# New Zealand Guidelines for the Monitoring and Management of Sea Water Intrusion Risks on Groundwater

Prepared for

Envirolink Project 420-NRLC50

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# Table of Contents

# 1.0 Introduction

This report presents a technical guideline to help in the analysis of risks to groundwater arising from sea water intrusion in the New Zealand setting. The preparation of this guideline document, and the Excel spreadsheet that accompanies it, is in response to an Envirolink proposal submitted by a sub-committee of the Regional Council Groundwater Forum, who selected the title Saline Intrusion Monitoring (SIM) tool.

The guideline has been structured to provide the following information:

- a review of coastal groundwater monitoring that is currently being undertaken throughout New Zealand (Section 3);
- a classification of the type of sea-water intrusion risk scenarios that occur in New Zealand (Section 4);
- predictive methods for identifying situations where there is the potential for sea water intrusion to adversely affect groundwater usage (Section 5);
- a description of chemical indicators of sea water intrusion (Section 6);
- a consideration of the effects of sea level rise on sea water intrusion risks (Section 7);
- recommended approaches for monitoring sea water intrusion risks (Section 8);
- recommended approaches for management of sea water intrusion risks (Section 9).

An Excel spreadsheet has been prepared to utilise the predictive methodologies described in sections 5 and 7 of this report and can be downloaded from the internet via the Envirolink website, the PDP web site www.pdp.co.nz, or at the following web address: http://file.pdp.co.nz/upload/public/sea_water_intrusion2011

# 2.0 Preliminary Comments

In all coastal areas, there is a naturally occurring interface between:

- fresh groundwater derived from rainfall recharge on the land surface and inland seepage from surface waterways;
- saline groundwater due to the occurrence of sea water within the strata that occurs underneath and adjacent to those areas where surface sea-water is present.

Under natural conditions, there is a hydraulic gradient in the fresh groundwater system towards the sea coast, and seepage of fresh groundwater out into the sea occurs at, and off-shore of, the coastal margin.

For an unconfined aquifer, the fresh groundwater at the water table and sea water form an interface at the costal margin. At greater depths, the location and shape of the interface between the fresh groundwater and the sea water is largely determined by the hydraulic gradients and the mixing that occurs between these two water types, recognising that due to the greater density of sea-water it has a greater total head than simply the elevation of sea level. This can allow the interface to occur at inland locations in the deeper parts of an aquifer that has a permeable hydraulic connection to the sea under natural conditions, as shown in Figure 1.

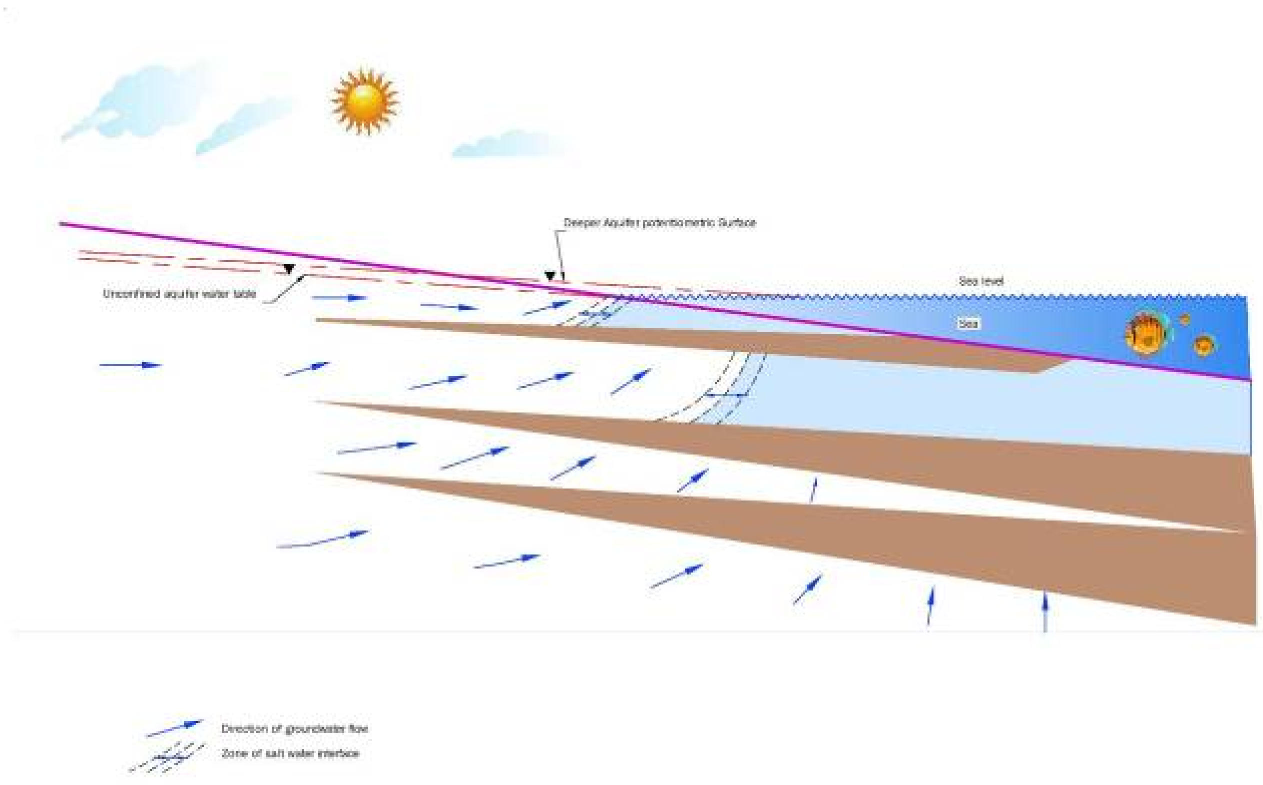


**Figure 1: Schematic Diagram of Sea Water Interface**

For confined aquifers with higher hydraulic heads and/or greater hydraulic gradients in a seaward direction the interface may be further offshore and in some deep confined aquifers with no permeable hydraulic connection to the sea there may be no interface present (as shown by the deepest aquifers in Figure 1).

