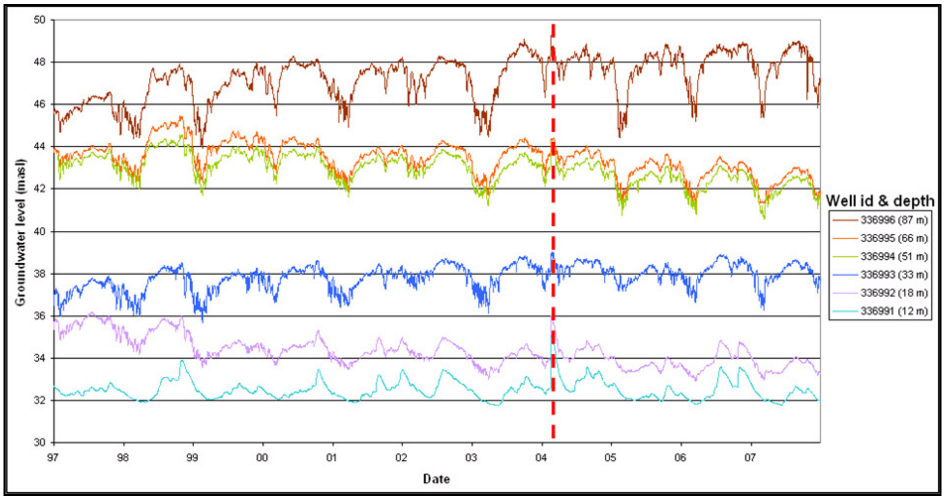

Figure 32. Daily average groundwater levels as monitored in the Whakarongo multi-level piezometer system. The dashed red line demarcates the February 2004 storm event (Source: Zarour, 2008a).

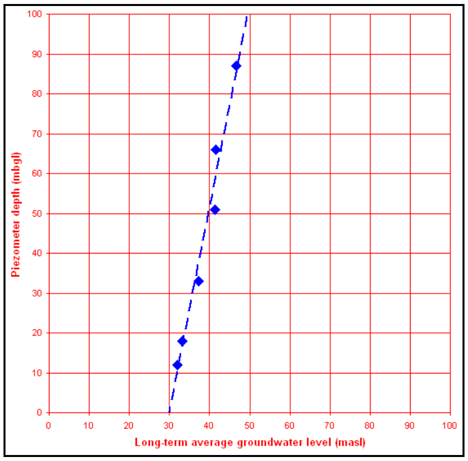

Figure 33. Relation between screen depth and head as observed in the Whakarongo multi-level piezometer setup (Source: Zarour, 2008a).

195. Quick response to recharge at all monitored depths is remarkable in the Region. This is perhaps best exemplified by the elevated measurements recorded in the Whakarongo piezometers between mid-February to mid-March 2004 in response to the February 2004 storm event (Figure 32).

196. Seasonal groundwater level fluctuations observed in the Region, eg. Figure 32, reflect changes in aquifer storage as a result of recharge and withdrawals of water from distant or nearby wells. The magnitude of seasonal groundwater level fluctuation through the Region is highly variable, ranging from a few centimetres to a few metres. In wells that are monitored manually on monthly basis, pumping effects mask natural fluctuation and it is very difficult to distinguish between the various components that combine to produce the observed fluctuation (eg. Figure 34). The magnitude of groundwater level fluctuation is generally inversely proportional to aquifer transmissivity and storativity.

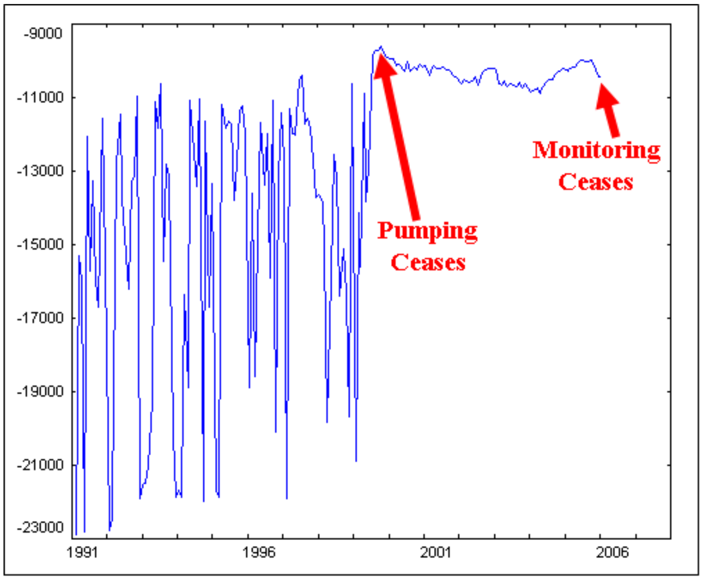

Figure 34. Long-term monthly groundwater level monitoring in Well 352111, Moutere Road, in the Horowhenua District (Source: Zarour, 2008a). Pumping effects stopped masking the hydrograph upon cessation of pumping from the well.

197. Groundwater levels in the Region generally are lowest by the end of the irrigation season in May and peak up around the end of winter (September-October). This coincides well with the regional rainfall pattern. Rich (1959)[37] notes that rainfall in the Region is fairly evenly distributed throughout the year. He further notes that rainfall seasonal variation is moderate, with a late summer minimum and early winter maximum.

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[37] This is a Harvard University geology PhD thesis

He draws attention to a rainfall secondary maximum that occurs in October, during spring. On the whole, this pattern matches well with the observed groundwater level fluctuation throughout the Region, including the occurrence of a secondary maximum. Therefore, it is reasonable to conclude that annual groundwater level recovery occurs due to recharge from rainfall through the period from June to October, while demand for groundwater is at its lowest. Generally speaking, only a small lag is noticeable between recharge and abstraction events, and their subsequent respective effects on groundwater levels in the Region (see Paragraph 195).

198. Groundwater levels in most monitored wells in the Region show long-term stability (eg. Figure 32). This reflects long-term balance between groundwater inputs and outputs, and is an indication of sustainable exploitation of the resource. Nonetheless, groundwater level declines have been noticed in some wells in different parts of the Region and at different times. I provided examples of this in Zarour (2008a) and discussed them (eg. Well 336113 in Figure 35). There, I concluded that the dropping groundwater levels noticed in some wells is probably a reflection of deteriorating well conditions coupled with the monitoring methodology, rather than a sign of resource depletion.

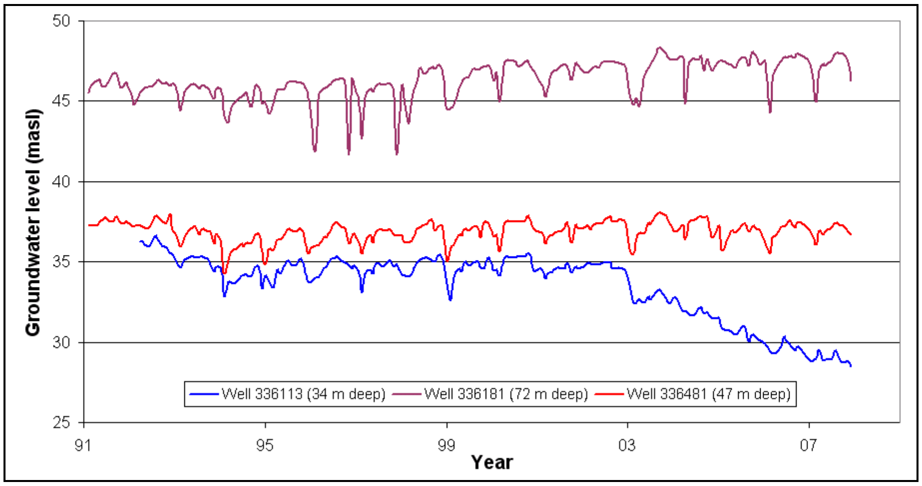

Figure 35. Groundwater level hydrographs observed in wells in the Aokautere area near Palmerston North (Source: Zarour, 2008a).

199. Rising groundwater levels are noticed in several areas under various aquifer conditions. For example, the groundwater level hydrograph for the 43 m deep Well 312009 in the Rangitikei coastal area shows persisting long-term rise (Figure 36).

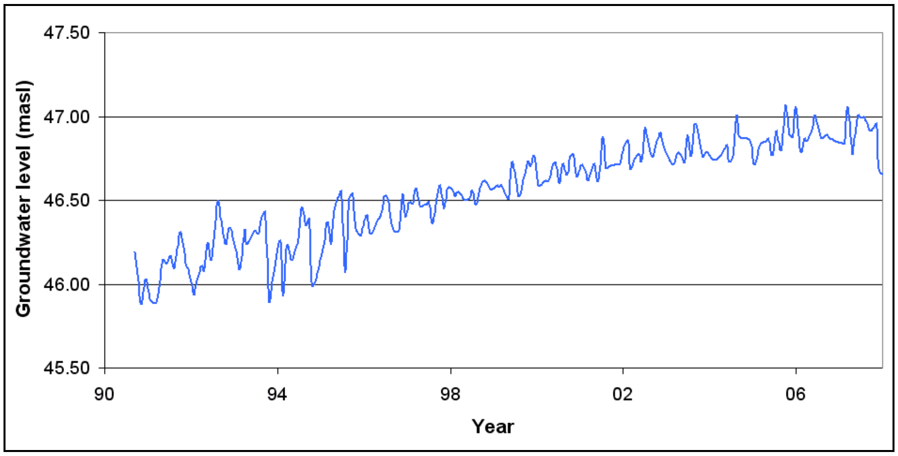

Figure 36. Hydrograph showing rising groundwater level in a 43 m deep well (312009) in the Rangitikei coastal area (Source: Zarour, 2008a).

200. In almost all the monitored wells in the Horowhenua District, groundwater levels are apparently stable but in fact they are slightly, slowly and steadily declining (eg. Figure 37). This is confirmed when the data is examined in more detail (eg. Figure 38 and Figure 39).

201. In my opinion, this decline is not significant from a pure groundwater resource perspective. Nonetheless, I argue in Zarour (2008a) that "*what may be established as an acceptable rate of groundwater withdrawal with respect to change in groundwater levels may reduce the availability of surface water to an unacceptable level*". I believe that the noticed drop in groundwater level in most wells in the Horowhenua District will eventually affect the dependent surface water features, particularly Lake Horowhenua. Various management options need to be considered to develop a prudent approach to manage the resource in that area that is technically, economically, culturally and environmentally viable.

202. It should be noted that effects of groundwater pumping tend to manifest themselves slowly and in a cumulative manner. Hence, both current and planned resource developments must be carefully considered in the regional groundwater management plan. This must constitute an integral part of a comprehensive environmental management strategy. Within this context, we need to note that the most important attribute of the concept of groundwater resource sustainability is that it fosters a long-term management perspective (Zarour, 2008a; Section 7.2). From a strategic perspective, the long-term approach to sustainability of the Region's groundwater resources may involve allowing frequent temporary withdrawals from groundwater

storage that are balanced by intervening additions to groundwater storage over a long planning horizon, say 10-20 years. However, this may not be a feasible option where groundwater abstraction can deplete interconnected surface water systems.

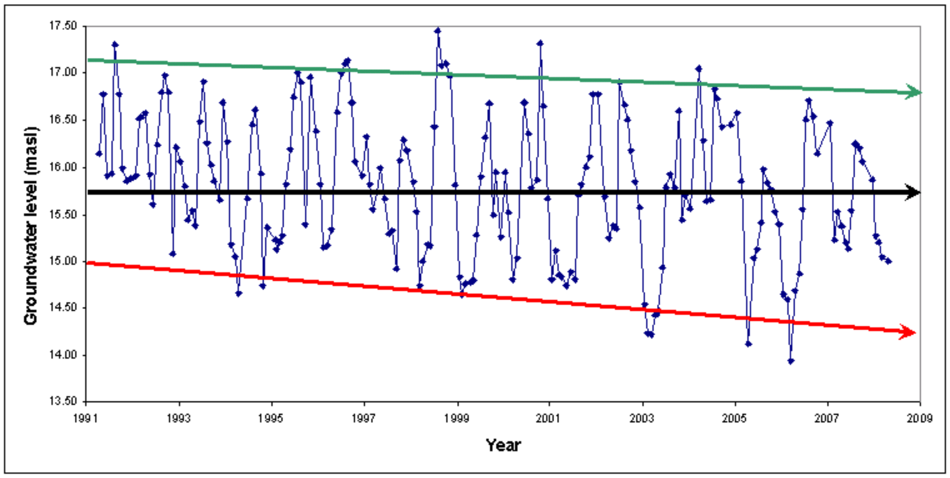

Figure 37. Groundwater level hydrograph for Well 362951 in the Horowhenua District, which is typical of wells in the district. Blue dots represent actual monthly measurements, blue line is the long-term groundwater level hydrograph, the black arrow represents the visual long-term average, the green and red arrows represent visual average maximum and minimum levels, respectively. For well location see Figure 40.

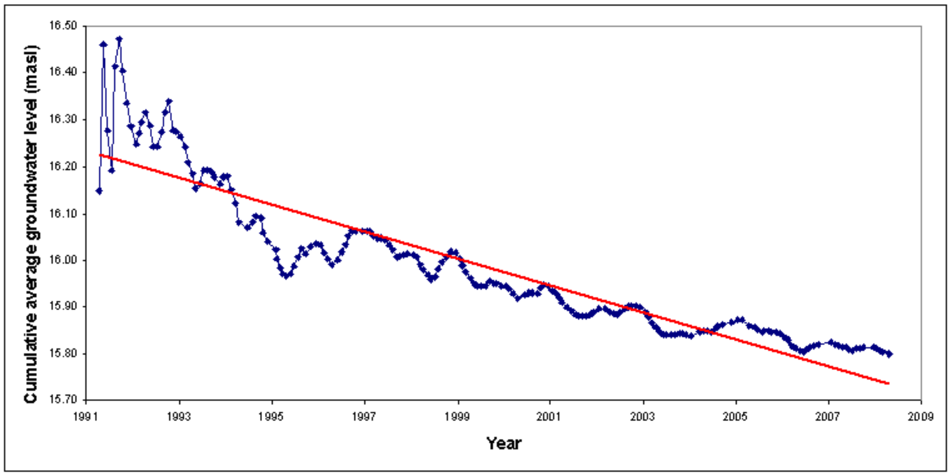

Figure 38. Long-term cumulative average groundwater level for Well 362951 in the Horowhenua District. For well location see Figure 40.

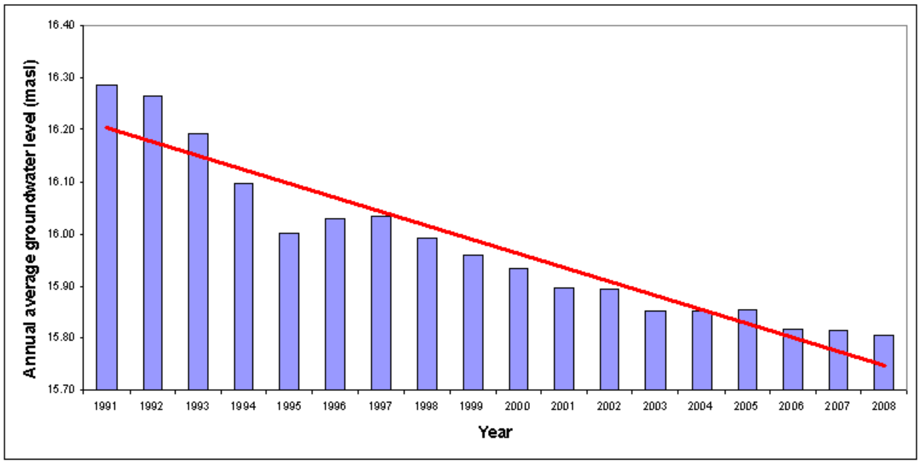

Figure 39. Long-term annual average groundwater level for Well 362951 in the Horowhenua District. For well location see Figure 40.

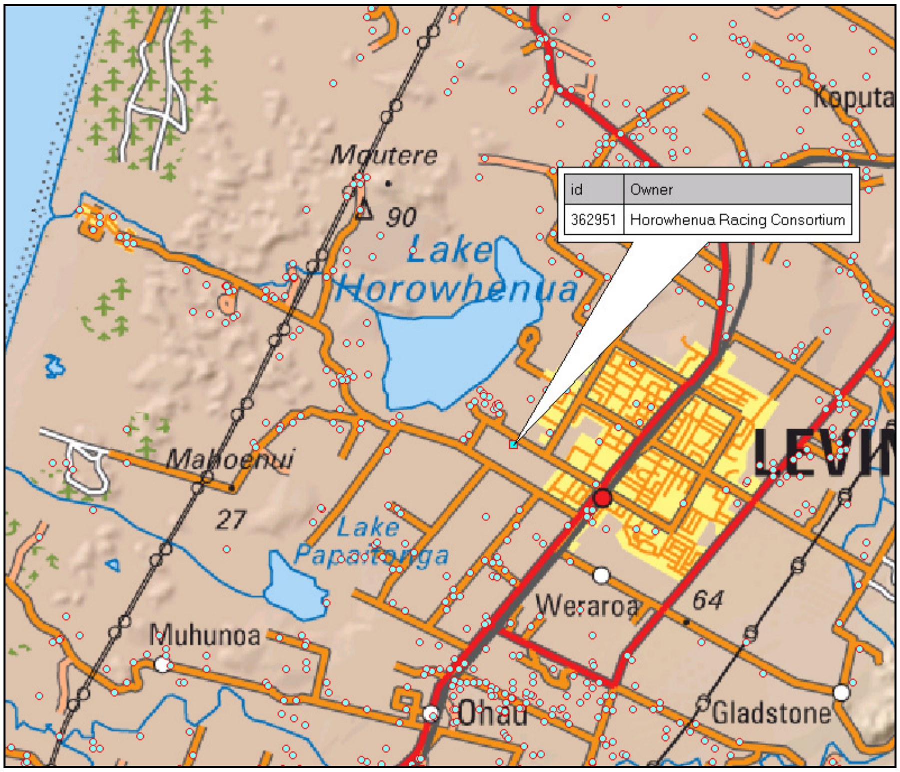

Figure 40. Map showing location of Well 362951 in the Horowhenua District in relation to main features in the area.

203. Notwithstanding the noted decline in groundwater levels in some wells, I believe that generally the groundwater resource is highly resilient. Regional long-term groundwater level monitoring records show general stability and limited local declines and rises,

indicating that the resource has been managed sustainably. However, special attention needs to be given to the complicated interrelationships between the various components of the environment, eg. the effects of groundwater resource development on groundwater-dependent surface water features and the associated ecosystems.

Key messages – Groundwater level fluctuations and trends

i. Groundwater level is the cumulative result of balance between water inputs and outputs, and a reflection of hydrogeological characteristics and conditions of the aquifer which involves different time-frames.

ii. Effects of groundwater pumping tend to manifest themselves slowly and in a cumulative manner.

iii. Pumping effects may mask natural seasonal groundwater level fluctuations.

iv. Seasonal groundwater level fluctuations observed in the Region reflect the synchronised balance between inputs (eg. rain recharge) and outputs (including pumping).

v. Seasonal groundwater level fluctuations vary in magnitude across the Region, in a manner that is inversely proportional to the resource yield potential.

vi. Quick response of groundwater levels to recharge is remarkable in the Region.

vii. Noticed isolated drops in groundwater levels in some wells probably reflect deteriorating well conditions.

viii. Groundwater levels in some wells in the Region are noticed to rise.

ix. In almost all monitored wells in the Horowhenua, groundwater levels are slightly, slowly and steadily declining, which may affect groundwater dependent surface water features, particularly Lake Horowhenua.

x. The most important attribute of the concept of groundwater resource sustainability is that it fosters a long-term management perspective, which may involve allowing frequent temporary withdrawals from storage that are balanced by intervening recharge.

xi. Regional long-term groundwater monitoring records show general stability, indicating a highly resilient resource that is managed sustainably.

xii. Potential effects of groundwater abstraction on other components of the environment need to be considered in plans and assessments of resource consent applications, eg. pumping effects on groundwater dependent surface water ecosystems.

Groundwater level variation with depth

204. I explain in Zarour (2008a) that groundwater levels can increase or decrease with depth. Abrupt changes indicate the occurrence of distinct aquifers, but gradual or linear change such as that noted in the Whakarongo multi-level piezometer setup (Figure 33, p 84) indicates hydraulic continuity.

205. In groundwater recharge areas, groundwater head decreases with depth, making it possible for water to percolate downwards and enter the aquifer. In groundwater discharge zones heads are higher at depth so that water flows upwards to shallower depths or to the land surface. Studying groundwater level variation in space is important for the characterisation of groundwater systems and identification of recharge and discharge areas. For example, the Lower Manawatu Valley is considered a groundwater discharge zone because of the upward hydraulic gradient that occurs in it (Zarour, 2008a; Section 3.2.3, p 24).

Key messages – Groundwater level variation with depth

i. Groundwater levels increase with depth in discharge areas, but decrease with depth in recharge areas.
ii. Abrupt changes in groundwater head with depth indicate separate aquifers, but gradual change indicates hydraulic continuity.
iii. Gradual groundwater head changes in the Region are indicative of hydraulic continuity, ie. interconnected leaky aquifer systems.

Groundwater level areal distribution and groundwater flow

206. In Section 3.2.4 of Zarour (2008a), I explain that groundwater potential energy is expressed in terms of head or level, which form the water table or piezometric surface. The slope of this surface is referred to as the hydraulic gradient. Groundwater flow is proportional to the hydraulic gradient. Groundwater flow lines are perpendicular to the contour lines, and the flow direction is the same as the down-gradient direction.

207. A groundwater level contour map, also known as piezometric, potentiometric or equipotentiometric map, is a useful method to represent groundwater heads, flow directions and flow magnitude; it also is useful to decipher aquifer properties and conditions.

208. Ideally, equipotentiometric maps are constructed using concurrent or semi-concurrent measurements of groundwater heads. This data is not available in the Region and the cost of collecting it for general, regional-scale water resources assessment purposes would be considerable. Collection of such data becomes cost-effective on smaller scales and for specific reasons, eg. Horizons' recent detailed hydrological survey of wells and surface water systems in the Horowhenua District to provide reliable data for geological modelling and water allocation assessment.

209. Despite the noted seasonal fluctuation in groundwater level, and the evident vertical change in groundwater head across the Region, I believe that depth variations and temporal fluctuations can be ignored on big scales such as that of the Region and the watersheds in it. World prominent groundwater scientists assert that vertical flow components can be safely ignored in regional scale assessments (Zarour, 2008a; Section 3.2.4, p 27).

210. Long-term groundwater level monitoring data is available for about 150 wells in the Region, and Horizons' groundwater database contains groundwater level measurements for more than 3,200 wells that have been taken either when the wells were drilled, or at some other stage. Bekesi (2001) and Zarour (2008a) used this data to produce groundwater level maps for the area to the west of the axial ranges. This area is known in geological literature as the South Wanganui Basin (SWB). This term is used in Zarour (2008a), and in this evidence, to indicate all the land in the Region that lies to the west of the axial ranges. The groundwater level maps for the SWB by Bekesi (2001) and Zarour (2008a) are very compatible, and collectively are considered to reasonably represent average groundwater level conditions in that area. Due to lack of data and the hydrogeological nature of the area to the east of the axial ranges, ie. the Tararua District, a similar map is not technically feasible there.

211. The groundwater level map for the SWB (Figure 41) shows that groundwater generally flows in a south-westerly direction that becomes westerly near the coast, ie. groundwater flows in this basin from the elevated country towards the Tasman Sea in similar directions to that of surface water systems. The map shows a strong relationship with surface water features in the area. Discharge of groundwater into the major rivers is particularly clear in the map. The map suggests that coastal lakes such as Lake Horowhenua represent groundwater discharge zones and areas of strong surface water/groundwater interaction. The map also shows the influence of topography, where the elevated interfluvial areas (ie. land between rivers) coincide with groundwater divides. These NE-SW oriented topographic highs correspond to geological structures

(ie. anticlines), drawing boundary lines for the Regional groundwater management zones, as discussed in Paragraph 240 of this evidence. The influence of geological structures (ie. faults and associated anticlines) on the groundwater flow system has been noted by a number of investigators (Zarour, 2008a). These structures are shown in Figure 42 and their effects on the area's geology are presented schematically in Figure 43.

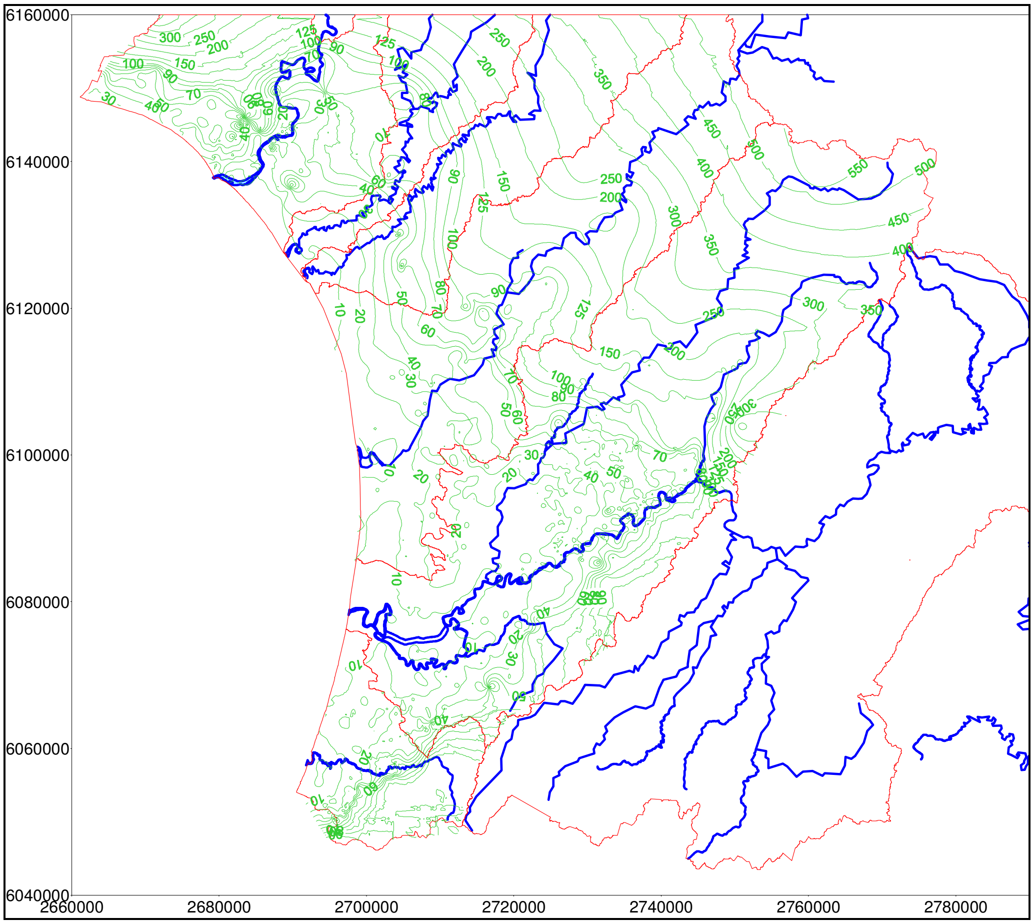

Figure 41. Groundwater levels in the South Wanganui Basin (SWB). The green lines represent groundwater level contours in metres above mean sea level. Blue lines represent rivers and red lines boundaries of Groundwater Management Zones (Source: Zarour, 2008a).

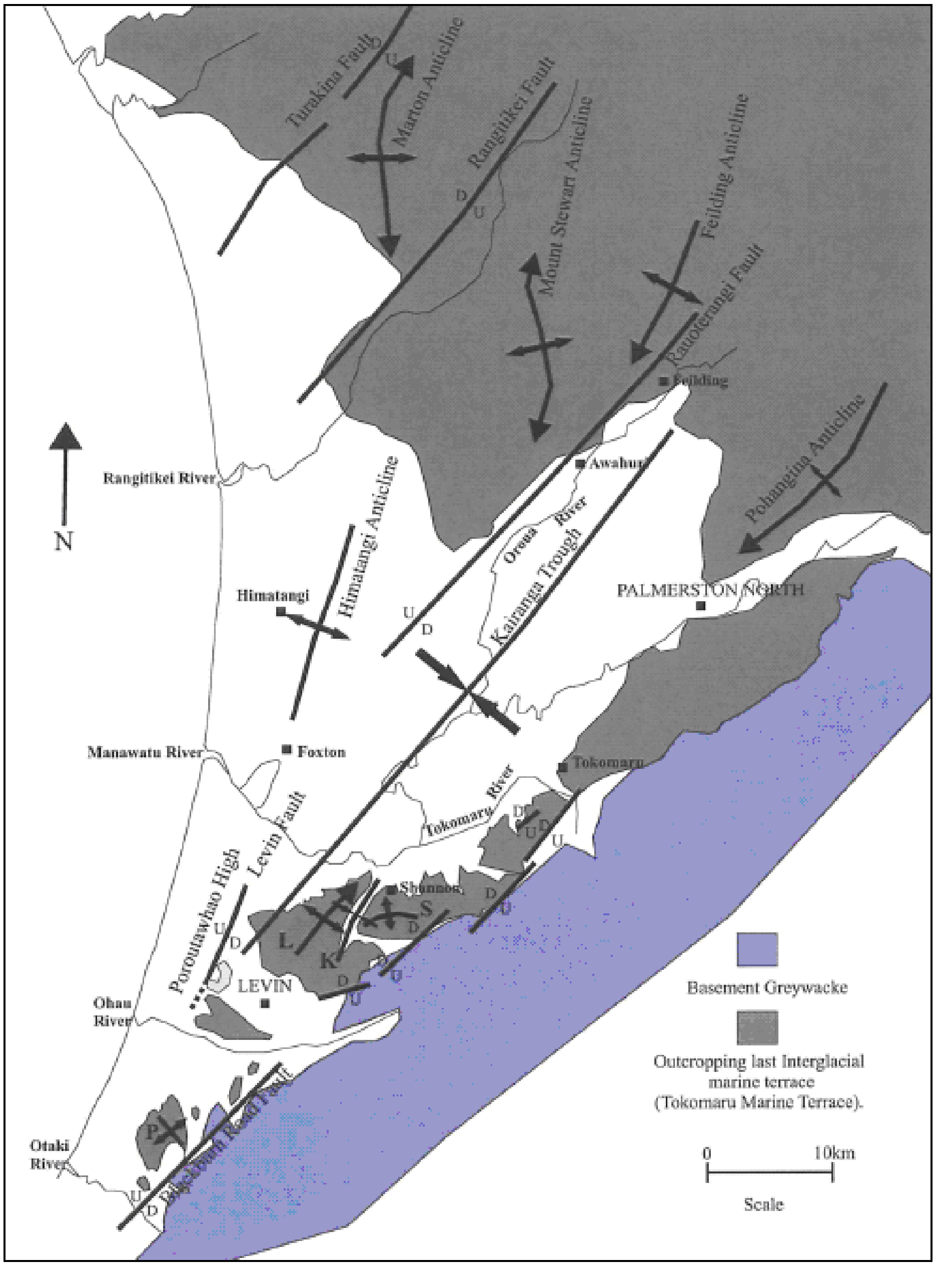

Figure 42. Main structural features of Horizons' Region west of the axial ranges (Hughes, 2005)[38]. The grey shade covers the Tokomaru Marine Terrace and older geological strata.

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[38] Victoria University of Wellington MSc Thesis. Available online.

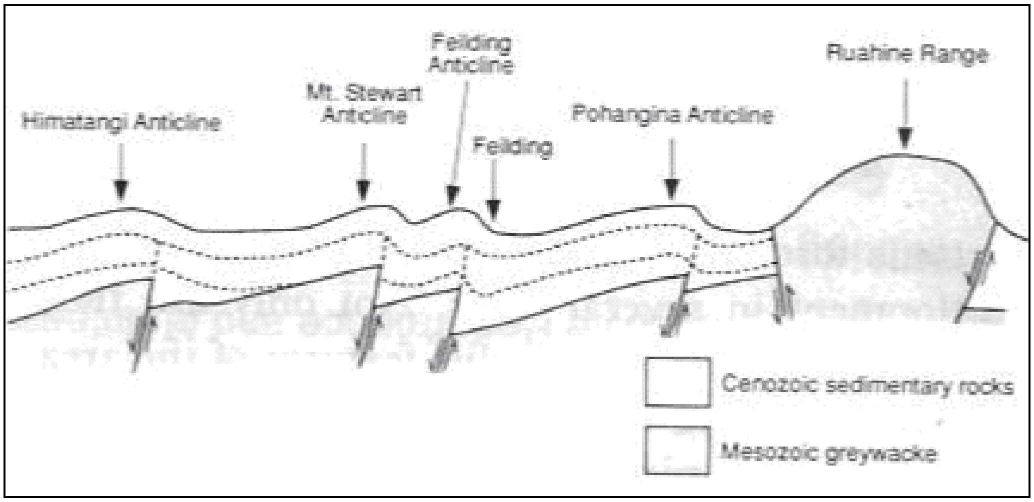

Figure 43. Sketch of section between Tangimoana and the Ruahine Ranges showing the relationship between structure and relief (Source: Heerdegen and Shepherd, 1992).

212. The potentiometric surface in the SWB that is presented in Figure 41 greatly resembles the topography. Hence, it would be fair to conclude that groundwater resource development in the Region has not yet remarkably stressed the system, as indicated by the absence of notable deviation from expected conditions. Additionally, this equipotentiometric map clearly shows that groundwater level in the western coastal area is positive, ie. seawater invasion into the coastal fresh groundwater system in that part of the Region is not yet an inevitable hazard.

Key messages – Groundwater level aereal distribution and flow

i. Groundwater flows in proportion to the hydraulic gradient and follows its direction.
ii. Groundwater level maps are useful to depict heads, flow directions and other hydrogeological information.
iii. Groundwater level maps ideally are constructed using concurrent or semi-concurrent groundwater head measurements, but average values may be used for regional-scale mapping.
iv. Bekesi (2001) and Zarour (2008a) produced compatible groundwater level maps for the area to the west of the axial ranges, ie. the South Wanganui Basin (SWB).
v. A groundwater level map for the area to the east of the axial ranges, ie. the Tararua District, is not technically viable.
vi. Groundwater flows in the SWB in a south-westerly direction that becomes westerly near the coast, similar to surface water run-offs.
vii. Topography in the SWB, which is an expression of structural geology, greatly influences groundwater flow.
viii. Groundwater divides (boundaries of basins) coincide with topographic highs.
ix. The resemblance between the potentiometric surface and topography in the SWB indicate that the groundwater abstraction in the area has not yet remarkably stressed the resource.
x. The general groundwater flow pattern indicates hydraulic continuity between surface and subsurface waters in different places across the Region.

The proposed groundwater resource management framework and allocation limits

Geological setting

213. Management of groundwater resources requires a practical framework (ie. conceptual understanding or model), in which management units and corresponding allocation limits are stipulated. Historically, this has not been incorporated in regional policy statements and plans.

214. A solid groundwater resources management framework must be based on a good understanding of the geology and the subsurface and surface hydrology of the resource, ie. its hydrogeology. Hydrogeological units are defined in space in terms of their areal extent and upper and lower bounding surfaces (ie. vertical dimension). The vertical dimension is often presented as the top and bottom of a geological unit, eg. the Late Quaternary sequence.

215. In the previous sections of this evidence, I presented aspects relating to groundwater quality and quantity in the Region that can be combined with the geology to produce the required conceptual framework for the regional groundwater resource.

216. In Zarour (2008a), I discuss the Region's geological and physiological settings which have been shaped by tectonism[39], and the consequent structural geology, together with global-scale glacio-eustacic[40] changes in sea levels, particularly during the Pleistocene[41]. There, I also clarify that the Region is divided geologically and hydrogeologically by the Ruahine and Tararua axial ranges into two main areas, or basins:

i. The South Wanganui Basin (SWB), and
ii. The Eastern Subdivision (ES)[42].

217. The South Wanganui Basin (SWB) includes all the land area in the Region to the west of the axial ranges. Old literature refers to it as the New Zealand Geosyncline and there is a tendency in recent publications to simply call it the Wanganui Basin (WB). The Eastern Subdivision (ES) includes all the land area in the Region to the east of the axial ranges, which geologically consist of more than just one basin.

218. A basic geological map for the North Island is presented in Figure 44, and a simplified time-scale is presented in Table 4, to help with the geological relationships and time-scale terminology used in this evidence.

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[39] Large-scale relative movement of the plates that form the Earth's crust. See Box 11, p 177 in Zarour (2008a) for concise information on this subject. The Region's tectonic setting is described in Section B-3, p 176 in Zarour (2008a).

[40] Global glacio-eustatic changes of sea level and their effects on the geology and hydrogeology of the Region are concisely presented in Appendix C (p 197) in Zarour (2008a).

[41] Pleistocene: The geological time from 1.8 million years ago to the Present.

[42] Unlike the South Wanganui Basin (SWB), this is not a formal geological name.

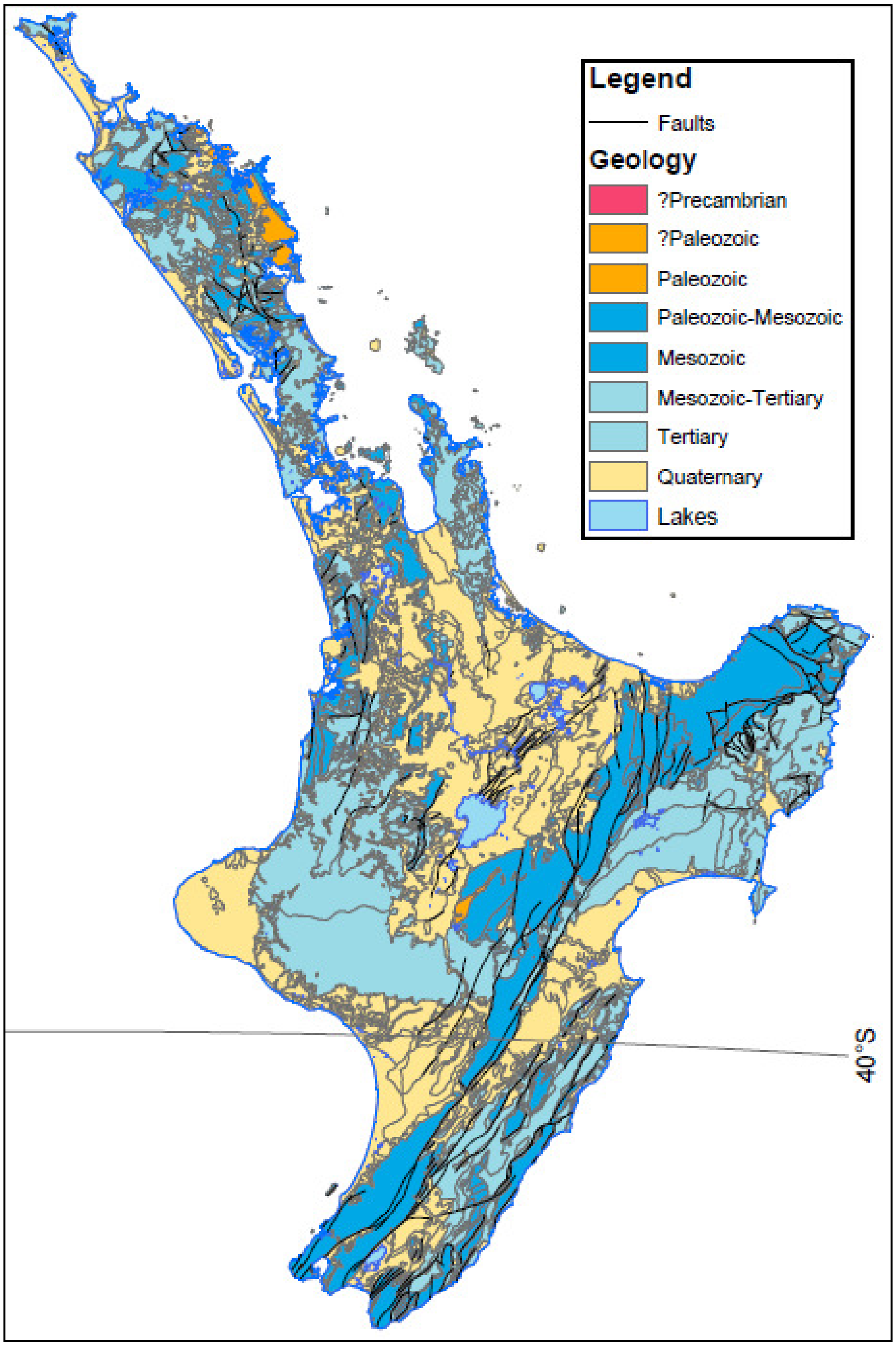

Figure 44. Simplified geological map for the North Island (Adopted from Waikato University geology website[43]).