The interface between groundwater and saline water is not a sharp boundary, but rather there is a diffuse transitional zone due to:

- variations in the fresh water hydraulic gradient that occur throughout the year;
- variations in sea-water head due to tides and weather related fluctuations;
- diffusive mixing between waters of different chemical concentrations.

However, only a small proportion of sea water is required to mix with fresh groundwater in order to cause adverse water quality problems, as indicated by the following comparison in chloride concentrations:

- typical fresh groundwater – 10-30 $g/m^3$;
- aesthetic guideline value in Drinking Water Standards for New Zealand 2005 (revised 2008) – 250 $g/m^3$;
- typical sea water – 20,000 $g/m^3$.

Therefore, around 1.2% of sea water mixed with fresh water can cause undesirable aesthetic effects for a groundwater supply. Other problems can occur in areas of coastal geothermal water, such as at Waiwera north of Auckland, where sea water intrusion can cause an unhelpful cooling of the geothermal groundwater resource.

The sea water can move inland and contaminate productive groundwater aquifers due to:

- the landward movement of surface sea water and/or;
- a lowering of the hydraulic head and/or gradient in the fresh groundwater.

Even if hydraulic conditions exist that would allow sea water to migrate into a fresh water aquifer, there is still a timing factor to consider regarding how quickly that movement will occur. The time over which any sea water effects may occur is significantly affected by how permeable the hydraulic connection is between the fresh water aquifer and the areas of saline groundwater and/or the sea water source. This degree of hydraulic connection is often poorly defined, and as a result, it is often difficult to accurately predict how and when the intrusion of saline groundwater will occur until it has actually been observed. Therefore, monitoring of groundwater at coastal locations provides the best opportunity to characterise the way in which the interface changes under differing conditions of hydraulic head and gradient and to identify high risk situations arising from prolonged periods of low groundwater levels and/or changing groundwater quality. Through these monitoring observations, effective management strategies can be put in place to control future occurrences of sea water intrusion.

To aid in the understanding and management of this issue, this guideline has been prepared to describe the results of coastal monitoring from around New Zealand, and use that information to consider appropriate monitoring and management regimes.

## 3.0 Coastal Groundwater Monitoring in New Zealand

At the present time, the monitoring and management of groundwater resources in New Zealand is carried out by 15 regional councils and unitary authorities, whose boundaries are shown in Appendix A, along with a summary of their approach to coastal groundwater management and monitoring that is undertaken specifically for the purpose of assessing the sea water intrusion issue. The key points that can be drawn from the regional summaries in Appendix A are:

- there is a good awareness of sea water intrusion risks by New Zealand's groundwater managers;
- there are a wide variety of practices regarding management and monitoring, as defined in regional planning documents. Some approaches are based on a generic intention to avoid the problem, whereas others are quite prescriptive regarding the definition of conditions under which restrictions are placed on abstractions and land use activities to avoid the problem;
- given the length of the New Zealand coastline, there are only a small number of actual sea water intrusion problems that have occurred;
- most of the sea water intrusion that has occurred to date has been into shallow unconfined aquifers. These problems tend to be short-lived and are adequately managed by a change in the magnitude and/or location of groundwater abstraction sites;
- the maximum inland extent of sea water intrusion effects in unconfined aquifers that has been observed is around 400 m in South Dunedin;
- in some areas, sea water intrusion has developed in confined aquifers (such as the Woolston-Heathcote area in Christchurch) and created a longer lasting effect. This is most likely due to the impeded migration path for sea water to enter the aquifer, which occurs over a prolonged period. Such situations arise due to a lack of monitoring and early detection, and consequently may take a long time to be rectified;
- the maximum inland extent of sea water intrusion effects in confined aquifers is around 2 km in the Woolston-Heathcote area of Christchurch;
- the deepest bore that is reported to have been affected by sea water intrusion is 125 m deep at Waitara;
- in those areas where sea water intrusion has occurred, groundwater levels tend to have been drawn down below mean sea level.

The approach of the Regional Councils to the management of sea water intrusion issues is summarised in Sections 3.1 and 3.2, based on the information in Appendix A.

## 3.1 Management Approach

### 3.1.1 Planning Documents

Most Councils have a specific reference to management of sea water intrusion risks in their planning documents. Most commonly, this is a statement of general intent to avoid sea water intrusion problems. For example, the Otago Regional Plan: Water includes the following policy:

> *"… to manage the taking of water from any bore such that groundwater contamination by sea water is avoided".*

Some Councils go further than this and have policies that include specific controls relating to extra restrictions within a certain distance of the coast and/or extra restrictions at times of low water levels. For example:

- the Proposed Variation 6 of the Waikato Regional Plan has a smaller permitted activity allowance for water takes within 600 m of the coastal marine area;
- Horizons Regional Council require extra pumping test and monitoring requirements within 5 km of the coastline;
- Environment Canterbury requires restrictions on abstractions to maintain a particular water pressure in their coastal confined aquifers.

### 3.1.2 Consent Conditions

A standardised approach to consent conditions is followed by some Councils. For example, Northland Regional Council uses a condition similar to the following:

*"To prevent saline contamination, the Regional Council reserves the right to require the Consent Holder to cease the taking of groundwater from any or all the bore/s at such times as the chloride concentration in water delivered by any of the bores is measured by standard methods to be greater than x grams per cubic metre."*

Many other Councils address consents that might cause sea water intrusion on a case-by-case basis.

## 3.2 Monitoring Approach

### 3.2.1 Regional Monitoring Network

The following table provides an indication of the number of coastal monitoring wells that each Council implements for their regional monitoring network that are specifically identified as being for the purpose of monitoring sea water intrusion risks.