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[43] http://sci.waikato.ac.nz/evolution/images/geology_era.pdf

Table 4. Simplified geological time-scale and overview of main events in Horizons' Region (Source: Zarour, 2008a).

	Period	Epoch	Estimated Beginning[44]	Main Geological Activity in the Manawatu-Wanganui Region	
Cenozoic	Quaternary	Holocene	0.012	Post-glacial	Uplift and erosion of older strata Beginning of alluvial-marine cyclic deposition
		Late Quaternary	0.128	Predominantly Alluvial deposits	
		Castlecliffian to Mid Quaternary	0.362	Alternating alluvial and marine deposits	
		Pleistocene	1.8	Deposition of thick marine siltstone and mudstone	
	Tertiary	Pliocene	5.3		
		Miocene	23.8	Erosion faulting and folding	
		Oligocene	33.7		
		Eocene	55		
		Paleocene	65		
Mesozoic	Cretaceous		145	Formation of basement greywacke strata	
	Jurassic		200		
	Triassic		251		
Paleozoic	Permian		299		
	Carboniferous		359		
	Devonian		417		
	Silurian		443		
	Ordovician		490		
	Cambrian		542		
Precambrian			3800		

219. Rocks in the Region can be grouped into four main geological units as follows:

i. The tectonically uplifted [*Torlesse Terrane*] greywacke basement rock which underlies the entire Region and forms the Ruahine and Tararua axial ranges. These are the oldest rocks in the North Island (Permian-Jurassic, but mostly Triassic). The greywacke basement is buried by up to 4-5 km of younger deposits within the South Wanganui Basin (SWB). However, they also occur at very

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[44] Million years ago.

shallow depths (< 20 m in places) in the Horowhenua District, eg. the Poroutawhao basement high which is located approximately midway between the foothills of the axial ranges to the east and the seashore to the west. These rocks also crop out in places in the Eastern Subdivision (ES) to form mountains between the axial ranges and the eastern coast on the Pacific Ocean (Figure 44). Unfractured greywacke cannot yield water to wells and springs, ie. this unit can not be considered an aquifer.

ii. The Wanganui Basin Late Pliocene to Late Castlecliffian (c. 3.6-0.7 Ma) marine deposits, which also occur in the Eastern Subdivision. The unit consists of a number of lithostratigraphic groups, including Paparangi, Okiwa, Nukumaru, Maxwell, Okehu, Kai Iwi, and Shakespeare groups. Primarily, these rocks have been deposited in a marine environment and consist of siltstone, mudstone, sandstone, pumiceous sand, and minor limestone and conglomerate. However, the Maxwell Group is largely of non-marine origin. These rocks dip to the south and southwest around the southern side of the Taranaki coastline. They are cut by northeast-southwest orientated faults in a number of places. These deposits normally constitute aquitard material, due to their grain size and compaction. Sandstone and pumiceous sand formations within this unit have significant intergrain pore space, but structure, confining silt and mud beds above and below and topography limit their potential as aquifers, mainly though restricting recharge. Hence, these deposits may be able to yield enough water to wells for limited need purposes like domestic or farm supply, but they will not be able to support larger needs, eg. for large-scale irrigation.

iii. Late Castlecliffian to middle Quaternary interbeds of marginal marine and terrestrial, deposits. Deposits relating to the time from c. 420 Ka BP to the start of the Last Interglacial (c. 128 Ka BP) represent alternating warm, high sea level stand, marine benches, and cool climatic, low sea level stand, alluvial aggradational fans. Formation of these deposits became possible when the Region suddenly started to emerge from the sea about 700 Ka BP, allowing for terrestrial deposition. Global-scale sea level fluctuation resulted in the sea level rising and land being submerged during interglacial times, when polar snow was freed, alternated with sea level drops and emergence of land during glacial periods. Large-scale glaciation did not take place in the Region due to its latitude. Rather, the climate was cool during global glacial periods and warm during interglacials. The stratigraphic relationship between the marginal marine deposits and the alluvial gravel deposits is complicated by tectonic uplift of the Region. Tectonic folding and faulting through the period of deposition have restricted river courses to areas between anticlinal crests for much of this period, and alluvial gravels lap against older elevated deposits around the anticline axes, ie. channelled deposition environment. During cool [glacial] periods, the deposition of gravel in the floodplains was associated with deposition of loess[45] on the elevated land, capping older deposits. The gravely sections in this unit can form productive aquifer zones. The sandy and tephric subunits within the marine parts of the sequence can accommodate and transmit water, so that they can be considered a potential groundwater resource. Subunit thickness, continuity and geological structure control the groundwater resource potential of these strata. Loess cover may restrict recharge to all or some of these units, resulting in a thick unsaturated zone. While these deposits contribute recharge to the general groundwater resource in the Region, generally they are not capable of yielding much water to wells and springs.

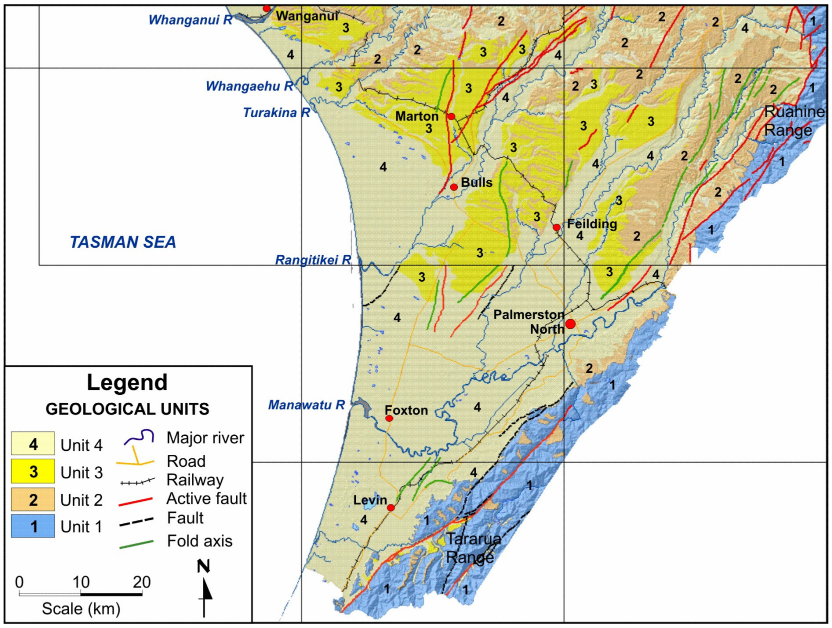

Figure 45. Main geological units in the South Wanganui Basin (Source: Begg et al., 2005).

iv. Late Quaternary deposits (128 Ka BP to present day). From a groundwater resource perspective, these deposits constitute the most significant section in the entire geological sequence in the Region. They are extensive in the Region and occupy a broad crescent between Wanganui, the Manawatu Gorge and Levin (Figure 45). They also occur in valleys and floodplains to the east of the axial

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[45] Silt-dominated sediment of aeolian (windblown) origin. Loess is a common deposit in and near areas that were glaciated during the Quaternary Period, and most loess deposits are indirectly related to glacial periods

ranges, ie. the Eastern Subdivision (ES). The Late Quaternary sequence in the Region is characterised by unconformities[46], resulting from sea level change and tectonic deformation. The three-dimensional distribution of the units that comprise this sequence is difficult to map. In general, this sequence consists of Last Interglacial marginal marine sands and interbeds of other sediments which, in the current floodplains, underlie Last Glacial terrestrial, mainly gravel, deposits. The sequence ends with Holocene deposits, mainly sands. Last Glacial gravels predominantly have been laid down as floodplain and valley fill deposits. In places, they are clay-bound and interdigitated with fine grained overbank, swamp or lacustrine[47] deposits (eg. Figure 46). In the Eastern Subdivision of the Region, these deposits normally unconformably overlay older material (eg. Figure 47). These deposits are cleaner (ie. have less fine material content) in the proximity of the old rivers that deposited them. Traditionally, well drillers in the Region have preferred screening gravel-rich material such as these deposits.

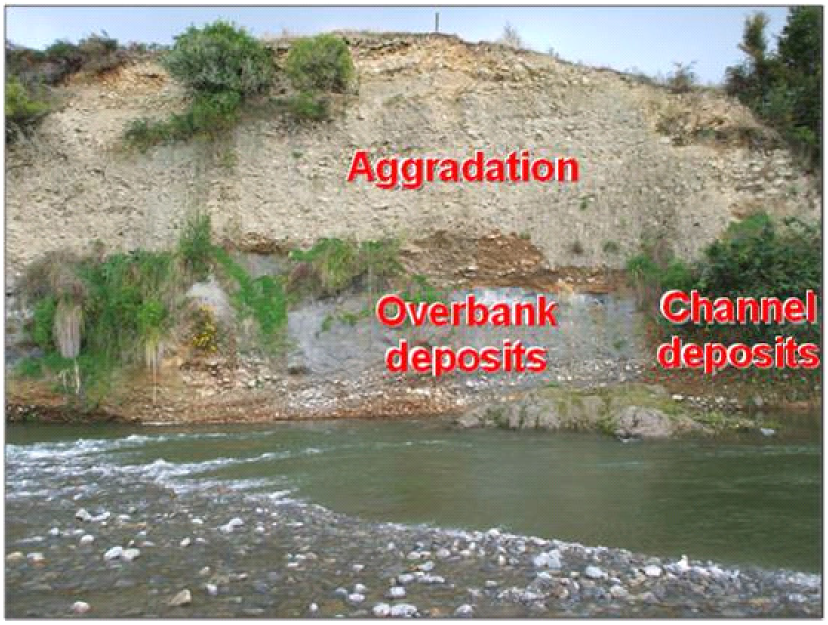

Figure 46. Section into Last Glacial deposits incised by the Ohau River at Gladstone Reserve, Horowhenua District (Photo by: Hisham Zarour, 2007). The fine-grained overbank deposits have been traced in the field and found to have very limited aereal extent. If such deposits are tapped by a well, they may be wrongly interpreted to constitute an extensive aquitard that separates the sequence into upper and lower aquifers (Source: Zarour, 2008a).

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[46] Geological time unrepresented in the sequence, indicating erosion and/or interruption in deposition.
[47] Lacustrine: a geological term meaning of lakes, especially in connection with sedimentary deposition.

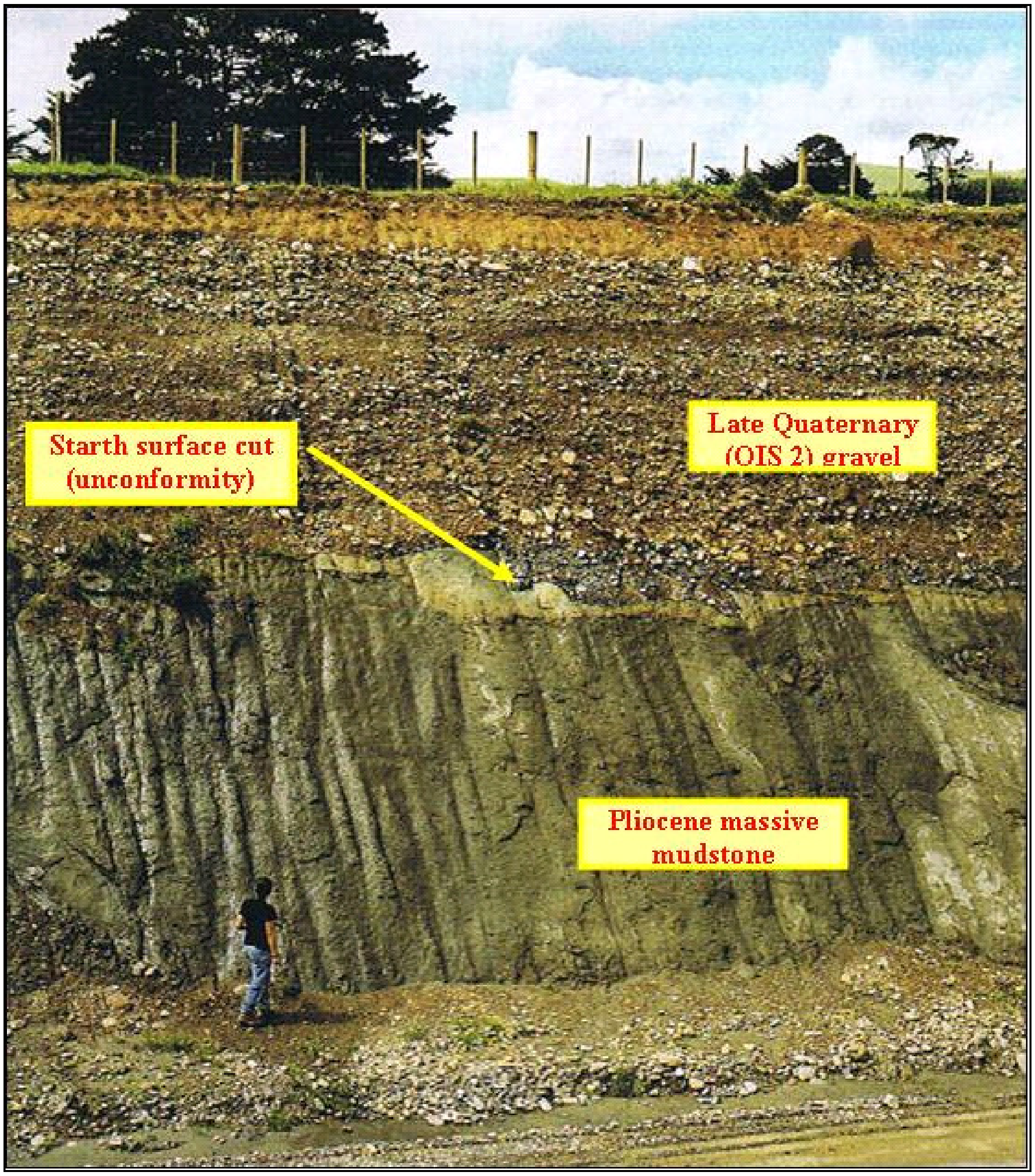

Figure 47. Road cut exposure showing strath[48] surface cut on Pliocene massive mudstone unconformably[49] overlain by slightly weathered poorly sorted alluvial gravels that relate to OIS 2[50] (Source: Begg and Johnston, 2000)[51].

220. Where they overlap in the South Wanganui Basin, the unit designated in the evidence as Unit 4 and the upper section of the unit designated above as Unit 3 often occur in hydraulic continuity and comprise the bulk of the regional groundwater resource. Hence,

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[48] Bedrock surface cut by stream (Alan Palmer *pers. comm.*, 2008).

[49] Unconformity in geology is a surface between successive strata and representing a missing interval in the geologic record of time. Unconformity is produced either by an interruption in deposition or by erosion of depositionally continuous strata followed by renewed deposition.

[50] This is the most recent unit in the Last Glacial geological sequence.

[51] Exposure is on State Highway 2 near Waiwaka, close to Makakahi River in the Tararua Groundwater Management Zone.

they are grouped together in Mr Callander's evidence (Paragraph 3.2). I prefer keeping them separate because the unit I designate here as Unit 3 is normally absent from the geological sequence in the Eastern Subdivision. Mr Callander's and my approach are compatible, and the small variation in classification does not change the bigger picture.

221. The Region's geological history during the late Cenozoic in general, and in the mid-Late Quaternary in particular, as explained in Appendix E of Zarour (2008a), is ultimately responsible for today's physiographic setting. The Region's landforms are exclusively geologically young, the entire area having emerged from the sea in less than the last million and a half years (Begg *et al.*, 2005). As can be seen in Figure 48, landforms in the Region can be classified into the following four broad areas:

i. The axial ranges.
ii. The uplifted partially dissected marine terraces (dissected uplands).
iii. The loess mantled fluvial aggradation surfaces and marine benches (coastal lowlands).
iv. The coastal strandplains (the plains).

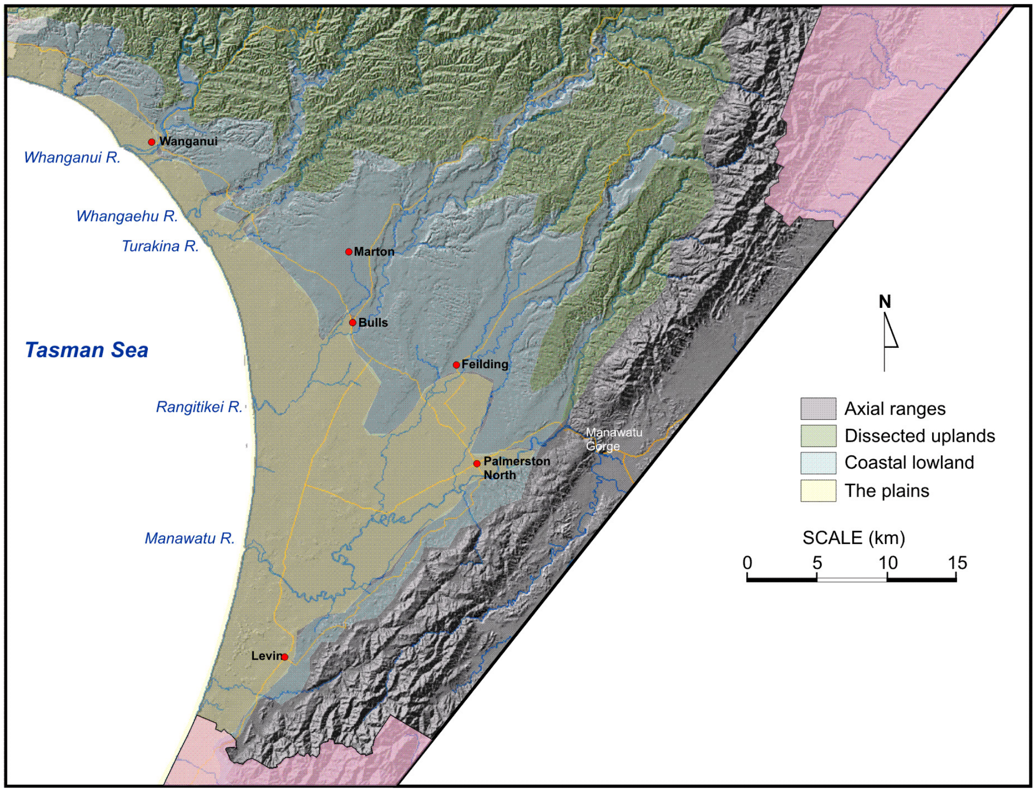

Figure 48. Physiography of the South Wanganui Basin (Source: Begg *et al.*, 2005).

222. The boundaries between these units are not clear cut, but rather diffuse.

223. The northeast-southwest oriented axial ranges dominate the central landscape. The Manawatu River cuts through the axial ranges via the Manawatu Gorge, which is walled on either side by steep greywacke bluffs. The ranges rise to elevations exceeding 1,000 m to the north and south of the Gorge.

224. The dissected upland landscape consists of uplifted, partially dissected marine terraces. It is characterised by dissected drainage patterns developed on Late Tertiary marine sediments that were deposited in the Wanganui Basin and have subsequently been tilted and uplifted. In general, relief and dissection increases inland, and valley profiles are V-shaped. In some places, more resistant sand beds, shell beds or landslide-prone mudstone within the siltstone and sandstone marine deposits result in lines of steep V-shaped gorges or gently undulating belts traversing the landscape. Both the axial ranges and the dissected uplands are immediately underlain by relatively impermeable rock and sediment and, therefore, have limited or nonexistent groundwater yield potential.