**Table 1: Dedicated Sea Water Intrusion Monitoring Well Networks**

| Number of Wells on the Regional Monitoring Network Related to Coastal Groundwater Issues | Regional Council |
|---|---|
| 10-24 | Northland, Tasman, Canterbury |
| 1-10 | Auckland, Horizons, Wellington, Marlborough, West Coast |
| 0 | Waikato, Bay of Plenty, Gisborne, Hawkes Bay, Taranaki, Otago, Southland |

Those Councils with no, or very small numbers of regional coastal monitoring bores, focus their monitoring on particular consent related issues rather than as a part of their regional groundwater programme, which is an appropriate monitoring response.

### 3.2.2 Consent Monitoring

All Councils implement specific monitoring of groundwater levels and/or groundwater quality on resource consents where sea water intrusion has a realistic potential to be an issue.

## 4.0 Classification of Sea-Water Intrusion Risk Scenarios

Based on the current information, it appears that the risk of sea water intrusion effects occurs in the following two aquifer types:

- unconfined aquifer extending less than 1 km inland from the coastline (the greatest inland distance that saline effects have been observed is around 400 m in South Dunedin);
- confined aquifers where drawdown effects can extend over distances of 5 km (a Horizons guideline) although actual observed effects are limited to 1.3 km (Havelock) and 2 km (Woolston Heathcote).

The following table summarises the risk scenarios present in the New Zealand setting for these two aquifer types.

**Table 2: Classification of Sea-Water Intrusion Risks in New Zealand**

| **Sea-Water Intrusion Risks** | | | **Examples of Occurrence** | **Examples of Monitoring Where no Problem has Occurred to Date** |
|---|---|---|---|---|
| **Method of Sea-Water Intrusion** | **Aquifer Type** | **Cause of Intrusion** | | |
| Lateral intrusion of sea water into an aquifer adjacent to the sea | Unconfined | Groundwater abstraction bores | Makikihi, South Canterbury | Rarangi, Marlborough |
| | | Drainage effects from leaky stormwater and sewer pipes | South Dunedin | No monitored examples |
| | | Reduction in groundwater discharge | | Russel (Northland) |
| | Confined | Groundwater abstraction bores | Havelock, Marlborough | West Coast of Horizons region<br>Linkwater, Marlborough<br>Wairau Aquifer, Marlborough |
| Downwards seepage from a saline surface waterway that overlies an aquifer | Unconfined | Groundwater abstraction bores | Hau Zone and Waimea Plains, Tasman | No monitored examples |
| | Confined | Groundwater abstraction bores | Woolston-Heathcote, Christchurch | No monitored examples |
| | Unconfined or confined | Landward movement of surface seawater | Hau Zone, Tasman | No monitored examples |
| Upconing of deep saline sea water that is present within the aquifer | Unconfined or confined | Groundwater abstraction bores | Opoutere Motor Camp, Waikato | No clearly proven examples, although may be difficult to distinguish from lateral intrusion |
| Alteration to natural barriers between sea water and an aquifer | Confined | Examples include dredging of marine sediments, damage to aquitards by drilling or abandoned boreholes in areas of sea water inundation | Abandoned boreholes are a possible cause of sea water intrusion into the Woolston-Heathcote area of Christchurch | No monitored examples |
| Improving groundwater quality due to abstraction | Confined | Reduced salinity due to increased freshwater movement into dead end aquifers | Wairau Aquifer at Rarangi, Marlborough<br>Linkwater, Marlborough,<br>Manawatu | No monitored examples |

# 5.0 Predictive Methodologies for Assessing the Occurrence of Saline Intrusion on Groundwater

The precise numerical characterisation of the movement of sea-water in groundwater is considerably more complex than normal groundwater flow modelling. For fresh groundwater flow, heterogeneous and anisotropic properties within the flow system and at its boundaries are difficult to adequately characterise. These same difficulties occur within the interface zone between fresh water and saline water. In addition, sea-water has different flow characteristics due to its greater density and a different chemistry. Therefore, within the interface zone we have:

- advective groundwater flow;
- variable density flow in the transition zone from fresh water to sea-water;
- diffusive movement of water between high concentration sea-water and low concentration fresh water (although this may not be significant in aquifer systems dominated by advective flow).

There is often considerable uncertainty regarding the hydraulic characteristics of the strata between the fresh water aquifer and the sea, as that strata often occurs offshore and is typically unexplored by boreholes or test pumping.

Numerical models are available to estimate the variable density and concentration effects of the sea-water/fresh water groundwater interface (e.g. SHARP, SUTRA, HST3D and the SEAWAT programme of MODFLOW). These models provide an opportunity to assess heterogeneous and anisotropic hydrogeologic settings and can best be used to understand the way in which sea-water and fresh groundwater interact and to target investigation requirements by considering the sensitivity of the interface to a range of parameters where there are information gaps. However, due to the difficulties of accurately characterising the input to these models, they do not necessarily offer significant advances in predictive accuracy compared to an approach based on analytical solutions, coupled with monitoring.

Analytical equations that deal solely with the effects of changes in hydraulic head or gradient are gross simplifications of the real situation, and also cannot be expected to accurately predict the position of the salt water interference. However, they do provide a more straightforward assessment that can be used to identify situations where there is an increased risk of sea water intrusion issues and where there is a need for more rigorous monitoring and/or field investigations to check on this issue. This monitoring needs to focus on both groundwater level and hydraulic gradient conditions (as described by the equations in this section of the report) in combination with groundwater quality parameters (as described in Section 6 of this report).

The key analytical equations that can be used for this purpose are described in text books such as Domenico and Schwarz (1990) and Todd and Mays (2005) and are summarised in the remainder of this section.

### 5.1 Ghyben-Herzberg's Equation

Under static hydraulic conditions, the interface between an area of fresh water and an area of sea-water may be approximated by the difference in densities of these two types of water, i.e.:

$$\rho_s = \rho_f (z + h_f)$$ *Equation 1*

Where: z is the depth below sea level to the saltwater interface;

$h_f$ is the height of fresh water above sea level that maintains a balance with the saltwater interface;

$\rho_f$ is the density of fresh water;

$\rho_s$ is the density of sea-water.

Many of the analytical solutions involve the following ratio of the difference in densities between fresh water and sea water:

$$\Delta\rho = \frac{\rho_f}{\rho_s - \rho_f}$$

Typical values for $\rho_f$ are 1.0 tonnes/m$^3$ and for $\rho_s$ are 1.025 tonnes/m$^3$, which results in the following relationship for static conditions with a perfect hydraulic connection between fresh groundwater and the sea.

$$z = \Delta\rho h_f = 40 h_f$$ *Equation 1a*

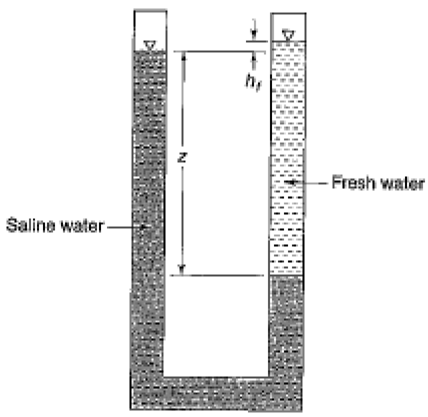


**Figure 2: Ghyben Herzberg relationship between fresh water and sea water under hydrostatic conditions (from Todd and Mays, 2005).**

Figure 3 shows the type of interface that is often shown in text books to represent the interface position that can be calculated by the use of the Ghyben-Herzberg method.

However, such a representation is actually inaccurate, because it shows a fresh water hydraulic gradient towards the sea, whereas the equation is based on static conditions.

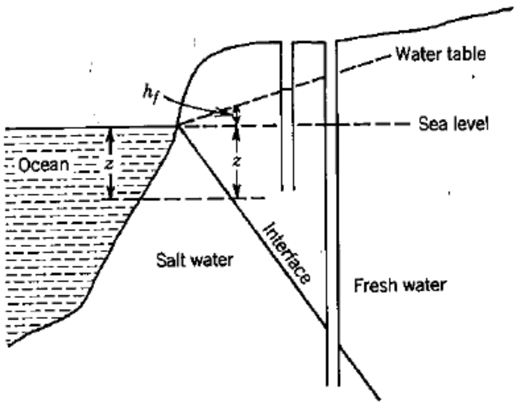


**Figure 3: Ghyben-Herzberg relationship of the interface position (from Domenico and Schwartz, 1990).**

Therefore, for most situations, it must be recognised that Ghyzben-Herzberg's equation is a simple and conservative guideline that does not represent a real groundwater system, because it assumes a direct permeable connection between a static body of fresh water and a static body of sea-water.

The equation is perhaps best used to indicate a range of groundwater level pressures above which no sea water intrusion problems should exist. If groundwater pressures fall below the values that Ghyben-Herzberg indicate might be a problem, it should simply be used to indicate a set of circumstances where a greater intensity of monitoring should be undertaken.

### 5.2 Glover's Equation

Glover's equation takes into account the fresh water gradient and provides some indication of the shape and extent of the interface.

$$z = \sqrt{\frac{\Delta\rho^2 q^2}{K^2} + \frac{2\Delta\rho q x}{K}} \qquad \textit{Equation 2}$$

Where: z is the depth to saline water (metres);

K is the hydraulic conductivity of the strata (metres/day);

q is the fresh water flow through the aquifer per unit length of shoreline (metres$^2$/day);

x is the distance inland from the coast;

$$\Delta\rho = \frac{\rho_f}{\rho_s - \rho_f}$$

$\rho_f$ is the density of fresh water = 1 kg/L;

$\rho_s$ is the density of sea-water = 1.025 kg/L.

Utilising Darcy's equation, it can be seen that:

q/K = ib

Where: i is the hydraulic gradient of the fresh water;

b is the thickness of the unconfined aquifer.

Therefore, the equation can be re-written in a form, using parameters that can be more easily estimated, as follows:

$$z^2 = 2ibx\Delta\rho + (ib\Delta\rho)^2$$ *Equation 2a*

This equation indicates that the variable factors that control the position of the interface are the thickness of the aquifer (b) and the fresh water hydraulic gradient (i) which corresponds to the related parameters of hydraulic conductivity of the aquifer strata (K) and the rate of fresh water throughflow (q).

A schematic diagram of Glover's equation is shown in Figure 4.

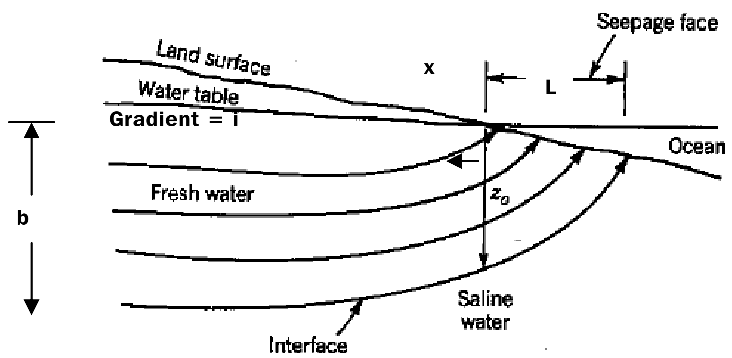


**Figure 4: Glover relationship of the interface position (modified from Domenico and Schwartz, 1990).**

The equation can also be used to define the following components of the interface:

- the shape of the water table is defined as:

$$h_f = \sqrt{\frac{2ibx}{\Delta\rho}}$$ *Equation 3*

- the length L of the offshore zone through which fresh water discharges into the sea corresponds to the situation where z = 0:

$$L = \frac{ib\Delta\rho}{2}$$ *Equation 4*

- the depth of the interface at the coastline ($z_0$) occurs where x = 0:

$$z_O = ib\Delta\rho$$ *Equation 5*

Comparing equations 4 and 5, it can be seen that the depth to the interface at the coastline is twice the length that the seepage surface extends offshore.

The Glover equation is most relevant for an unconfined aquifer dominated by advective flow with a permeable hydraulic connection to the sea.