225. The coastal lowland is an area of loess-mantled fluvial aggradation surfaces and marine benches characterised by gently dipping to rolling topography with some stream dissection. It lies between the dissected upland and/or axial ranges and the plains. This landform includes the landscape between the valleys of the major rivers that drain the South Wanganui Basin (eg. the interfluves that separate between the Whangaehu, Turakina, Rangitikei and Manawatu rivers). Typically, the groundwater table is deep beneath such terrains (ie. it can be > 120 m). These lands are considered groundwater recharge areas. Surface water divides (ie. catchment boundaries) correspond with the highest points on the interfluves. The same lines are considered groundwater divides that separate adjacent Groundwater Management Zones, because deep groundwater tables in topographically elevated recharge areas constitute legitimate groundwater divides. The crests of a number of important active anticlines (Figure 42 and Figure 43) are included in this landscape class. Also included is an area of low hills butting against the western foot of the Tararua Range that relate to the Last Interglacial period, ie. the Tokomaru surface and underlying Otaki Sand formation.

226. The plains encompass the low-lying land in the South Wanganui Basin (SWB), which extends between the coastal lowland to the east and the Tasman Sea to the west. In some places this land is mantled by sand dunes. This landscape can be subdivided into:

i. Alluvial plains.
ii. Sand country (or strandplains[52]).

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[52] Strandplains: a series of dunes, usually associated with and parallel to a beach, sometimes containing small creeks or lakes that have very low or negligible freshwater input.

227. The alluvial plains vary slightly in character between the main river systems in the area. The Rangitikei River, which is located nearly in the middle of the South Wanganui Basin (SWB), has the steepest gradients in the coastal section of the basin, which results in higher ability to carry gravel all the way to the coastline. In the Horowhenua District, there is a distinct margin (a Holocene sea cliff) between the sand country and the alluvial plains, in contrast to further north where the sand country merges with the alluvial plains.

228. The strandplains, or sand country, are characterised by dunes up to 30 m in elevation and inter-dune swamp, and is also underlain by river silt, sand and minor alluvial gravel. Dune morphology varies from longitudinal dunes to barchan[53] dunes to shore-parallel mounds. The dune shapes are probably influenced by topography and, consequently, wind velocity.

229. A large proportion of the rainfall on the plains percolates through the ground and turns into groundwater recharge. The plains have the highest groundwater resource potential in the Region as they also receive subsurface flow from other units.

The Region's groundwater resource

230. From the above discussion, it is clear that greywacke and old marine deposits in the axial ranges, and the uplifted partially dissected marine terraces, are not capable of furnishing enough water to wells and springs. Therefore, they do not qualify as aquifers, except the Nukumaru deposits which are tapped by Wanganui District Council for municipal water supply. The bulk of the regional groundwater resource consists of the younger alluvial deposits (age < c. 360 Ma) that can be found in the coastal lowlands and plains. In the Eastern Subdivision, these deposits are limited in the river valleys and floodplains. In the South Wanganui Basin, they are more extensive, extending between the hinterlands and the Tasman Sea, and thickening seawards. Collectively, they form a stratified heterogeneous hydrogeological sequence. Where enough recharge reaches permeable sand and gravel sections in this hydrogeological system, large yields from wells are possible. This is the system that produces most of the groundwater that is tapped in the Region through an estimated 9,500 wells.

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[53] A crescent-shaped windblown sand dune, the arms of which point downwind; formed by winds of almost constant direction and of moderate speeds. Also known as barchane, barchan, and crescentic dune.

Key messages – Geological setting and resource definition

i. Effective groundwater resource management requires a defensible, practical conceptual model.

ii. Until the Proposed One Plan, regional policy statements and plans did not contain a conceptual model for the Region's groundwater resource.

iii. Geological and hydrological information is needed to develop a hydrogeological model.

iv. The Region can broadly be divided into two areas: (1) the South Wanganui Basin (SWB); and (2) the Eastern Subdivision (ES).

v. The Region comprises four main geological units: (1) the greywacke basement; (2) Late Pliocene to Late Castlecliffian marine deposits; (3) Late Castlecliffian to middle Quaternary interbeds of marginal marine and alluvial deposits; and (4) Late Quaternary beach sand and alluvium.

vi. The Region can be subdivided into four physiographic units: (1) the axial ranges; (2) the uplifted dissected marine terraces; (3) the coastal lowlands; and (4) the coastal plains.

vii. The greywacke and old marine deposits in the axial ranges and the uplifted dissected marine terraces do not form good aquifers.

viii. The Nukumaru aquifer provides Wanganui with its municipal water.

ix. The younger alluvial deposits in the coastal lowlands and plains constitute the main groundwater resource in the Region.

x. The general regional groundwater resource is conceptualised as a stratified heterogeneous hydrogeological sequence, within which permeable sand and gravel horizons are highly productive.

Regional hydrogeological conceptual model

231. In Zarour (2008a) I note that groundwater studies have been underway in the Region since 1945 and that research has significantly increased during the last 20 years. In Appendix G of that report, I account for all previous groundwater resource studies in the Region and provide a summary of the main conclusions reached by each of them regarding hydrostratigraphy, groundwater recharge, flow, and quality. In Sections 4.1 and 4.2 of that report, I discuss and comment on various attempts to develop a hydrogeological conceptual model for the Region and/or different areas within it.

232. My research indicates that many investigators favoured a model which subdivided the hydrostratigraphic succession in the Region in general, and in the Manawatu Catchment

in particular, into discrete aquifers of specific thicknesses and/or depth ranges. However, Russell (1989), Schumacher (1999), Bruns (2000) and Bekesi (2001) explicitly did not divide the groundwater system into distinct aquifers. All investigators acknowledged hydraulic continuity within the system, but some preferred arbitrary partitioning of the system into discrete aquifers. In addition, they all indicated in some manner that recharge of aquifers in the Region predominantly occurs at topographic highs, eg. the Pohangina Anticline

233. In Zarour (2008a), I argue that in none of the distinct aquifers proposals was aquifer subdivision undertaken on a defensible, definite basis. Additionally, the number, thickness and extent of aquifers perceived by various investigators widely varied. This inconsistency is a reflection of the absence of solid hydrogeological grounds on which to base aquifer subdivision in the Region. Here, I would like to draw the Panel's attention to the argument by Catuneanu (2006)[54] that "*the concept of sequence* [such as a hydrogeological system of aquifers and aquitards] *is as good, or acceptable, as the boundaries that define it*", and that: "*it is useless to formalise a unit* [eg. an aquifer] *when the definition of its boundaries is left to the discretion of the individual practitioner*". I see this to be the situation with the various proposals to divide the groundwater system in the Region, and various parts in it, into distinct aquifers as they remarkably disagree among themselves and fail to provide a reproducible system of classification.

234. In Section 4.2 of Zarour (2008a), I identify some possible reasons which lead some investigators to call for the vertical division of the Region's groundwater resource into distinct aquifers. These include:

i. Occasionally legitimate, arbitrary mathematical modelling layers have been confused as being genuine hydrostratigraphic units. Often modellers try to fit the environment to their models rather than fitting their models to the environment.

ii. Some investigators did not note that it is only the uppermost veneer (mostly < 100 m) of the sedimentary sequence in the Region (which reaches up to c. 5 km in thickness in places) that has value as a groundwater resource. Importantly, most wells in the Region are less than 100 m deep (Paragraph 254) and there is no clear relation between well depth and yield in the Region (Paragraph 255). Nonetheless, many hydrogeologists would be tempted to subdivide a 100 m thick hydrogeological sequence into distinct aquifers.

iii. Many researchers did not note the fact that geological deformation (ie. faulting and folding) has controlled and restricted fluvial sediment transport and deposition during the late mid- to Late Quaternary period (ie. the last 400,000 years). This is

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[54] This is a sequence stratigraphy textbook.

the period during which the groundwater-bearing strata were deposited. Hence, it is unrealistic to assume unlimited lateral extension and continuity of aquifers over structural features.

iv. As a consequence of the previous point, stratigraphic units (ie. geological layers) often have been confused with hydrostratigraphic units. In Zarour (2008a) I clarify that aquifer classification must be based on hydraulic continuity rather than just geological characteristics. For example, there is no hydrogeological relationship between Last Glacial deposits in the Rangitikei “delta” and the same geological unit in the Horowhenua District. Also, assuming full hydraulic isolation of distinct overlaying aquifers, as suggested by some investigators, is hydrogeologically impossible as some of such proposed units do not crop out anywhere in the Region. If these are truly separate aquifers, where do they receive replenishment from?

v. Some investigators had difficulties in explaining the noted head increase with depth in places in the Region, without subdivision of the aquifers by the means of extensive separating aquitards. As explained in Paragraph 205, this is normal in discharge areas (Figure 49) and Figure 49 does not necessarily mean discrete aquifers.

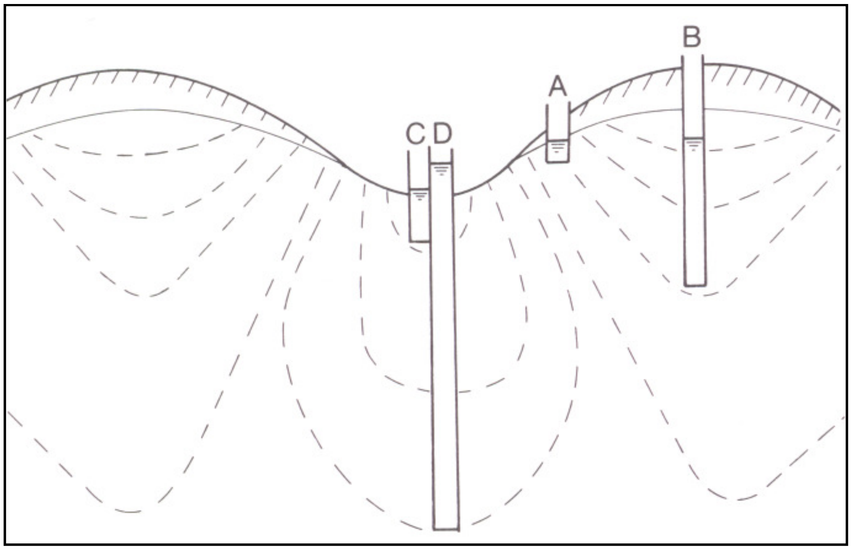

Figure 49. Water level in a well rises to the elevation of the hydraulic head represented by the potential at the intake end of the well. The water level in wells A and B is the same because both wells terminate on the same equipotential line (ie. groundwater level contour line). Dashed lines represent equipotentiometric levels (Source: Driscoll, 1986)[55].

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[55] This is the second edition of a classical industry reference book. The third edition was released in July 2008, but is on back order.

vi. Conceptualisation of the Region's groundwater resource into discrete, overlaying units (aquifers) appealed to well owners because of its implications for abstraction effects. Applicants for groundwater abstraction permits arbitrarily used a vague, informal classification of aquifers to claim that they would not affect users in other aquifers or the surface hydrological environment.

235. Accordingly, I believe that an explicit conceptualisation of a single, heterogeneous[56], anisotropic[57], hydraulically interconnected (ie. leaky) groundwater system that occurs in hydraulic continuity with connected surface water bodies, such as that proposed by Russell (1989), Schumacher (1999), Bruns (2000) and Bekesi (2001) (Paragraph 232), represents a reasonable conceptualisation of the Region's groundwater resource. Figure 50 presents the recommended conceptualisation schematically. I argue in Zarour (2008a) that this is not to say in any manner that groundwater resource in the Region must always be [mathematically] modelled as a single-layer system. The number of modelling layers is seen more as a function of modelling scope, scale and technique, to mention only a few considerations. One can use as many modelling layers as deemed necessary to represent the system, but such layers should not be confused with or identified as perceptible hydrostratigraphic units.

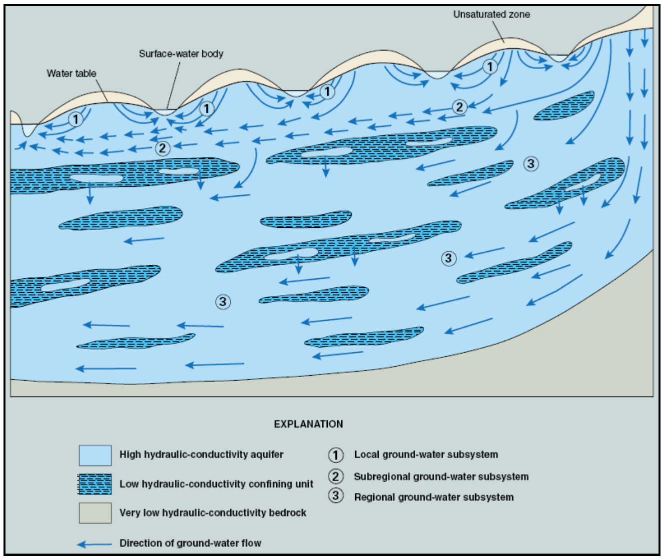

Figure 50. A regional groundwater flow system that comprises subsystems at different scales and a complex hydrogeological framework (Source: Alley *et al.*, 1999).

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[56] Properties of homogeneous material are constant in space so that they are the same throughout the extent of the material. Properties of heterogeneous material change in space so that they vary from one place to the other.

[57] Properties of isotropic material are the same in all directions in any given point. Anisotropic material has different properties in different directions at the same point.

236. In Wanganui, however, the Nukumaru Group constitutes a distinct aquifer that is separate from the Quaternary sequence. The geological settings of these strata are such that they do not constitute an important aquifer elsewhere in the Region.

237. Another significant aspect of the hydrogeological setting in the South Wanganui Basin (SWB) is the evident effect of geological structure on groundwater flow systems. These structures effectively correspond with groundwater divides. They crop out in the northeastern parts of the basin, but plunge beneath younger sediments towards the coast (Figure 42). Where buried, the older sediments that constitute these anticlines are frequently intercepted by bores, eg. in the Rongotea area. There, they occur in hydraulic connection with the younger deposits. However, this material becomes aquitard at depth, generally beyond approximately 100 m. Hence, the proposed conceptualisation of a thick interconnected leaky system is coupled with areal division of the Region into Groundwater Management Zones to produce a practical framework for groundwater management in the Region.

238. The obvious strong interdependence of groundwater and surface water systems throughout the Region is also an important element in the overall hydrogeological picture. This is discussed in this evidence in the section starting with Paragraph 270.286, p 142.

239. The leaky aquifer conceptual model enables accounting for effects of activities (eg. abstraction) at different depths, reaching the ground surface and hydraulically connected surface water bodies. Division of the Region into Groundwater Management Zones facilitates calculation of hydrological budgets and accounting for cumulative effects of abstraction. Last but not least, alignment of the Groundwater Management Zone boundaries with those of the [surface] Water Management Zones allows effective integrated resource and environmental management.

Key messages – Regional hydrogeological conceptual model

i. Hydrogeological investigations in the Region commenced in 1945.
ii. Zarour (2008a) provides a full account of previous investigations.
iii. Some investigators suggested discrete aquifers with specific thicknesses and/or depths, but still acknowledged hydraulic continuity through the entire sequence.
iv. Other investigators suggested an interconnected leaky aquifer model.
v. Discrete aquifers proposals are inconsistent and irreproducible. Hence, they cannot be adopted as a basis for resource management.
vi. The main groundwater resource only consists of the uppermost veneer (≤ 100 m) of the 4-5 km thick sedimentary sequence.
vii. Mathematical modelling units should not be confused with genuine hydrostratigraphic units.
viii. Anticlines (folds) are an important geological feature that controls the regional hydrogeology and the areal extent of regional hydrogeological zones.
ix. As a mater of definition, groundwater head increases with depth in discharge areas and decreases with depth in recharge areas.
x. In some cases, an informal, vague, arbitrarily division of the groundwater resource into distinct aquifers has been used to argue absence of adverse effects on other users of the resource and the environment.
xi. The Region's groundwater resource is best conceptualised as a single, heterogeneous, anisotropic, hydraulically interconnected (ie. leaky) groundwater system that occurs in hydraulic continuity with connected surface water bodies.
xii. In Wanganui, the Nukumaru Group constitutes a distinct aquifer that is separate from the Quaternary sequence.
xiii. The proposed conceptualisation of a thick interconnected leaky system is coupled with areal division of the Region into Groundwater Management Zones to produce a practical environmental management framework.
xiv. The leaky aquifer conceptual model enables accounting for effects of activities at different depths and hydraulically linked surface water bodies.
xv. Division of the Region into Groundwater Management Zones facilitates calculation of hydrological budgets and accounting for cumulative effects of abstraction.
xvi. Groundwater-surface water interaction is an important aspect in many parts of the Region.
xvii. Alignment of the Groundwater Management Zone boundaries with [surface] Water Management Zones allows effective integrated environmental management.

Groundwater Management Zones

240. Synthesis of geological and hydrological information presented in this evidence, and referenced reports, show that continuing, traceable confining beds (aquitards) that separate distinct confined aquifers, as suggested in some earlier studies, do not exist in the Region. Hence, the system is conceptualised as schematically presented in Figure 50. However, geological and hydrogeological information strongly imply lateral boundaries that separate the system into a number of flow regimes. The axial ranges represent the main divide that separates the eastern terrains from the western land, which is in turn traversed by smaller NE-SW oriented geological structures that subdivide this area into smaller groundwater basins. These basins can have their distinctive water balances and, hence, are considered to be suitable management units. This is the basis for dividing the Region into Groundwater Management Zones (GMZs) as presented in Figure 51.

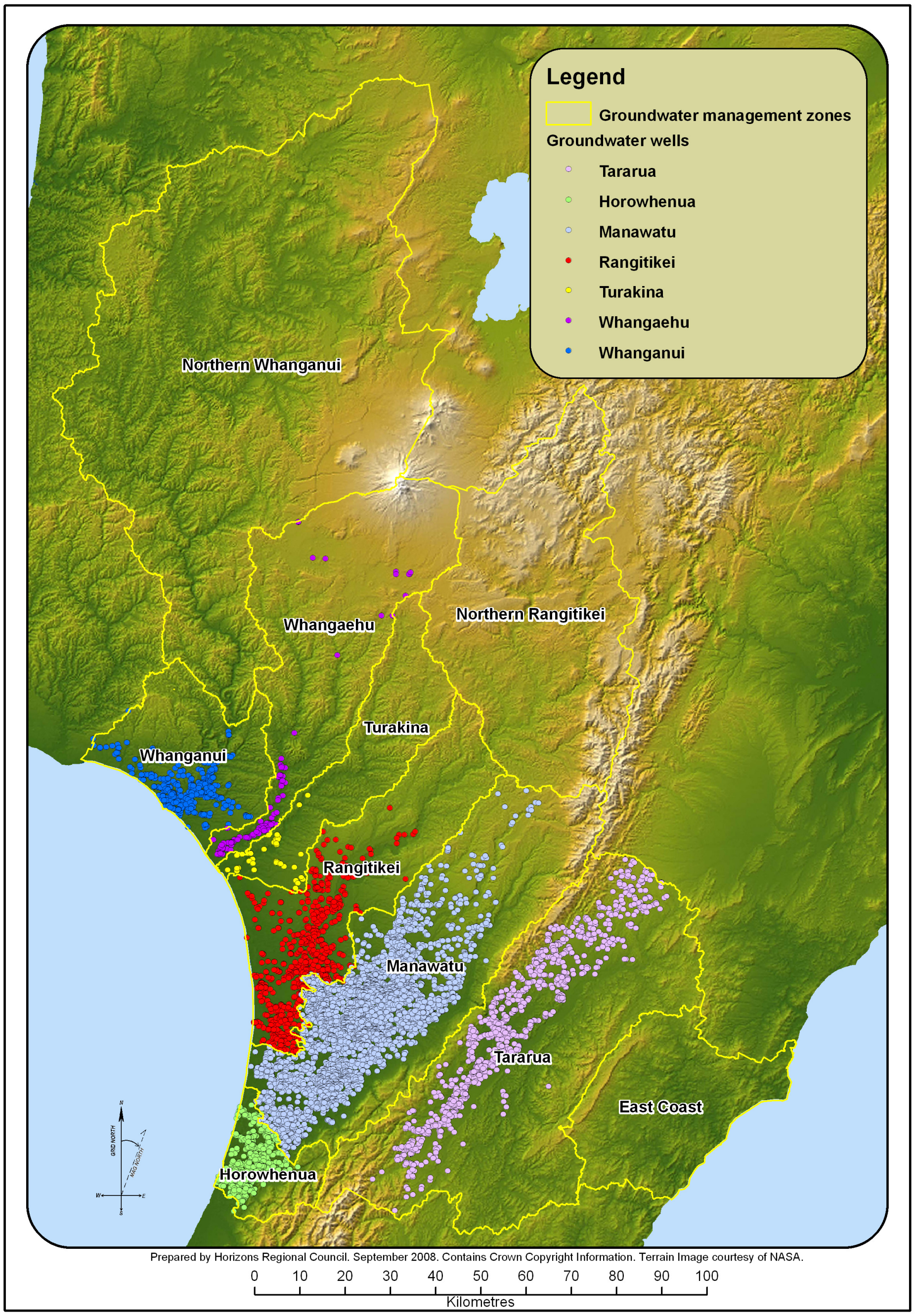

Figure 51. Groundwater Management Zones in Horizons' Region and registered[58] wells as at June 2008 (Modified after Zarour, 2008a).