Further variations of Glover's equation are presented in Section 7 with regard to the effects of sea level rise.

### 5.3 Upconing

Upconing is a situation that can arise if saline water is already present at depth within a pumped aquifer and is lying beneath a pumping well. It occurs when the commencement of pumping causes saline water to be drawn upwards into the well due to the lowering of the fresh water head caused by the pumping.

The risk of upconing can be assessed by calculating the new equilibrium elevation of the interface in response to pumping:

$$z_u = \frac{Q\Delta\rho}{2\pi dK}$$ *Equation 6*

Where: $z_u$ is the rise in the interface caused by pumping (m);

Q is the pumping rate from the well ($m^3$/day);

d is the distance from the base of the well to the original pre-pumping interface (m);

K is the hydraulic conductivity of the strata (m/day).

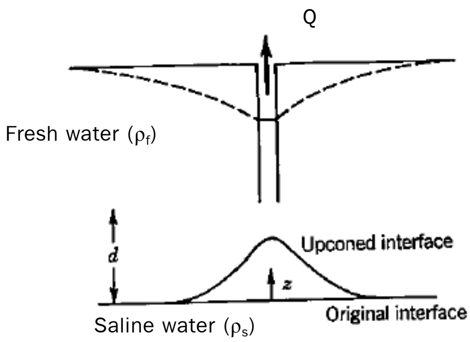


**Figure 5: Upconing of interface in response to pumping (from Domenico and Schwartz, 1990).**

As a guideline, Dagan and Bear (1968) suggest that the interface will remain stable provided that upconed heights do not exceed one-third of d.  On that basis, the maximum permitted pumping rate should not exceed.

$$Q_{\max} = \leq \frac{0.6\pi d^2 K}{\Delta\rho} \qquad \textit{Equation 7}$$

This situation is only relevant where saline water is already present at depth within the pumped aquifer.  Such a situation may be determined by direct observation via borehole sampling, or inferred by an appropriate interpretation of the Ghyben-Herzberg or Glover equations.

## 5.4 Critical Well Discharge

Strack (1976) introduced the concept of a critical abstraction rate which, if exceeded, creates an unstable situation where sea water will move inland to the well.  The scenario for an unconfined aquifer is shown in Figure 6.

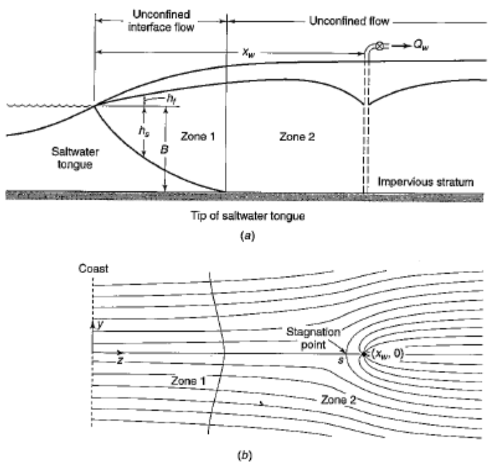


**Figure 6: Pumping from a shallow coastal unconfined aquifer (from Todd and Mays, 2005).**

Strack's equation to define the position of the toe of an interface under steady conditions:

$$\frac{1}{2}(1+\Delta\rho)\frac{b^2}{\Delta\rho^2} = \frac{q}{K}x + \frac{Q_w}{4\pi K}\ln\left[\frac{(x-x_w)^2+y^2}{(x+x_w)^2+y^2}\right] \qquad \textit{Equation 8}$$

Where:

$$\Delta\rho = \frac{\rho_f}{\rho_s - \rho_f}$$

b: depth to base of aquifer below mean sea level;

q: fresh water flow per unit length of shoreline (assumed uniform from infinity to the coast);

$Q_w$: constant pumping rate of the well superimposed on q;

K: hydraulic conductivity of the aquifer;

$x_w$: distance between the well and the shoreline (see Figure 6);

($x$, y): x-y coordinates of the toe of the interface (see Figure 6).

On the coastal side of a pumping well, a stagnation point occurs which marks the divide between groundwater that is drawn towards the pumping well (due to the drawdown cone caused by pumping) and groundwater flow towards the coast (due to the natural hydraulic gradient). The position of this stagnation point ($\chi_s$, $y_s$) is defined as:

$$x_s = x_w\left[1 - \frac{Q_w}{\pi q x_w}\right]^{1/2}; y_s = c \qquad \textit{Equation 9}$$

The critical point of instability for the salt water interface occurs when the toe of the interface passes through the stagnation point. Once that situation occurs, the saline water can move directly towards the well as the protective hydraulic head and gradient barrier has been breached. The equations that define the critical pumping rate causing saline water to breach the stagnation point in an unconfined aquifer are:

$$\lambda = 2\left(1-\frac{\mu}{\pi}\right)^{1/2} + \frac{\mu}{\pi}\ln\left[\frac{1-(1-\mu/\pi)^{1/2}}{1+(1-\mu/\pi)^{1/2}}\right] \qquad \textit{Equation 10a}$$

where:

$$\lambda = \left(\frac{Kb^2}{qx_w}\right)\left(\frac{1+\Delta\rho}{\Delta\rho^2}\right) \qquad \textit{Equation 10b}$$

and

$$\mu = \frac{Q_w}{qx_w}$$ *Equation 10c*

Therefore, the critical pumping rate is determined by:

- solving equation 10b for $\lambda$;
- using the value of $\lambda$ in equation 10a to solve for $\mu$;
- using the value of $\mu$ in equation 10c to solve for Qw, which is the critical pumping rate.

For a confined aquifer setting, equation 10b is replaced with the following:

$$\lambda = \left( \frac{Kb^2}{qx_w \Delta\rho} \right)$$ *Equation 10d*

Therefore, the same approach to determining the critical pumping rate for a confined aquifer is achieved by:

- solving equation 10d for $\lambda$;
- using the value of $\lambda$ in equation 10a to solve for $\mu$;
- using the value of $\mu$ in equation 10c to solve for Qw, which is the critical pumping rate.