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[58] Registered wells, ie. listed in Horizons' database.

Proposed changes to the original framework in the Proposed One Plan and Zarour (2008)

241. As a result of recent discussions with Dr Jon Roygard, Manager Science, Horizons, I agreed to adopt the following changes to the original framework which I proposed in Zarour (2008a):

   i. Changing the name of the originally named “Eastern Groundwater Management Zone” into the “Tararua Groundwater Management Zone” to express its relevancy to the District which it covers (ie. Tararua).
   ii. Changing the name of the originally named “Wanganui Groundwater Management Zone” into the “Whanganui Groundwater Management Zone” (ie. with an h), to make the zone’s name consistent with the names of the Whanganui River and the [surface] water catchment.
   iii. Addition of three new units, namely:
      a. The East Coast Groundwater Management Zone.
      b. The North Whanganui Groundwater Management Zone.
      c. The North Rangitikei Groundwater Management Zone.

242. The final proposed Groundwater Management Zones Framework is shown in Figure 51. The addition of the above listed three new Groundwater Management Zones is deemed necessary for completeness purposes and for better compatibility with the [surface] Water Management Zones. There are no consented groundwater abstractions in these new zones and only very few wells. No allocation limits are established for these zones, because they are not known to have a potential for exploitable groundwater resource. Establishing allocation limits there is impractical and is not necessary.

243. In addition, Dr Roygard and I agreed to seek changing the allocation limits originally presented in Schedule C in the Proposed One Plan into the limits presented in Table 5 in this evidence. This is not a change in approach, but rather a correction of an error in the numbers originally presented in the POP that resulted from erroneous GIS[59] calculations. From the beginning, allocation limits were intended to be set at 5% of average annual rainfall for the reasons provided in the following section, but a random error in the original GIS calculations produced different numbers. The mistake has been discovered during my work on Zarour (2008a) and the calculations have been redone as part of that work. The new numbers have been double checked internally at Horizons and independently by Mr Callander in 2008. As can be seen in the section of this evidence on use and demand (page 258), this change will not alter the overall picture.

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[59] GIS: Geographic Information System.

Table 5. Area and mean annual precipitation for different groundwater management zones in Horizons' Region (Source: Zarour, 2008a). The table does not include zones where there is no significant groundwater resource potential; namely, the North Whanganui, the North Rangitikei and the East Coast Groundwater Management Zones.

GMZ	Area[60] (km²)	Average Rainfall[61] (mm/y)	Total rainfall[62] over zone ($x10^6$ m³/y)	Allocation calculated as 5% of total rainfall over zone ($x10^6$ m³/y)
Whanganui	938	983	922	46
Whangaehu	1,982	1,236	2,449	122
Turakina	959	1,041	998	50
Rangitikei	1,564	956	1,496	75
Manawatu	2,683	1,236	3,317	166
Horowhenua	388	1,369	531	27
Tararua	3,163	1,509	4,771	239
Total/average	**11,677**	**1,240**	**14,484**	**724**

Groundwater allocation limits

244. As illustrated above, maintaining constant groundwater levels requires that total discharge and total recharge be equal. Abstraction from wells is included in the total discharge term of the hydrogeological balance equation. However, abstraction must not adversely affect other natural output components in the hydrogeological balance equation, like seepage into the sea and surface water features. For most renewable groundwater resources, abstraction must not exceed 50% of recharge.

245. The regional groundwater resource receives replenishment from precipitation and flowing surface water systems, which at times and in places can also constitute groundwater discharge zones. As discussed in Zarour (2008a), accounting for recharge from surface water features is possible, but difficult. Assessment of recharge from precipitation is possible through the determination of the areal extent of the recharge area and the recharge rate. The recharge volume is the product of these two values.

246. A number of investigations have looked at groundwater recharge in the Region. I summarised these and commented on them in Section 4.5 (p 75) in Zarour (2008a). Investigators who looked at groundwater recharge in the Region reported values in the

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[60] Measured from the Groundwater Management Zones map (Figure 51, p 114).

[61] Calculated by dividing the total mean annual rainfall over the Groundwater Management Zone (column 3) over the area of the respective Groundwater Management Zone (column 1).

[62] Weighted average interpolated from the regional rainfall isohyetal map (Figure 52, p 118)

range of 100-400 mm/year. Nevertheless, I do not believe that there is reliable knowledge of recharge mechanisms, rates and locations.

247. In the absence of reliable estimates of recharge, groundwater allocation limits can be established as a proportion of rainfall, as suggested in a Ministry for the Environment report (Lowry *et al*., 2001). The report indicates that a conservative allocation of sustainable groundwater abstraction could be 20% of annual rainfall. Figure 52 shows the long-term average rainfall over the Region.

248. To compensate for the lack of recharge estimates suitable for water balance analysis on the regional scale, or on the scale of regional Groundwater Management Zones, I compared abstraction from wells (Table 6, page 123) with long-term rainfall average values (Table 5, p 116) in Zarour (2008a). I found out that current groundwater abstraction represents only a small fraction of the precipitation that falls over the Region and its various Groundwater Management Zones (Table 7, p 133). Hence, I recommended to the One Plan Team that they set groundwater annual allocation limits at 5% of average annual rainfall. This is one-fourth of the limit recommended by the Ministry for the Environment (Lowry *et al*., 2001), but still not unduly restrictive. As can be seen in Table 7 (p 133), abstraction across the Region and its various Groundwater Management Zones represents a tiny fraction of rainfall, and does not come near 5% of annual rainfall.

249. As mentioned in Mr Callander's evidence, the Proposed National Environmental Standard (NES) on Ecological Flows and Water Levels (Ministry for the Environment, 2008) sets a three-level system to assess the potential degree of hydrological alteration that may result from groundwater allocation, as follows:

- Low: up to 10% of recharge.
- Medium: 11-25% of recharge.
- High: over 25% of recharge.

250. As noted in Mr Callander's evidence (Paragraph 5.12), the allocation limit of 5% of average annual rainfall is estimated to be around 10-15% of average annual recharge, placing it in the low-medium classification of the proposed National Environmental Standard (NES). The supporting document for the NES suggests that its guidelines are conservative, and I agree.

Key messages – Groundwater allocation limits

i. Groundwater allocation depends on recharge and must allow for sustaining environmentally important flows.

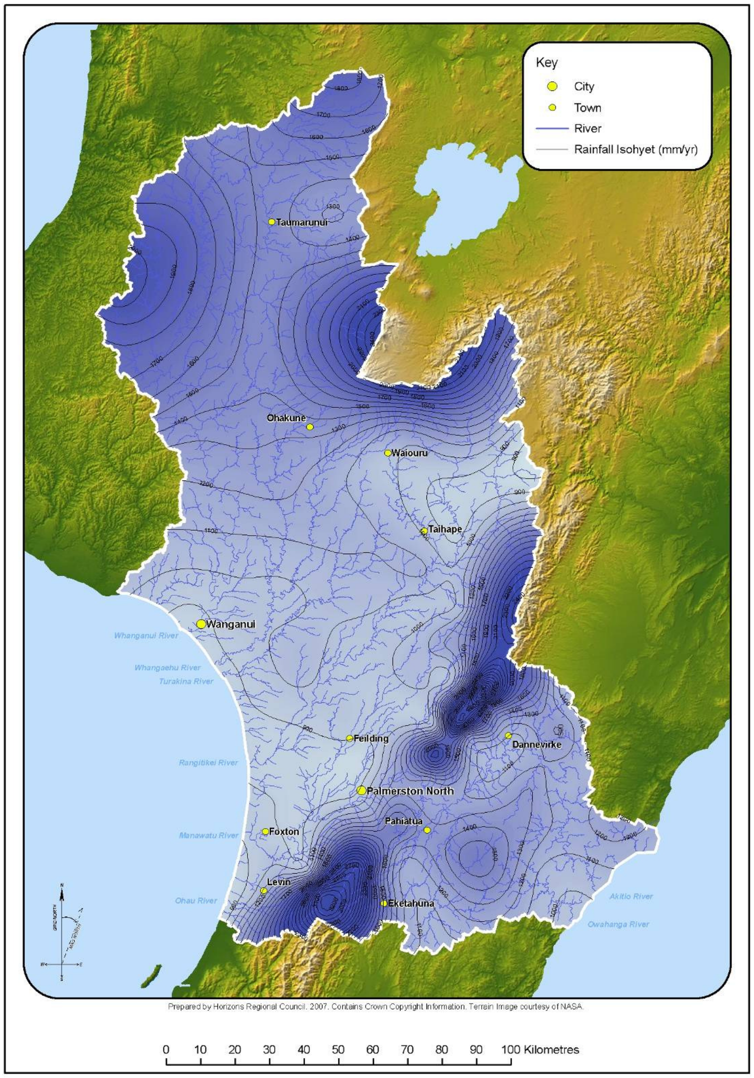
ii. The Region's groundwater resource is recharged from rain and/or surface water bodies.

iii. Reliable recharge estimates are lacking.

iv. Groundwater allocation limits can be determined as percentages of rainfall.

v. Setting allocation limits at 5% of recharge in the Region is feasible, conservative, and not unduly restrictive.

vi. 5% of annual average rainfall is approximately the equivalent of 10-15% of average annual recharge.



Prepared by Horizons Regional Council, 2007. Contains Crown Copyright Information. Terrain Image courtesy of NASA.

Figure 52. Isohyetal map showing average annual rainfall over Horizons' Region (Source: Zarour, 2008a).

Main feature of the Regional groundwater management zones

251. The North Whanganui, North Rangitikei and East Coast Groundwater Management Zones cover areas with nearly no groundwater resource potential. They mainly comprise basement rock terrains and have only very few wells. There are no consented groundwater takes in these parts of the Region. These zones have been defined merely for administrative purposes and no groundwater allocation limits are specified in them.

252. The other seven Groundwater Management Zones where there is useful groundwater yield potential are described in Zarour (2008a), and concisely in the following paragraphs:

i. Whanganui Groundwater Management Zone:
    a. Occurs at the northwestern edge of the large Tertiary South Wanganui [depositional] Basin (SWB).
    b. Late Quaternary alluvial deposits are relatively thin (< 30 m deep).
    c. Groundwater from Tertiary limestone and shell-bed sequences (the Nukumaru Group) provides for municipal needs. The Nukumaru aquifer outcrops 5.5 km north of Wanganui City and dips in a southerly direction so that it occurs at a depth of 600-700 m below the City where it becomes confined beneath thick overlying low permeability marine strata. The water from the limestone and shell beds is very hard in the unconfined part of the aquifer.

ii. Whangaehu and Turakina Groundwater Management Zones:
    a. Valleys are narrow, shallow and v-shaped. Thickness of Late Quaternary valley fill is limited.
    b. Low density of wells with mostly low yields due to tapping relatively impermeable deposits.
    c. The two zones are separated from each other by an elevated zone of older permeability, non-aquiferous strata.

iii. Rangitikei Groundwater Management Zone:
    a. Bounded by the Marton Anticline in the north and by the Feilding, Mount Stewart-Halcombe and Himatangi Anticlines in the south.
    b. Late Quaternary deposits occur with increasing thickness and increasing permeability (due to better sorting) down the valley.
    c. Groundwater in the Rangitikei “delta” occurs under unconfined to semi-confined (ie. leaky) conditions to a depth of up to 80-100 m. Yield from wells tapping this aquifer system is normally high.

   d. Older strata are less permeable and their groundwater tends to be hard and can have elevated iron and manganese concentrations
   e. Regionally significant wetlands, which are likely to be sustained by groundwater, occur in the coastal section of this zone.

iv. Manawatu Groundwater Management Zone:
   a. Extends in a northeast-southeast direction between the Feilding, Mount Stewart-Halcombe and Himatangi Anticlines to the northwest and the Ruahine and Tararua Ranges to the southeast.
   b. Traversed by three river systems namely, the Manawatu, the Oroua, and the Pohangina rivers. The Oroua and Pohangina rivers join the Manawatu River, which flows to the Tasman Sea.
   c. Contains the greatest number of wells and largest number of consented abstractions within the Region.
   d. Wells are relatively very productive due to the occurrence of a thick, permeable sequence of Late Quaternary strata, which extends inland for a considerable distance, eg. at the Whakarongo area in the Lower Manawatu Valley.
   e. Regionally significant wetlands, which are likely to be sustained by groundwater, occur in the coastal section of this zone.

v. Horowhenua Groundwater Management Zone:
   a. The southern most and smallest Groundwater Management Zone in the Region, with only 10 km distance between the Tararua Ranges to the east and the Tasman Sea to the west.
   b. Very permeable Late Quaternary deposits butting against the western foot of the Tararua Range enable infiltration of rainfall and losses from surface water features (eg. the Ohau River) to recharge groundwater.
   c. The Poroutawhao basement high limits the western extent of gravel strata, and creates upward groundwater flow into Lake Horowhenua.
   d. The strata are predominantly sandy in the western section of this Groundwater Management Zone.
   e. At the margins of this zone, the relatively less permeable Otaki sandy strata show poorer groundwater quality. Wells tapping this material are considerably less productive than those tapping the younger and the older, more gravely, strata.

vi. Tararua Groundwater Management Zone:
   a. Occurs on the eastern side of the Ruahine and Tararua Ranges.
   b. Productive aquifers limited to Late Quaternary deposits filling valleys and covering floodplains with depths not exceeding 30-40 m. These deposits are

underlain by low permeability Tertiary marine deposits and basement greywacke.

Groundwater use and wells[63] in the Region

252. Groundwater is an important environmental and socio-economic resource in the Region. In some areas it represents the only available reliable resource of good quality water for some or all purposes. For example, Wanganui (c. 40,000 population) totally depends on groundwater for its municipal supplies (Zarour, 2008a). Overall, groundwater has been providing for about half of the Region's consumptive demand. With a large proportion of the Region's surface water resource becoming fully allocated and/or subject to challenging restrictions during low flow periods, groundwater reserves are likely to be more in demand in the future.

253. Almost all of the groundwater that is currently used in the Region comes from drilled wells. Due to the geology of the groundwater resource in the Region, distinct springs do not exist. Most of the natural groundwater discharge to the ground surface and surface water bodies occurs in the form of seeps rather than as classic springs. Exploitation of groundwater from seeps is difficult, because water does not emerge at the surface from a distinct point or with a perceptible current. Downstream of the spring (or seep) head, the running water is considered a groundwater-dependent surface water body rather than groundwater. There, surface water values, policies and rules apply to the flowing water.

254. There are an estimated 9,500 groundwater wells in the Region (Figure 51, p 114, and Table 6, p 123). They generally are shallow, and the most productive tap Late Quaternary[64] deposits. Nearly 90% of the wells are less than 100 m deep and only 3% exceed 150 m (Figure 53, p 125).

255. I explain in Zarour (2008a) that over the last few years almost of the deep drilled wells that went beyond the Late Quaternary aquifer system into the Pleistocene or Tertiary sediments had to be backfilled and be completed above this low permeability material. I note there that occasionally wells in the Horowhenua District strike greywacke basement rock at shallow depths (ie. less than 20-80 m) at a considerable distance from the axial greywacke ranges. The Horowhenua District Council drilled a 280 m deep exploration well into older Pleistocene strata near Levin which encounter poor quality water below c.

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[63] The terms well, bore and borehole are used synonymously and interchangeably in Zarour (2008a) and in this evidence.
[64] The period between c. 125,000 ago and the present day.

100 m. I also note in Zarour (2008a) that a number of wells in the Tararua Groundwater Management Zone, where the Late Quaternary sediments are particularly thin, encountered thick marine low permeability strata after only a few metres of drilling. Hence, I conclude that yield and/or quality considerations are the reasons behind the remarkably shallow depth of water wells in the Region, with most less than 100 m deep.

Table 6. Basic water well and groundwater use statistics and estimates across various Groundwater Management Zones in Horizons' Region[65] (Modified after Zarour, 2008a).

GMZ[66]	Wells[67]			Consented takes[68]			Permitted takes[69]		Estimated Total Abstraction (m^3/y)[70]
	Registered[71]	Estimated Percentage of Unregistered Wells[72]	Estimated Total[73]	Number of Permits[74]	Total Maximum Limit (m^3/d)[75]	Estimated Consented Takes (m^3/y)[76]	Estimated Number[77]	Estimated Total Volume (m^3/y)[78]	
Whanganui	395	10	434	33	59,107	4,728,560	401	2,195,475	6,924,035
Whangaehu	114	10	125	8	4,535	362,800	117	640,575	1,003,375
Turakina	43	10	47	4	2,510	200,800	43	235,425	436,225
Rangitikei	895	20	1,074	62	166,835	13,346,800	1,012	5,540,700	18,887,500
Manawatu	4,350	25	5,437	172	302,416	24,193,298	5,265	28,825,875	53,019,173
Horowhenua	846	25	1,057	55	18,027	1,442,160	1,002	5,485,950	6,928,110
Tararua	1,068	20	1,281	10	19,362	1,548,960	1,271	6,958,725	8,507,685
North Whanganui	Negligible	NA[79]	Negligible	0	0	0	Negligible	Negligible	Negligible
North Rangitikei	Negligible	NA	Negligible	0	0	0	Negligible	Negligible	Negligible
East Coast	Negligible	NA	Negligible	0	0	0	Negligible	Negligible	Negligible
Total	**7,711**	**—**	**9,455**	**344**	**572,792**	**45,823,378**	**9,111**	**49,882,725**	**95,706,103**

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[65] This table does not incorporate riparian wells and takes. Riparian takes are takes from wells that are in direct and strong hydraulic connection with any surface water feature, eg. streams, wetlands, etc.

[66] GMZ: Groundwater Management Zone as defined in Figure 51.

[67] The terms well, bore and borehole are used synonymously in Zarour (2008a) and in this evidence.

[68] These are takes consented by Horizons to abstract more than 50 m³ of groundwater per day.

[69] These are wells that are allowed to abstract up to 50 m³/d of groundwater without a consent under Horizons' Permitted Activity rule.

[70] This is the sum of the estimated *permitted* takes and the estimated *consented* takes.

[71] Registered, ie. listed in Horizons Regional Council's groundwater database.

[72] Estimated percentage of unregistered wells is devised to account for the perceived net number of wells that Horizons does not hold records for. This is estimated on the basis of general knowledge of the area, land use and socio-economic activities, and the hydrogeological potential of the resource. It also accounts implicitly for abandoned and decommissioned wells.

[73] This is the sum of registered and estimated unregistered wells.

[74] As in the Horizons' consents database (R2D2) in May 2008.

[75] This is the sum of the maximum consented daily takes, representing gross short-term (daily) worst case scenario for demand for groundwater.

[76] This is the estimated actual average yearly abstraction from consented wells. Estimations are made assuming wells are pumped 100 days per year at 80 percent of their maximum consented daily take volume. These are estimated averages that do not account for differences between uses, eg. irrigation, municipal, etc.

[77] Estimated number of permitted takes is calculated as the difference between the estimated total number of wells and the number of consented wells.

[78] Estimated total take from permitted wells is conservatively estimated assuming an average daily take of 15 m³ per day per unconsented well throughout the year.

[79] NA: Not applicable

256. I note in Zarour (2008a) that yield from bores in the Region is clearly not related to depth. I also note that some wells have artesian heads (ie. groundwater level in such wells is above the top of the well, allowing free flow). Artesian wells are normally located in discharge zones. There is no obvious relationship between depth of wells and their artesian character. There is also no correlation between artesian head and well yield potential. I also note there that there seems to be a general increasing trend in the number of wells drilled in the Region every year (Figure 54) and in the total and average drilled depth (Figure 55).

257. In addition to their value as the main means of accessing and exploiting underground water resources, wells provide a direct window to study the subsurface environment.

Key messages – Groundwater use and wells in the Region

i. Groundwater is an important environmental and socio-economic resource in the Region.
ii. In some areas, groundwater is the only available reliable resource of good quality water.
iii. Groundwater provides for nearly half of the Region's consumptive water demand.
iv. Demand for groundwater is expected to continue to increase.
v. Distinct springs do not exist in the Region.
vi. Almost all of the groundwater used in the Region comes from drilled wells.
vii. There are an estimated 9,500 wells in the Region.
viii. Wells in the Region generally are shallower than 100 m.
ix. Low yield and poor water quality restrict the potential for deep wells across most of the Region.
x. There is no obvious relationship between depth of wells and their artesian characteristics and yield.
xi. There is a general increasing trend in the number of wells drilled in the Region every year and in their depths.
xii. Wells provide a direct window to study the subsurface environment.

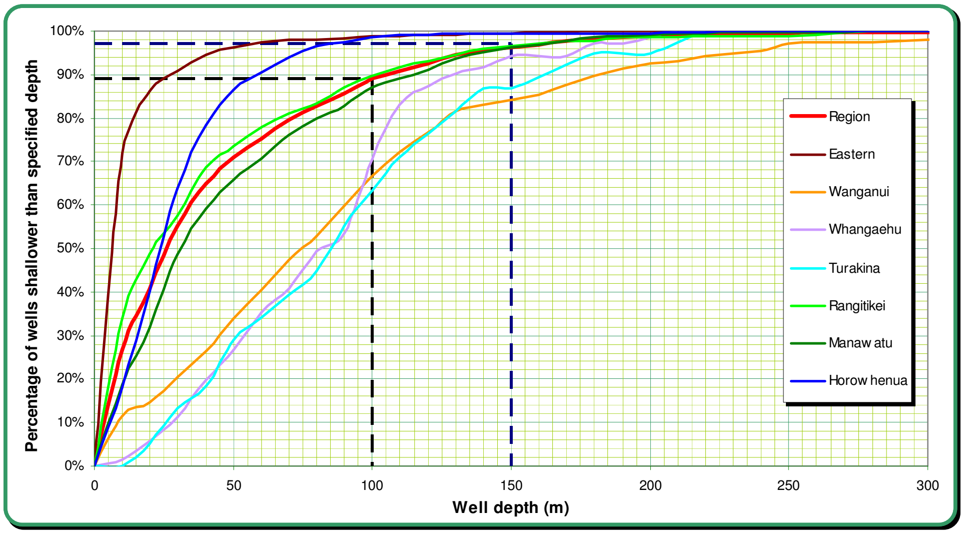

Figure 53. Well depth ranges in the Region and in various Groundwater Management Zones within it. The dotted straight lines intercept the regional curve at 100 m and 150 m depths to indicate that about 90% of all wells are less than 100 m deep while 97% are less than 150 m deep (Source: Zarour, 2008a).

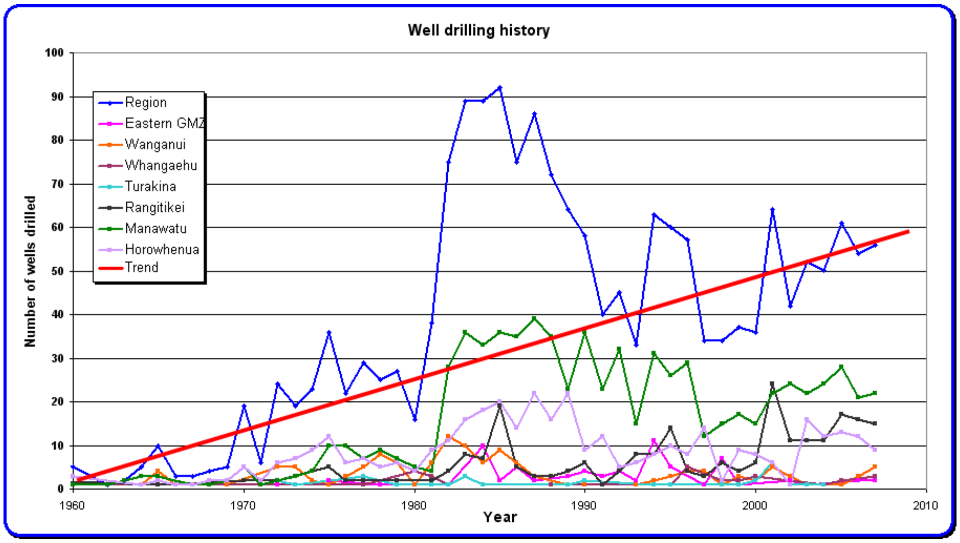

Figure 54. History of groundwater well drilling in Horizosn' Region and various Groundwater Management Zones within it for the period 1960-2007. The red straight line represents the regional trend (Source: Zarour, 2008a).

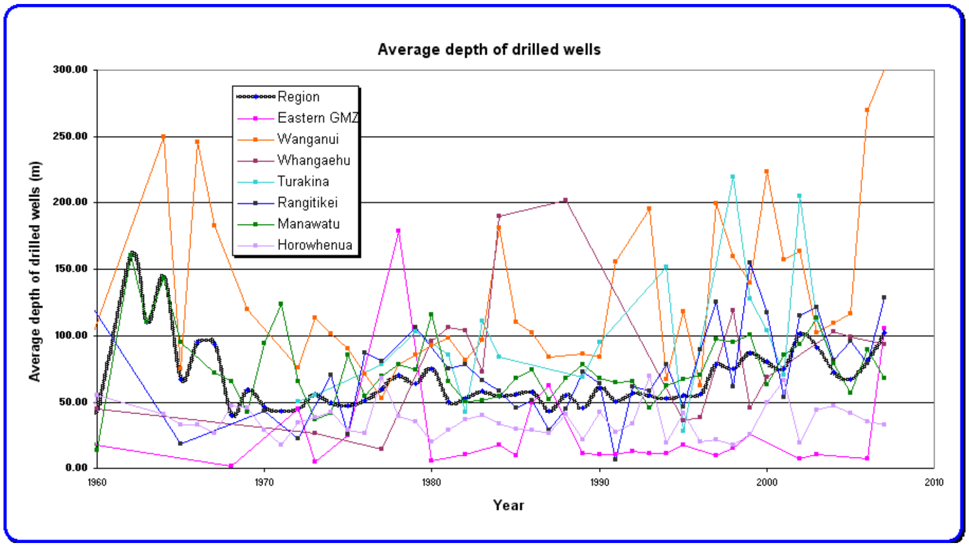

Figure 55. Average drilled well depth history in Horizons' Region and Various Groundwater Management Zones within it. Some wells are screened at depths shallower than their drilled depths and, hence, the drilled depth and the well depth (level of the bottom of the deepest screen) should not be confused (Source: Zarour, 2008a).

Groundwater use and demand

258. Studies of groundwater use and demand in the Region were lacking. Therefore, I analysed well and groundwater abstraction consent information to provide reasonable estimates of use and demand (Chapter 6 of Zarour, 2008a).

259. Basic statistics and estimates relating to groundwater demand and use are summarised in Table 6. In 2008, the estimated 9,500 wells in the Region collectively extracted an estimated 96 million cubic metres (mcm[80]) of water. Daily groundwater abstraction varies between seasons with demand peaking in summer and shrinking in winter. Available information does not enable reliable estimation of daily or seasonal abstraction volumes.

260. Through the period 1992-2007, ie. since the RMA came into force in 1991, the number of groundwater abstraction permits granted by Horizons fluctuated between 10 and 40 permits per year (Figure 56). The graph suggests a generally constant trend after 1995. I believe that the two "bounces" shown around 2001 and 2005 may be due to the renewal of expired consents which were initially granted for terms of 10 and 15 years

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[80] Also denoted as $x10^6$ m^3 in some sections in Zarour (2008a).

following the introduction of the RMA. However, this can only be verified, or otherwise, over time.

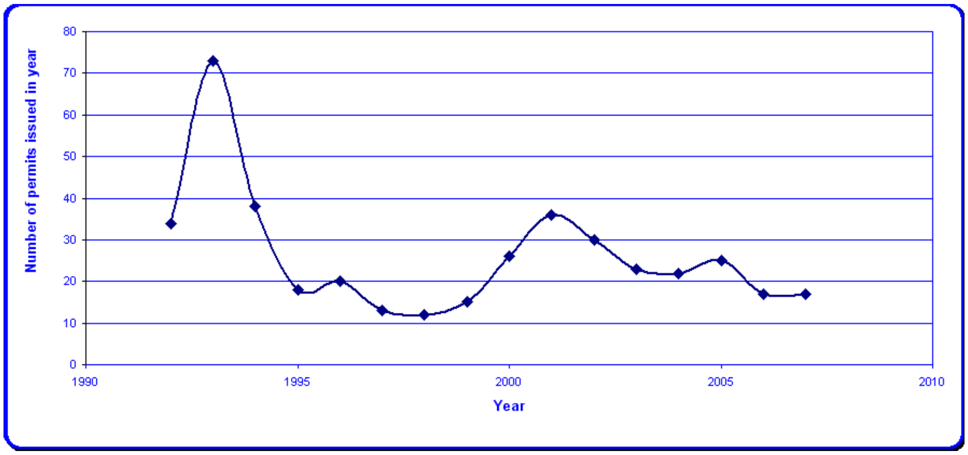

Figure 56. Number of groundwater and riparian abstraction consents issued between 1992 and 2007 by Horizons Regional Council (Source: Zarour, 2008a).

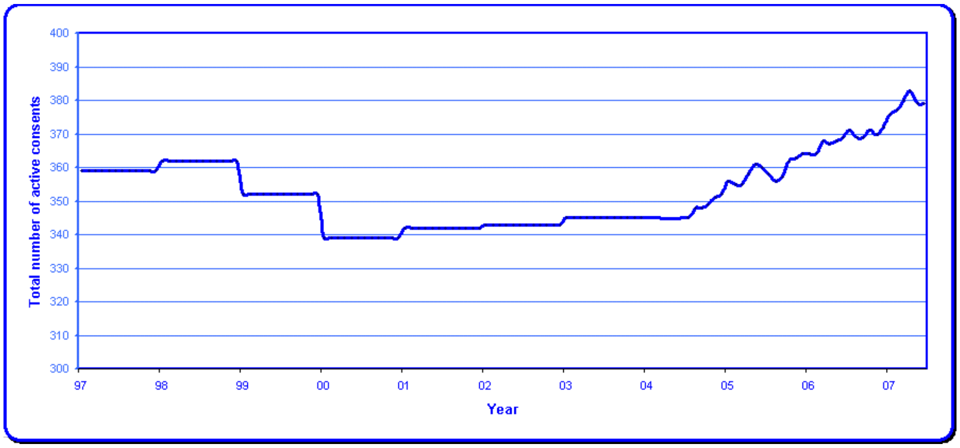

Figure 57. Number of active groundwater and riparian abstraction consents (permits) in Horizons' Region during the period 1997-2007 (Source: Zarour, 2008a).

261. Since the RMA came into force in 1991, the number of active groundwater and riparian consents in the Region grew as a result of accumulation of ongoing consents, renewals and new consents (Figure 57). In 2008, there were 379 active consents to take water from wells across the Region, allowing abstractions that range from as little as 18 m^3/d to as much as 13,680 m^3/d (Figure 58). Of this total number, 35 wells are considered riparian, ie. hydraulically connected to surface water systems, while the remaining 344 wells are considered as *'pure'* groundwater takes.

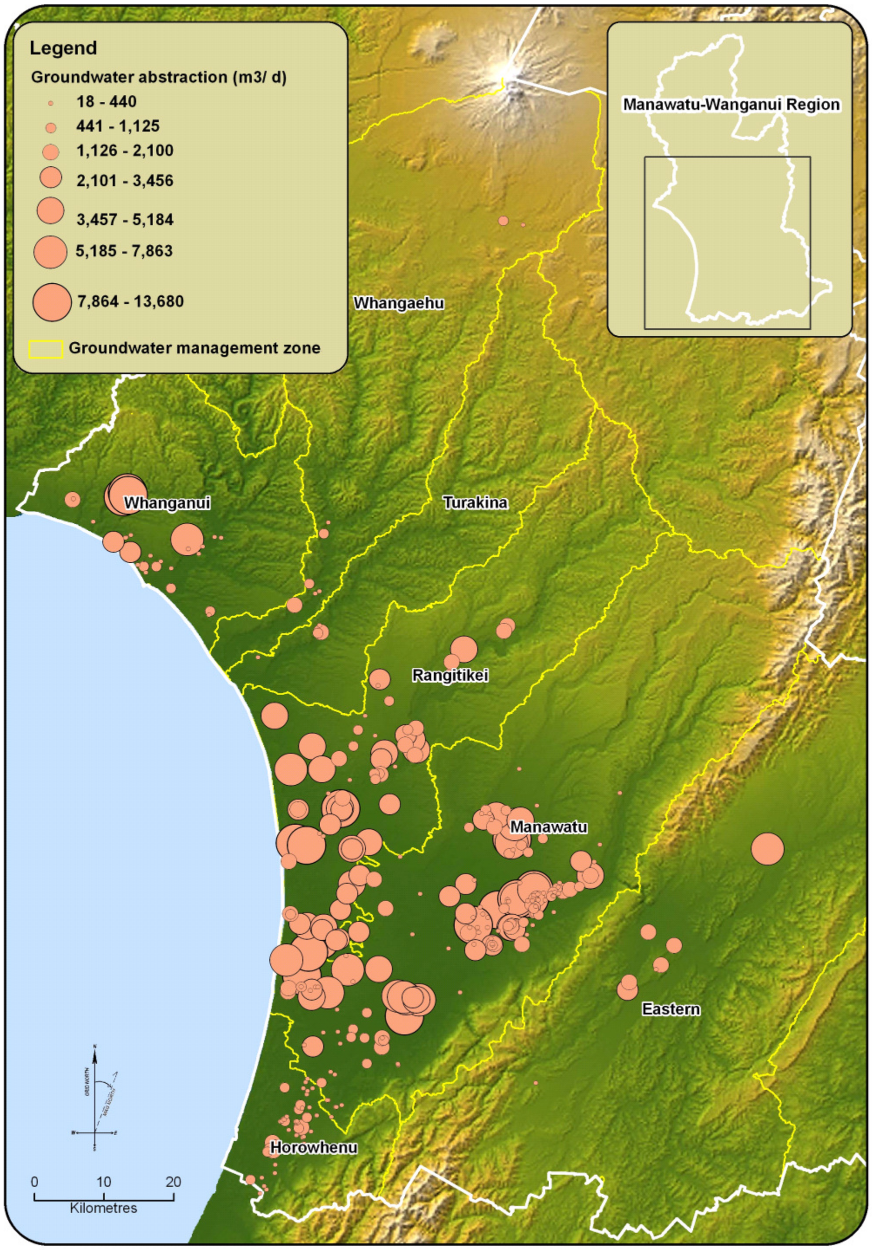

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Figure 58. Current groundwater and riparian abstraction consents in Horizons' Region as at June 2008. The orange circles indicate locations of consented bores, and the size of the circle is proportional to the maximum consented daily groundwater abstraction, with the smallest being 18 m³/d and the largest reaching 13,680 m³/d. Groundwater Management Zone boundaries are marked on the map as yellow lines and the outer white line marks the Region's boundary (Source: Zarour, 2008a).

262. I note in Zarour (2008a) that the distribution of groundwater abstraction consents in the Region is biased towards areas with thick Late Quaternary deposits, where the groundwater resource yield potential is the greatest. Attention is drawn here to the fact that while some of the groundwater consents in the Region appear to be enormous in terms of the allowed maximum daily abstraction volume, the actual takes associated with them in fact may be small or perhaps even nonexistent. This is often the case with the large municipal supply consents in the Manawatu District, eg. for the city of Palmerston North and the township of Feilding where groundwater forms a backup supply.

263. Figure 59 shows the total maximum daily abstraction limit allowed to be taken by active resource consents in the Region during the period 1997-2007. This is different from actual abstraction and represents the short-term (diurnal) worst case scenario for consented groundwater abstraction in the Region. The rising trend is obvious over the years, becoming more prominent after 2001. I expect this trend to continue for the next decade or so.

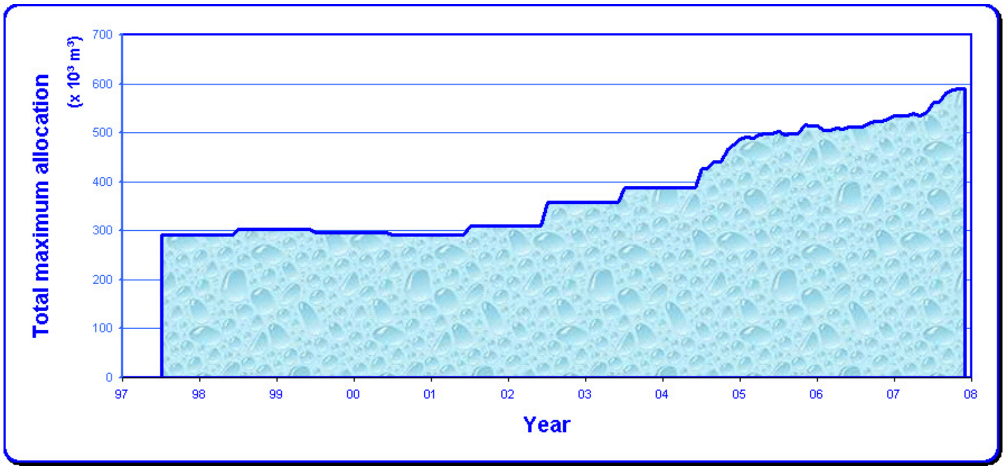

Figure 59. Demand for groundwater[81] as expressed in total maximum daily abstraction limit in active resource consents in Horizons' Region during the period 1997-2007. This is different to actual abstraction, and represents the short-term (diurnal) worst case scenario for abstraction of water from consented wells in the Region. The rising trend is obvious over the years, becoming more prominent after 2001 (Source: Zarour, 2008a).

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[81] Including riparian takes.

264. Demand for groundwater as expressed in terms of consent allocation is different from the actual abstraction. Historically, groundwater abstraction consents in the Region only specified a maximum daily limit in cubic metres per day (m^3/d), and occasionally also a pumping rate in litres per second (L/s) and/or cubic metres per hour (m^3/h). Recently, a maximum annual limit in cubic metres per year (m^3/y) has been included in groundwater abstraction resource consent conditions. This will enable more efficient allocation and management of the resource. Since about 2006, all new groundwater abstraction resource consents have been granted with an annual limit condition (Table 8, p 147). In addition, all new groundwater abstraction consents have abstraction metering conditions, with telemetry required for the larger ones or those located in sensitive areas, eg. wells in the coastal zone or wells near significant groundwater-dependent ecosystems. Horizons aims to have telemetry systems installed and operating on all bores consented to take up to 4,000 m^3/d and above.