## 5.5 Appropriate Interpretation of Predictive Equations

All these analytical equations described in Sections 5.1-5.4 are for steady state situations in homogenous isotropic aquifers, where there is a permeable hydraulic connection between the fresh water aquifer and the sea. These conditions are seldom met in natural groundwater settings, and the variations from these idealised settings that occur in the real world cannot easily be accommodated by analytical solutions. Therefore, when applying the results of these equations to groundwater management, it is important to recognise the differences between the real world and the theoretical calculation, and apply the results of the calculations with a recognition of the way in which the natural system will vary from the calculated result.

In particular, a common situation is for there to be some degree of low permeability impedance between the fresh groundwater aquifer and the sea, particularly due to fine grained marine sediments. This slows the response of the interface movement to changes in the fresh water head and/or gradient. If the critical values defined by the analytical equations are applied to instantaneous values of groundwater pressure or abstraction rate, they should primarily be used to indicate times when more intensive monitoring is required. However, the actual position of the interface, as indicated by the analytical equations, is more likely to be related to longer term average values of groundwater pressure and abstraction rates.

Therefore, it may be acceptable for groundwater levels to decline below the limits calculated by analytical solutions for a certain period of time without incurring any adverse effect on the aquifer, provided that the longer term average levels remain above the relevant analytical guideline value. Whilst this is a realistic description, the magnitude and duration of water level decline below the critical values defined by the analytical solutions is difficult to predict precisely, and is best understood by the experience gained by monitoring of pumping and related groundwater quality effects.

The analytical equations that have been described are therefore best used to provide a framework to guide the degree of monitoring and management that is applied at any particular location.

## 6.0 Chemical Indicators of Sea Water Intrusion

There can be many causes of saline groundwater, such as the occurrence of connate groundwater, geothermal water sources, interaction of groundwater with certain types of strata, wastewater discharges or effects from contaminated land. Therefore, care must be taken in determining whether sea water intrusion is actually occurring. Based on the discussion in the preceding section, the following criteria must apply for sea water intrusion to occur:

- there must be a body of surface sea water in close proximity with a feasible flow path into the aquifer;
- the hydraulic head and hydraulic gradient in the inland groundwater must be within the range in which sea water intrusion can feasibly occur (as indicated by the equations in Section 5 of this report);
- the water chemistry must be altered across a range of parameters that are present at elevated concentrations in sea water.

A strong indicator of sea water intrusion is if the chemical indicators of sea water intrusion increase during times of lower groundwater pressures. However, it is important to utilise the most appropriate chemical indicators to demonstrate the presence of sea water. The typical composition of sea water is listed in the following table.

| **Table 3: Typical Composition of Major Ions in Sea Water (modified from Hem, 1989)** | |
|---|---|
| *Cations* | |
| Sodium ($Na^+$) | 10,500 mg/L |
| Magnesium ($Mg^{2+}$) | 1,350 mg/L |
| Calcium ($Ca^{2+}$) | 410 mg/L |
| Potassium ($K^+$) | 390 mg/L |
| *Anions* | |
| Chloride ($Cl^-$) | 19,000 mg/L |
| Sulphate ($SO_4^{2-}$) | 2,700 mg/L |
| Bicarbonate ($HCO_3^-$) | 142 mg/L |
| Bromide ($Br^-$) | 67 mg/L |
| Nitrate ($NO_3^-$) | 0.67 mg/L |
| Total Dissolved Solids (TDS) | 35,900 mg/L |
| Electrical Conductivity | 4,800 mS/m |

If a fresh groundwater supply becomes contaminated by these elevated chemical concentrations in sea water, it can adversely affect the use of the supply for drinking water for people and stock (due to taste and corrosive problems), for irrigation (due to salinisation and/or effects of sodium on soil structure, as indicated by the Sodium Adsorption Ratio) and for some commercial or industrial uses that may be affected by the elevated chemical concentrations present in sea water.

With the exception of nitrate, the chemical components of sea water that are listed above occur at significantly higher concentrations than fresh groundwater. Therefore, electrical conductivity provides an excellent indicator parameter to monitor the changes in water chemistry that might arise at locations that are at risk from sea water intrusion. There is also a very close relationship between electrical conductivity and chloride, which is the major conservative anionic indicator of sea water. For example, data from aquifers in Canterbury and Marlborough indicate the following relationship:

$$\text{Chloride (mg/L)} = 2.3 \times \text{Electrical Conductivity at } 25^\circ\text{C (mS/m)} - 33$$

However, even if electrical conductivity is elevated, it is still necessary to confirm the sea water intrusion effect by chemical analysis due to the other potential factors affecting groundwater quality mentioned at the start of this section.

A comparison of the quality of groundwater in a coastal aquifer and sea water quality can identify chemical ratios that are likely to provide good indications of sea water intrusion. Useful ratios can be determined by comparing the chemistry of fresh groundwater for a particular area, relative to the composition of sea water and choosing pairs of anions or cations that have a high ratio in one type of water and a low ratio in the other. Typical ratios for assessing sea water intrusion effects are:

- Calcium : Magnesium;

- Bicarbonate : Chloride.

Both these ratios are typically high in fresh groundwater (greater than 1) and lower in sea water (less than 1). Consequently the ratios decrease as sea water intrusion occurs. A plot of these ratios versus electrical conductivity also helps to identify different groupings of wells that are affected by sea water intrusion, with the electrical conductivity providing a general indicator of increasing dissolved concentrations as sea water intrusion occurs.