265. Groundwater use in the Region has increased by about 30% over approximately the last decade (Figure 60). These estimates are made using the assumptions outlined in the footnotes for Table 6 (p 123), ie. assuming that on average all consented wells operate 100 days per year at 80% of their maximum consented daily take volume, and that permitted abstraction averages to 15 m^3/d/well all year round. Variations between various uses are not accounted for in these assumptions, which are thought to represent general long-term average conditions. Actual metering will enable more accurate, reliable assessments in the future.

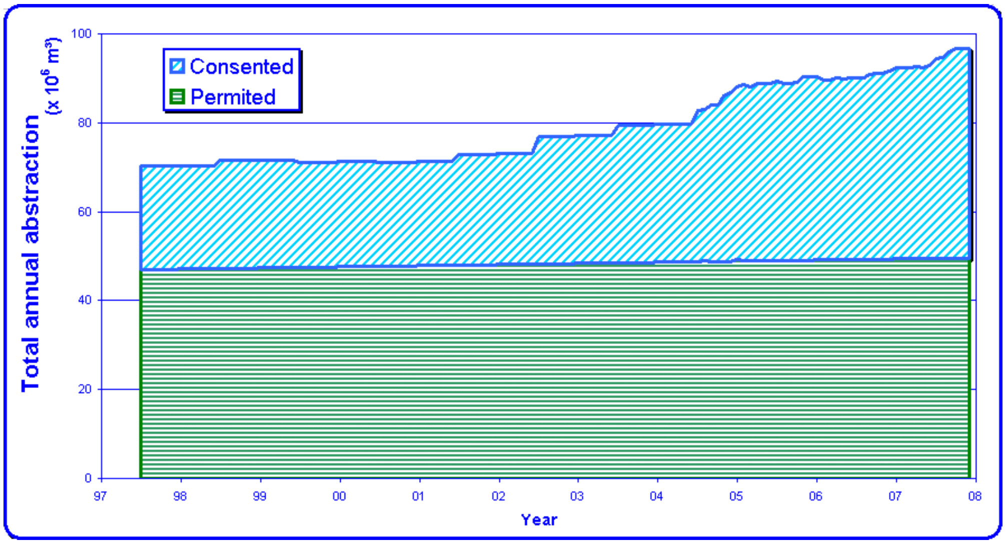

Figure 60. Estimates of total abstraction from water wells[81] in Horizons' Region between 1997 and 2008. Estimates of total abstraction are composed of the estimated total permitted abstraction and the estimated total consented take across the Region according to the assumptions outlined in the footnotes for Table 6, p 123 (Source: Zarour, 2008a).

266. For the year 2008, consented groundwater abstraction is estimated at about 46 mcm while the permitted takes are estimated to total about 50 mcm. Hence, total groundwater abstraction in the Region in 2008 is estimated at about 96 mcm. Over the foreseeable future, both demand for and use of the groundwater resource are expected to continue to increase at rates similar to those observed since the turn of the current century.

Key messages – Groundwater use and demand

i. Reasonable estimates of groundwater use and demand can be obtained from the analysis of well and groundwater abstraction consent information.
ii. Consented groundwater abstraction for 2008 is estimated at about 46 mcm and permitted abstraction is estimated at about 50 mcm, ie. total is about 96 mcm.
iii. Horizons issued 10-40 groundwater abstraction permits per year over the period 1992-2007.
iv. The number of consents granted per year has been almost constant since 1995 at c. 20 permits a year.
v. Since 1991, the number of active groundwater consents grew to reach about 345 in 2008.
vi. Groundwater use in the Region has increased by about 30% over the last decade.
vii. Demand for and use of the groundwater resource are expected to continue to increase at rates similar to those observed over the last decade.
viii. The distribution of groundwater abstraction consents is biased towards areas with thick Late Quaternary deposits.
ix. Seasonal groundwater use and demand cannot be calculated from existing information.
x. Horizons aims at having telemetry systems operating on all bores consented to take up to 4,000 m^3/d and above.

Groundwater demand-supply balance

267. Available information suggests that the groundwater resource in the Region has coped well with the noted increase in demand for groundwater over the past few decades. There is no indicator of deteriorating groundwater quality anywhere throughout the Region and groundwater levels are generally stable. These two observations indicate that exploitation of the resource has been occurring within its general long-term sustainable limits, ie. average long-term abstraction has been less than average long-term groundwater recharge.

268. Comparing estimated recent groundwater abstraction to estimated total precipitation over various Groundwater Management Zones provides a positive picture for the Region's hydrogeological budget (Table 7 and Figure 61). The analysis suggests that meeting today's groundwater demand requires only a few millimetres of recharge across the various Groundwater Management Zones. Groundwater recharge over all Groundwater Management Zones is expected to be much greater than what is required

to provide for current demand and the demand over the foreseeable future, assuming the current rates of increase continue.

Table 7. Estimated total groundwater abstraction in context of overall rainfall in various groundwater management zones in Horizons' Region (Modified after Zarour, 2008a).

GMZ	Estimated Total Abstraction (x10^6 m^3/y)[82]	Total rainfall over zone (x10^6 m^3/y)[83]	Groundwater abstraction as percentage of rainfall[84]	Required recharge equivalent (mm/y)[85]
Whanganui	6.924	922	0.75%	7.38
Whangaehu	1.003	2,449	0.04%	0.51
Turakina	0.436	998	0.04%	0.46
Rangitikei	18.888	1,496	1.26%	12.07
Manawatu	53.019	3,317	1.60%	19.76
Horowhenua	6.928	531	1.31%	17.87
Tararua	8.508	4,771	0.18%	2.69
North Whanganui	Insignificant	US[86]	US	US
North Rangitikei	Insignificant	US	US	US
East Coast	Insignificant	US	US	US
Total/average	**95.706**	**14,484**	**0.66%**	**8.20**

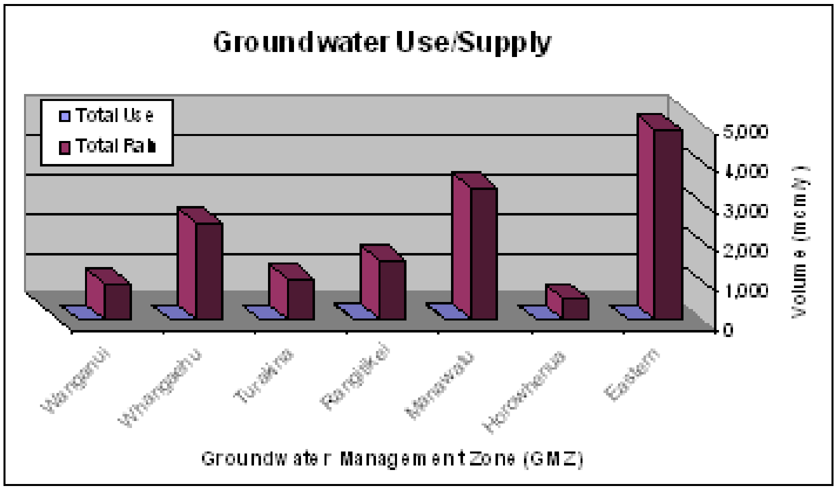

Figure 61. Estimated total groundwater abstraction (permitted and consented) versus total rainfall in various groundwater management zones in Horizons' Region in 2008 (Data from Zarour, 2008a).

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[82] From Table 6, p 123.

[83] From Table 5, p 116.

[84] Calculated from dividing the estimated total abstraction from wells in the Groundwater Management Zone over the total area of the respective zone.

[85] The required recharge equivalent is defined as the annual recharge rate over the Groundwater Management Zone needed to meet current groundwater demand in that zone.

[86] US: unspecified.

269. Comparing estimated recent groundwater abstraction to proposed groundwater allocation limits (5% of rainfall) over various Groundwater Management Zones asserts the positive hydrogeological balance in the Region and its Groundwater Management Zones (Figure 62).

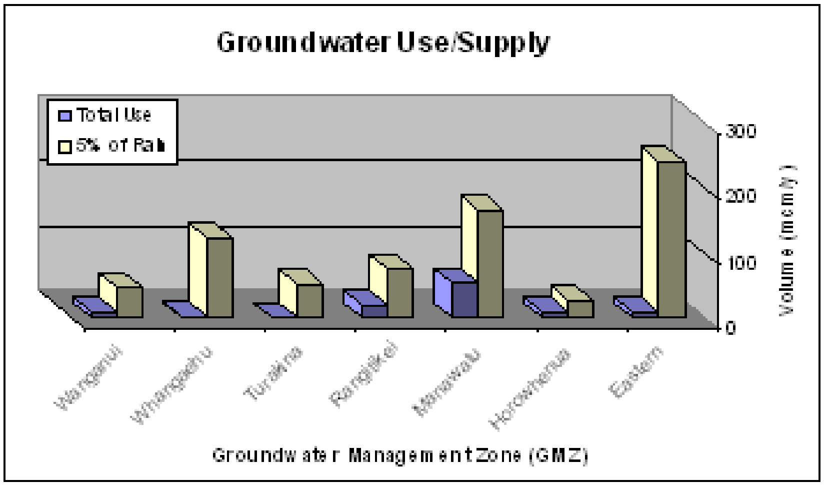

Figure 62. Estimated total groundwater abstraction (permitted and consented) versus allocable volume (5% of rainfall) in various Groundwater Management Zones in Horizons' Region in 2008 (Data from Zarour, 2008a).

270. In conclusion, I believe that the Groundwater Management Zones, and the Region in general, enjoy a positive hydrogeological balance. Nevertheless, I cannot overemphasise that other considerations relating to the effects of groundwater abstraction remain important in considering resource consent applications, eg. seawater intrusion hazard, drawdown effects on other users of the resource and potential adverse effects on groundwater-interdependent hydrological and ecological systems. All these aspects need to be considered when deciding on the overall feasibility of resource consent applications for groundwater abstraction.

Key messages – Groundwater demand-supply balance

i. There is no indicator of deteriorating groundwater quality anywhere in the Region and groundwater levels are generally stable, indicating sustainable development of the resource.
ii. Allocation limits for Groundwater Management Zones are established at 5% of rainfall.
iii. Current groundwater abstraction in Groundwater Management Zones is a tiny fraction of rainfall.
iv. Current groundwater abstraction in Groundwater Management Zones is much less than the proposed allocation limit of 5% of rainfall.
v. The groundwater supply demand balance is positive over the entire Region and its Groundwater Management Zones.
vi. Other considerations relating to the effects of groundwater abstraction remain important in considering resource consent applications.

Sustainable management of the Regional groundwater resource

271. From the above analysis, it is clear that there is an extensive groundwater resource in the Region and that general water availability is not limiting. The resource mainly consists of the Late Quaternary deposits that cover the valleys and floodplains on both sides of the axial ranges and is generally limited to within the topmost 100 m of the sequence (see section on wells, p 121).

272. Groundwater resource development by pumping from wells lowers groundwater levels, ie. causes drawdown. Drawdown effects resulting from pumping from a well or wells can be harmful to other wells and connected surface water bodies in the vicinity. This matter needs to be considered in plans and appropriate measures need to be incorporated to protect users of the resource and the environment. In addition, promoting water use efficiency must always be seen as a priority, and abundance does not justify waste.

273. Accordingly, the Proposed One Plan establishes the main objective of groundwater management in the Region as enabling people, industry and agriculture to take and use water to meet their reasonable needs, while ensuring that:

i. Water is used efficiently.
ii. Takes do not cause a significant effect on the long-term groundwater yield.

iii. Groundwater takes that are hydrologically connected to rivers, lakes or wetlands are managed within the minimum flow and allocation regimes established for those water bodies to protect their life-supporting capacity.
iv. Existing groundwater quality is maintained or enhanced.
v. Seawater intrusion into coastal aquifers is avoided.
vi. The effects of a groundwater take on other groundwater takes are managed.

274. In his evidence to the hearing Mr Callander comments on the groundwater quality objective (objective iv above) and recommends that it is phrased to indicate the need to preserve existing and future uses of the Region's groundwater resource and values. I believe this is both logical and practical and I endorse this recommendation.

275. In general, the above groundwater resource management strategic framework is compatible with similar ones across New Zealand and for other OECD[87] countries like the UK and US. In my opinion, this is a good approach that allows resource development while protecting the resource and its values.

Key messages – Sustainable groundwater management

i. General groundwater availability is not limiting where the resource exists in the Region.
ii. Although abundant, the resource must be used efficiently.
iii. The Region's groundwater resource mainly consists of Late Quaternary deposits that cover the valleys and floodplains on both sides of the axial ranges.
iv. Lowering groundwater levels (ie. drawdown) as a result of pumping potentially can adversely affect other users and/or the environment, including surface water bodies.
v. The Proposed One Plan has enabling objectives that ensure efficient use and sustainability of the resource.
vi. The objectives of the Proposed One Plan are inline with national and international trends relating to sustainable groundwater resource management.

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[87] Organisation for Economic Co-operation and Development.

Management of the effects of groundwater resource development

Groundwater abstraction drawdown effects

276. I explain in Zarour (2008a) that when a well is discharged through pumping, or by allowing it to flow if it is artesian, the groundwater level or head of the water in the well is lowered relative to that in the surrounding aquifer, thus creating a hydraulic gradient towards the well which causes water to flow towards and into it. This lowering of head is called groundwater level drawdown, or drawdown. Drawdown is largest at the pumped well and becomes smaller farther away. Hence, pumping creates a “cone of depression” around the well, as shown in Figure 63. The configuration of the cone of depression is defined in space and time and is a function of time, abstraction rate, aquifer properties, and conditions. The planar projection of the cone of depression is termed the area of influence, which for simplicity normally is assumed to be a circle and is described in terms of the “radius of influence”. Drawdown effects extend to hydraulically connected wells within the cone of depression of abstraction (Figure 64) and/or to surface water bodies (Figure 65).

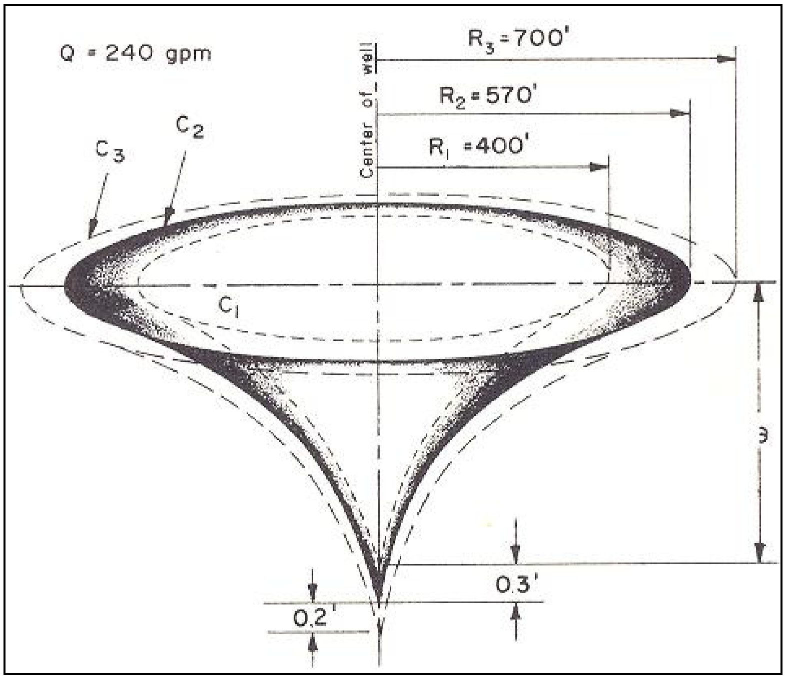

Figure 63. Change in radius and depth of cone of depression after equal intervals of time, assuming constant pumping rate (Source: Johnson, 1966)[88].

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[88] Second edition of this reference (Groundwater and Wells) was published in 1986 (Driscoll, 1986) and the third edition (Sterret, 2008) was released in July 2008, but is on back order.

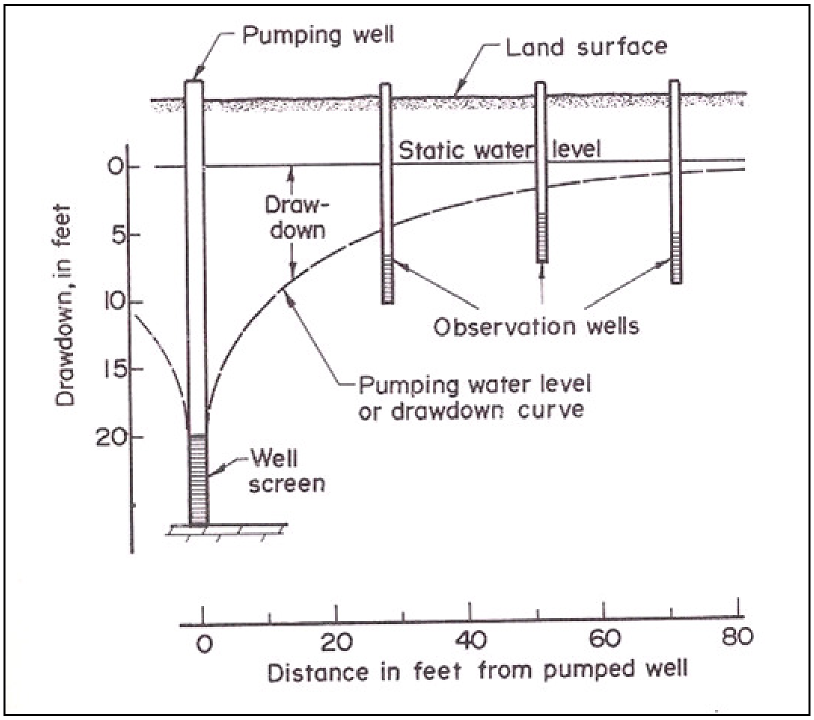

Figure 64. Trace of half the cone of depression showing variation in drawdown with distance from the pumped well (Source: Johnson, 1966).

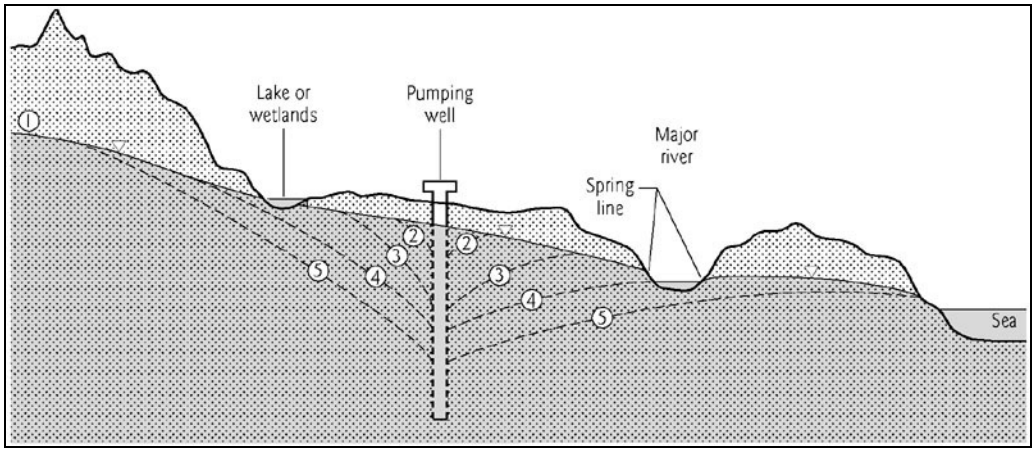

Figure 65. Possible drawdown effect on surface water systems (Source: Younger, 2007). Numbered dashed lines represent various phases of drawdown effects due to increasing groundwater resource development, starting with stage 1 (no depletion of surface water systems) and ending with stage 5 (depletion of all surface water features in the area).

Assessment of potential groundwater abstraction effects

277. I explain in Zarour (2008a) that prediction of drawdown effect requires information about the abstraction rates, and time and knowledge of aquifer parameters and conditions. The required aquifer parameters are mainly transmissivity (T) and storativity (S). Wells (1983) explains these parameters by drawing an analogy with surface waters which, unlike groundwater, can be seen and thus are easier to perceive. He expounds that the amount of water in any aquifer consists of two separate components: (1) the amount of water flowing through the aquifer, of which the surface water equivalent is stream flow; and (2) the amount of water stored in the aquifer in the pores and fractures, of which the surface water equivalent is dam storage. In a groundwater system, transmissivity (T) provides a measure of the possibility for groundwater flow through the aquifer and storativity (S) provides a measure of the storage component of the aquifer. By definition, T is the product of hydraulic conductivity (K) by the thickness of the aquifer (b).

278. Examination of hydraulic properties of geological material is possible through a variety of field and laboratory methods. Generally speaking, pumping tests are the most popular and practical method for assessment of aquifer parameters such as transmissivity (T) and storativity (S). I discuss pumping tests in Section 7.4.2 in Zarour (2008a). It should be noted that the terms “pump test” and “pump testing” are misnomers and should be avoided, as it is not the pump that is examined in such tests, but rather the aquifer and/or the well.

279. I note in Section 7.4.2.9 in Zarour (2008a) that a pumping test can be used to typify the aquifer, ie. reveal its hydraulic confinement and boundary conditions. Sufficiently long-running tests are needed for this and, hence, the extension of the permitted pumping test durations from five days in the last Regional Water and Land Plan to seven days in the Proposed One Plan.

280. In 2008, Horizons had records of about 320 pumping tests in the Region (Figure 66). Most of these tests are single well (ie. no monitoring wells) and/or short (only a few hours). Storativity cannot be evaluated using data from the tested well alone. Inclusion of other observation wells (piezometers) is required to assess aquifer storativity. Short pumping durations do not enable evaluation of aquifer conditions, including hydrogeological boundaries like degree of aquifer confinement, flow barriers, or connected surface water bodies.

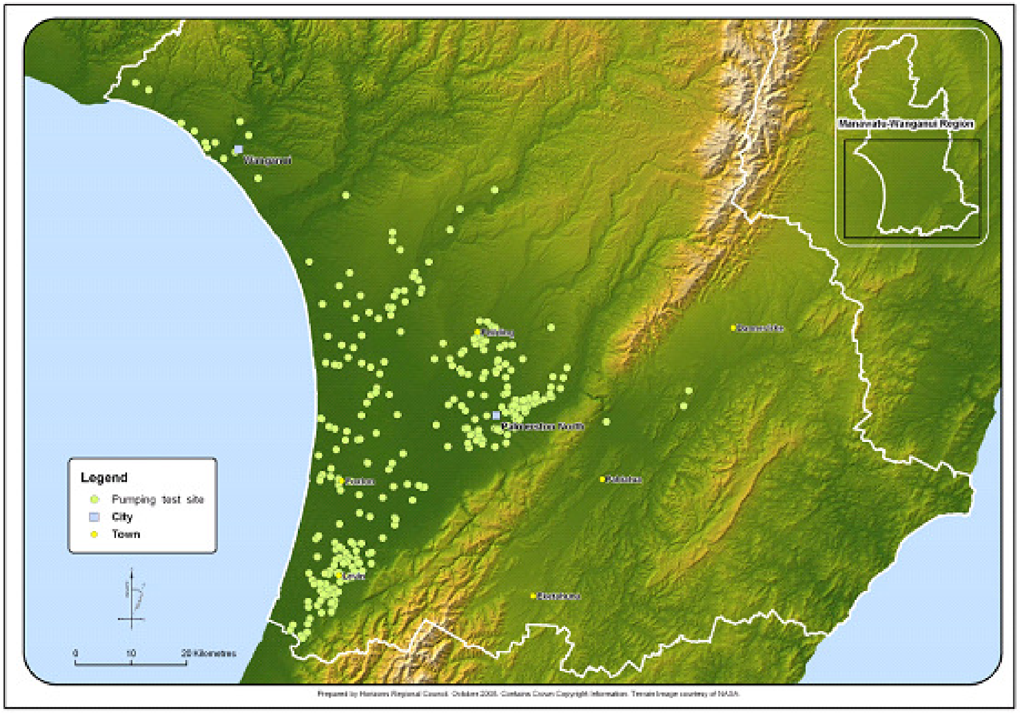

Figure 66. Map showing pumping test locations in Horizons' Region until March 2008 (Source: Zarour, 2008a).

281. A significant proportion of pumping tests in the Region display leakage effects that can be related to seepage of water from shallower and/or deeper levels, and/or recharge from linked surface water systems.

282. As noted in Zarour (2008a) and Mr Callander's evidence, a significant number of pumping tests in the Region have not been conducted appropriately, so the information that is required to assess the potential effects of abstraction cannot be clearly determined. To help resource consent applicants in the Region, Horizons has commissioned Pattle Delamore Partners Ltd (PDP) to prepare clear and practical guidelines for planning and undertaking pumping tests. Mr Callander provides more information on this matter in Section 7.0 of his evidence.

283. As noted in Mr Callander's evidence, the Proposed One Plan requires pumping tests to enable assessment of the potential effects of proposed abstractions and classifies pumping tests as a Permitted Activity (Rule 15-4), with conditions. It is noted here that general hydrogeological knowledge of an area can broadly indicate potential effects of abstraction of groundwater from a bore. Nonetheless, rigorous qualitative and quantitative assessment of individual and cumulative environmental effects of

groundwater exploitation is necessary on a case-by-case basis, to account for the combination of well design and hydrogeological conditions that is usually unique for every well. This makes pumping tests an absolute necessity in most cases where abstraction rates are 10 times and over the permitted limit of 15 m^3/d and 50 m^3/d for riparian and groundwater abstractions, respectively. Pumping tests may still be needed for smaller abstractions, depending on local conditions like well density and general availability of knowledge on the tapped resource.

284. Different equations suitable for different hydrogeological conditions are available to predict (ie. model) potential effects of abstraction on groundwater levels in other wells and on the wider environment. Assessment of environmental effects (AEE) incorporating pumping test analysis provides the basis for technical recommendations on the sought abstractions and appropriate practical conditions, eg. daily and annual maximum rates, pumping durations, monitoring requirements, etc.

285. The inherent uncertainty in hydrogeological assessment cannot be overemphasised. Therefore, even with the best quality information and technical assessment of applications, it is essential to regularly include review conditions in groundwater abstraction consents.

Key messages – Managing drawdown effects

i. Drawdown resulting from abstraction from wells can affect hydraulically connected wells and surface water bodies.
ii. Potential drawdown effect can be predicted where aquifer conditions and parameters are known.
iii. Pumping tests are the most popular and practical method for evaluating aquifer characteristics such as transmissivity (T) and storativity (S).
iv. Pumping tests can be used to typify aquifers, ie. reveal hydraulic confinement and boundary conditions, providing they are sufficiently long.
v. Some pumping tests in the Region indicate leakage from other levels in the groundwater system and/or from connected surface water bodies.
vi. Substandard quality aquifer tests cannot be used in hydrogeological assessments.
vii. There is a need for clear and practical guidelines for planning and undertaking pumping tests in the Region. Horizons has commissioned a project for this purpose.
viii. Rigorous assessment of individual and cumulative environmental effects of groundwater applications on a case-by-case basis is often unavoidable.
ix. Pumping tests are needed in most cases where abstraction rates are 10 times and over the permitted limit of 15 m^3/d and 50 m^3/d for riparian and groundwater abstractions, respectively.
x. A range of analytical and mathematical solutions is available to predict potential effects of abstraction on other wells and on the wider environment.
xi. The inherent uncertainty in hydrogeological assessment cannot be overemphasised and, therefore, review conditions are often needed in groundwater permits.

Groundwater-surface water interaction

286. During dry periods, groundwater is the main source of water in surface water bodies. This is one indicator of hydraulic continuity between groundwater and surface water systems. Also, many surface water bodies exhibit losses and gains of water along their courses during various times and in various areas, eg. Figure 67.

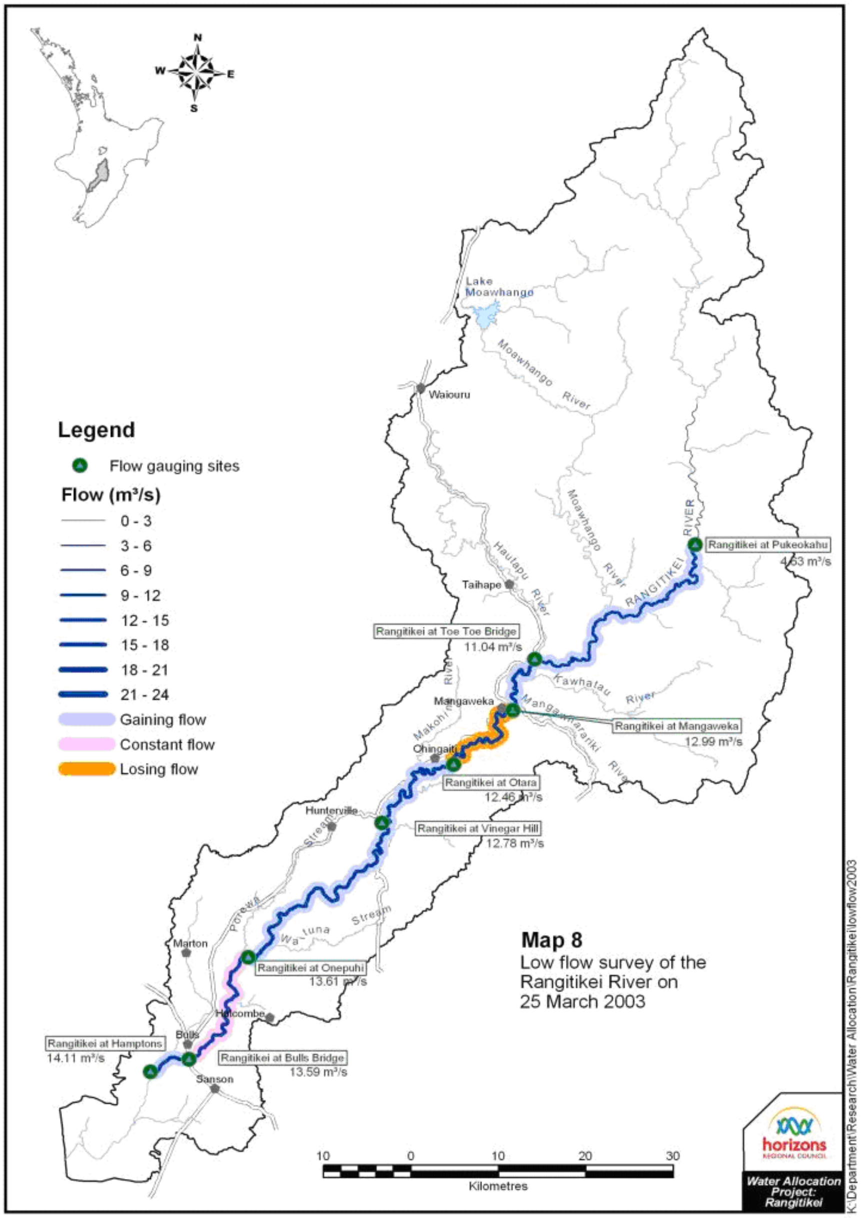

Figure 67. Low-flow survey of the Rangitikei River on 25 March 2003 (Source: Roygard and Carlyon, 2004), showing stretches of the river gaining and losing flow on the survey date.

287. As illustrated in Figure 65, groundwater drawdown effects can extend to linked surface water systems, eg. rivers, lakes, wetlands, etc. Although this is not limited to streams, this phenomenon is termed "stream depletion" in hydrology literature. Stream depletion occurs when a well beside such a system either induces or increases seepage directly from this system or intercepts seepage that would otherwise enter it (Lough and Hunt, 2006).

288. Many signs can indicate hydraulic continuity between groundwater and surface water systems. There are established methods to assess surface water depletion as a result of groundwater abstraction. In 2000, Environment Canterbury (ECan) published its guidelines for the assessment of groundwater abstraction effects on stream flow (PDP and Environment Canterbury, 2000)[89]. These guidelines are practical and relevant to the hydrology of Horizons' Region.

289. Groundwater abstraction can affect connected surface water, provided that all three of the following criteria apply:

   i. Water can flow between the surface water and adjoining groundwater resource.
   ii. The rate of water movement between these two water bodies is dependent on the groundwater gradient adjacent to the surface water system.
   iii. The groundwater gradient adjacent to the surface water body is affected by groundwater abstractions.

290. For any potential setting where stream depletion effects may occur, an initial screening of water level and hydraulic conductivity data should be undertaken to determine whether stream depletion is likely to be a significant issue. The key parameters which determine the magnitude of the stream depletion effect are:

Q – the abstraction rate from the well.

l – the separation distance between the well and the stream.

t – the length of time over which the well is pumped.

T – the transmissivity of the aquifer.

S – the storage coefficient of the aquifer.

λ – the stream bed conductance[90].

291. Where stream depletion is a possibility, the following relationships apply:

   i. Stream depletion effects increase with higher pumping rates.
   ii. Stream depletion effects increase with smaller separation distances. Where separation distances are greater than 2,000 m, stream depletion effects are unlikely to be significant, except in the long-term.
   iii. Stream depletion effects increase with longer pumping periods.
   iv. Stream depletion effects increase with higher values of transmissivity (T).
   v. Stream depletion effects increase with smaller values of storage coefficient (S). However, aquifers with values of S less than 5×10^{-4} are likely to be confined. Under these circumstances there is unlikely to be sufficient hydraulic connection

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[89] Document can be downloaded free of charge from ECan's website (http://www.ecan.govt.nz).

[90] A measure of the permeability and dimensions of the stream bed and the hydraulic gradient across it.

to a stream to cause significant stream depletion effects, unless the stream channel penetrates the low permeability confining layer or there are discrete springs penetrating the confining layer.

vi. Stream depletion effects increase with higher values of stream bed hydraulic conductance. If the streambed conductance is less than 0.01 m/day then it is unlikely that stream depletion effects will occur.

292. To make sure effects of abstraction on connected surface water bodies and associated ecosystems are not more than minor, applicants seeking groundwater abstraction from systems that are connected, or that are suspected to be connected to surface water features, are required to provide an assessment of potential depletion effects of the sought abstraction on the linked surface water systems. I recommend requiring this to be in accord with ECan's guidelines.

293. Upon identification of the magnitude of potential effects of a groundwater abstraction on connected surface water bodies, an appropriate management approach can be adopted. This is explained in Mr Callander's evidence, in Paragraph 5.31.

Key messages – Groundwater-surface water interaction

i. During dry periods, groundwater is the main source of water in surface water bodies.
ii. Many surface water bodies in the Region interact with groundwater in different ways, places and times.
iii. Groundwater abstraction can have depletion effects on the linked surface water bodies.
iv. There are criteria to determine the possibility of stream depletion, and a number of methods to assess the magnitude of this if necessary.
v. ECan's guidelines for the assessment of groundwater abstraction effects on stream flow are very practical and relevant to conditions in Horizons' Region.
vi. Applicants seeking groundwater abstraction from systems that are potentially connected to surface water are required to provide an assessment of potential depletion effects of the sought abstraction on the linked surface water bodies, preferably following ECan's guidelines.
vii. Stream depletion effects can be managed in the way described in Mr Callander's evidence.

Groundwater use efficiency considerations

294. Promoting efficient use of the Region's groundwater resource is one of the identified groundwater resources management objectives in the Proposed One Plan.

295. The Proposed One Plan requires drilling and management of wells in the Region, including abandonment, to be according to the New Zealand Environmental Standard for Drilling of Soil and Rock; NZS 4411:2001 (Standards New Zealand, 2001). Mr Callander's evidence explains what is considered to be a "properly constructed bore" and how effects only on such wells should be considered in determining groundwater abstraction applications in the Region. The purpose of promoting NZS 4411:2001 is two fold: (1) to protect the resource through making sure no excess drawdown occurs and avoid pollution short-cut paths; and (2) to ensure that the resource is not unnecessarily locked in an attempt to protect inefficient wells. I fully support Mr Callander's recommendation regarding the classification of drilling as a Controlled Activity, as a measure to enhance the efficiency of groundwater development in the Region and ensure resource protection. This also will help Horizons' efforts to maintain a reliable database that can be used in hydrogeological assessments, and in identifying potential effects and potentially affected parties during technical assessments of the feasibility of resource consent applications of different types. These include applications for groundwater abstraction, discharge to land, discharge to water, land use, etc.

296. Horizons also promotes the efficient use of water across all sectors. Efficiency here is defined in terms of abstraction and consumption of groundwater in volumes that are proportional to need. For example, Horizons uses a special version of SPASMO-IR[91], a modelling tool developed by HortResearch, to calculate the amount and timing of irrigation for optimal use of water for various crops under different farming conditions. Requirements for human and livestock are determined on per capita basis, as explained in Dr Roygard's evidence. Industrial demand is determined according to the special requirement for each industry on case-by-case basis.

297. Horizons uses resource consent conditions as measures to ensure efficient use and protection of the resource. Table 8 lists current standard groundwater consent conditions in the Region and notes their applicability under different circumstances.

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[91] SPASMO: Soil Plant Atmosphere System Model.

Table 8. Standard groundwater consent conditions in Horizons' Region (Source: Zarour, 2008a).

Condition	Applicability
♦ Daily abstraction limit	♦ All consents, according to actual needs[92] and potential effects on other users of the resource and the environment
♦ Annual abstraction limit	♦ All consents, according to actual needs[93] and potential effects on other users of the resource and the environment
♦ Abstraction metering and provision of water take records	♦ All consents
♦ Groundwater level, Electrical Conductivity, temperature and/or water quality monitoring and sampling[94]	♦ Takes with special potential effects on other users or the environment (eg. riparian and coastal wells)
♦ Surface water stage, flow and quality measurements and/or sampling	♦ Riparian takes with special potential effects on surface water features
♦ Ecological monitoring	♦ Takes with special potential effects on significant ecosystems as defined by Horizons
♦ Telemetry of collected data, eg. abstraction, water level, etc	♦ Takes ≥ 4,000 m³/d and takes in sensitive areas (eg. riparian and coastal wells)
♦ Phased abstraction stepping up	♦ Takes in sensitive areas where effects are uncertain (eg. riparian and coastal wells)
♦ Abstraction reduction and/or cut-off	♦ Takes in sensitive areas where effects can become severe under special conditions (eg. riparian and coastal wells during droughts)

Key messages – Groundwater use efficiency

i. Efficient use is a key groundwater resources management objective in the Region and in the Proposed One Plan.

ii. Horizons promotes the efficient use of water across all sectors and uses the appropriate tools to achieve this.

iii. Appropriate resource consent conditions promote resource use efficiency and protection.

iv. Ensuring that wells are properly constructed is possible through the adoption of appropriate standards such as the New Zealand Environmental Standard for Drilling of Soil and Rock (NZS 4411:2001).

v. I fully support Mr Callander's recommendation to classify drilling as a Controlled Activity, to enhance resource use efficiency and protect it.

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[92] Daily actual need for domestic supplies is calculated on per capita basis – for stock according to the herd size; for irrigation based on crop, area and soil; and for industry on the basis of demonstrated need. Allocation includes allowance for system efficiency.

[93] Annual need is based on daily need and number of days of need, eg. an irrigation season for cropping, or 365 days for domestic and stock supplies.

[94] Can include the pumped well and/or other wells. Under special circumstances, purpose-built monitoring wells (piezometers) will be required to be installed.

4. CONCLUSION

298. Groundwater is an important socio-economic and environmental resource in the Region. Available information indicates that the resource has been managed within its sustainable limits and that there is no large-scale depletion in availability or deterioration in quality. The resource mainly consists of Late Quaternary deposits that fill the valleys and cover the floodplains. The Late Quaternary groundwater system cannot be divided into distinct aquifers. However, the Nukumaru strata in the Whanganui Groundwater Management Zone represents a separate aquifer. The proposed Groundwater Management Zones framework is appropriate to manage the resource and protect it. The groundwater resource is interlinked in many places with surface water bodies.

299. Availability of groundwater in the areas where the resource is exploitable is not a limiting factor in the Region, which enjoys a healthy hydrogeological balance. However, local effects of groundwater abstraction need to be considered in plans and when deciding on permits. The objectives, policies and rules in the Proposed One Plan are suitable to manage the resource beneficially, efficiently and sustainably. Policies and rules related to other components of the environment, alongside national standards and best practice guides, are also important in effective groundwater resource management.

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