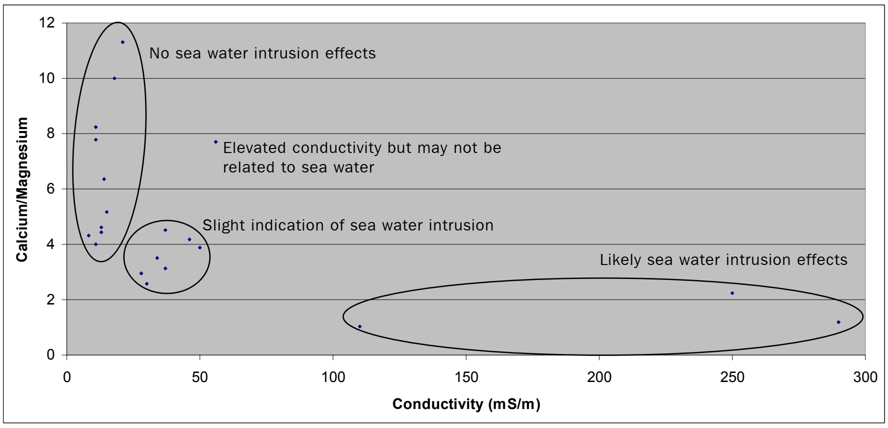


**Figure 7: Monitoring Data from Coastal Canterbury in March-April 2010.**

Standard graphical representations of water chemistry are also useful to identify different water types and whether or not they show characteristics of sea water intrusion effects. These are typically designed to represent the total solute concentration and identify the proportions assigned to each ionic species. To enable this comparison to occur, the concentrations are typically expressed in milliequivalents per litre, which indicates the relative contribution that each ionic species makes to the overall solution.

Use of appropriate graphical images can be far more effective than reviewing chemical concentrations set out in tables. Commonly used options are presented in Figure 8 and are briefly described below:

- **Trilinear diagrams** – cation and anion triangular plots occupy the lower left and right parts of these diagrams and points are projected into the diamond shaped space in the upper central portion of the diagram. Similar types of water cluster in similar areas of the plot;
- **Durov plots** – similar to trilinear diagrams but include additional information on pH and total dissolved solids;
- **Stiff diagrams** – use either three or four parallel axes (cations to the left, anions to the right) to provide a distinctive shape for different types of water. Provided that the same scale is used for all plots, the width of the shape provides an indication of the total ionic content;
- **Schoeller diagrams** – show each analysis as a line with similar waters falling onto parallel lines.

Other graphical techniques can also be used including radial plots or various formats of pie graphs. It is often useful to trial several different presentation options and to utilise the options that provide the best visual indication to demonstrate the different types of water that occur in any particular area.

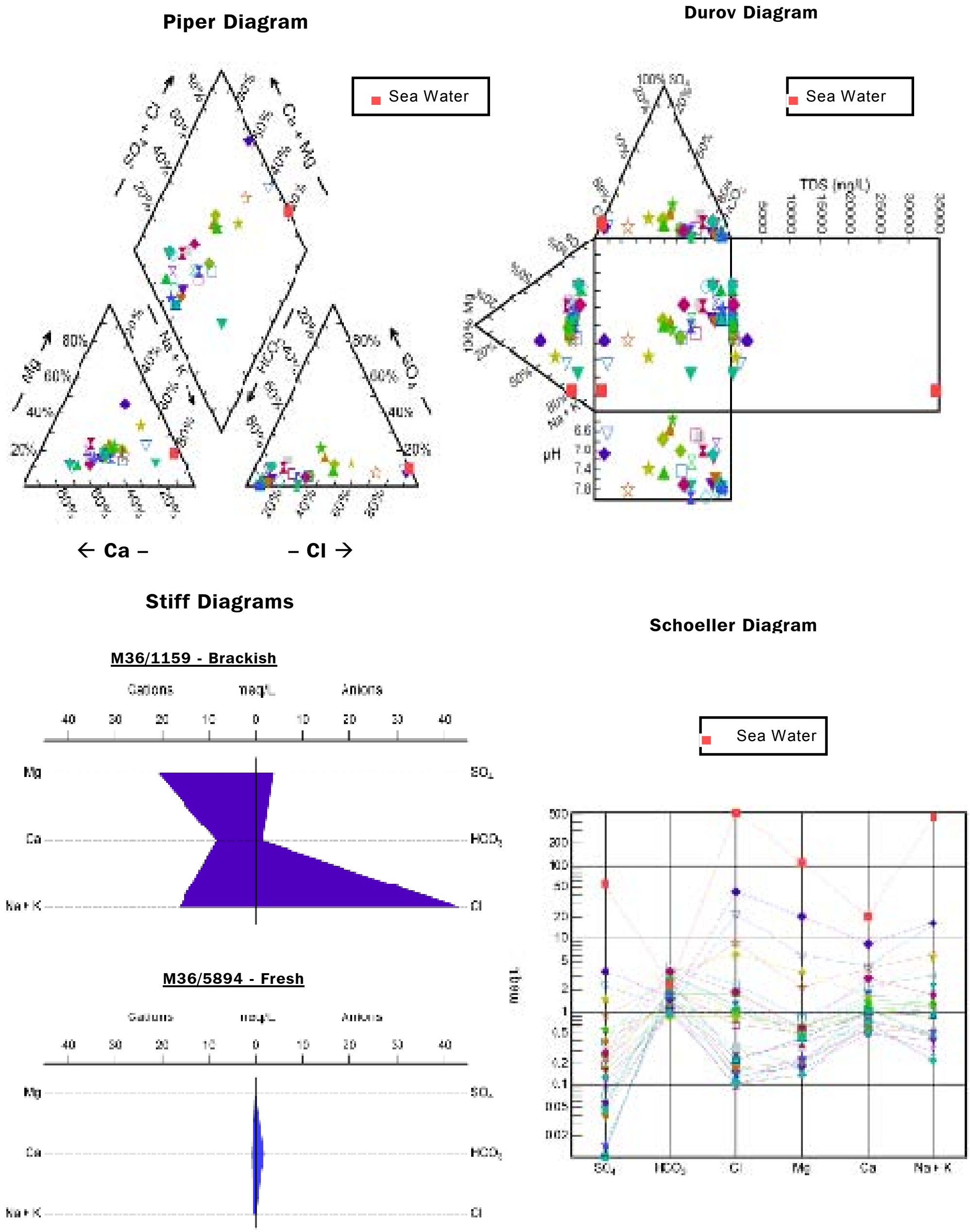


**Figure 8: Examples of graphical presentations to demonstrate sea water intrusion trends.**

In interpreting groundwater chemistry patterns, it is important to recognise that coastal rainfall and sea spray have elevated concentrations of the same chemicals that are elevated in sea water. For that reason, it is important that interpretations of groundwater chemistry are accompanied by groundwater level monitoring. For example, where increases in dissolved chemicals in the groundwater of an unconfined aquifer coincide with increased groundwater levels, it is an indicator that coastal rainfall recharge is a likely cause of the change in chemistry, not sea water intrusion.

Within the groundwater literature, there is often a suggestion that sea water intrusion should be avoided because the effects are not easily reversed. However, the experience in New Zealand indicates that this is not always the case, as noted in Section 3 of this report. Occurrence of sea water intrusion into shallow unconfined aquifers tend to be of a short-lived seasonal extent, with a reasonably rapid return to fresh water once pumping is reduced and recharge increases. This is most likely due to the relatively inert nature of the aquifer sediments with low adsorption characteristics such that the saline water can move in and out of the aquifer with relatively little retardation from the aquifer matrix. However, in areas where silty or clayey sediments exist, or in aquifers that respond more slowly to abstraction effects, there is the possibility of longer lasting salinity effects that may take longer to flush out.

## 7.0 Sea Level Rise

The sea water intrusion concerns discussed in the earlier sections of this document have primarily been related to the effects created by groundwater pumping close to the coastal margin. However, the increasing rate of sea level rise that is suggested to occur in the coming decades adds another mechanism that could cause the landward movement of sea water even if there is no increase in groundwater abstraction. In particular, one of the causes of sea water intrusion identified in Table 2 of this guideline is the landward movement of surface sea water, which is one of the effects resulting from sea level rise. This is of particular significance given the climate change effects that are expected to cause a rise in sea level to occur over the next few decades.

There are a number of causes of sea level change operating over different time scales. Dawe (2007) describes these as:

- short-term fluctuations arise from meterologic conditions such as wind, wave and barometric pressure (for example a 1.0 hPa drop in atmospheric pressure results in about a 1 cm rise in sea level, so low pressure systems can result in sea level rise of around 0.3 metres);
- medium term fluctuations operate on annual and inter-decadal climatic variations, which are mainly caused by:
  - seasonal temperature changes can alter sea levels by $\pm$ 0.08 m;
  - the Southern Oscillation (El Nino/La Nina cycles) can alter sea levels by $\pm$ 0.12 m;

– the Interdecadal Pacific Oscillation occurs over a 20-30 year cycle and can alter sea levels by up to ± 0.05 m.

These fluctuations will continue to occur against a background of rising sea level. Whilst there is still much uncertainty about the magnitude of climate change effects, it is appropriate to consider predictions of changes that might occur over the next 50-100 years.

The 2008 Climate Change Leadership Forum Report Number 7 states that historical measurements show global average temperatures have warmed by more than 0.7°C over the last 100 years. The ocean absorbs around 80% of this extra heat, causing expansion of the water coupled with melting of ice bodies. The result is that sea levels around New Zealand have risen by around 0.17 m over the last century. The average rate of increase has been 1.0 mm/year over the last 40 years, increasing to 3.1 mm/year between 1993-2003.

Figure 9 shows the historical observations of sea level rise and the range of model predictions which suggest the following potential range of changes:

- by 2040 +0.08-+0.22 m;
- by 2090s +0.18-+0.59 m.

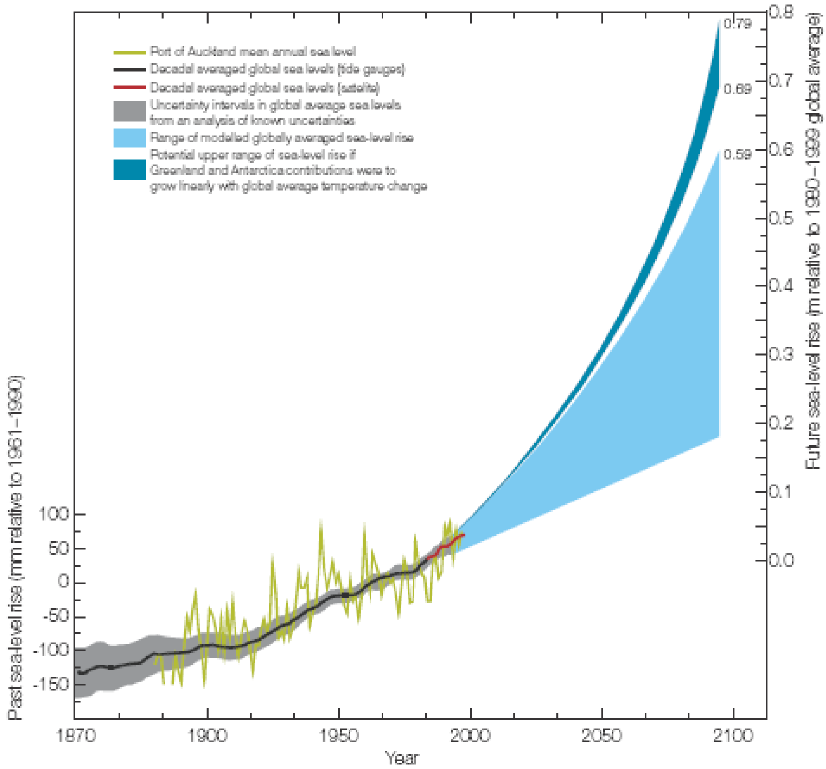


**Figure 9: Observations of past sea level rise and projections of future global mean sea level rise to the mid-2090s.**

By the mid-2090s, a further 0.1-0.2 m sea level rise might occur if contributions from Greenland and Antarctic ice sheets were to grow linearly with global temperature changes.

Government advice of climate change makes the following recommendations for planning decisions related to sea level rise in New Zealand:

- for planning and decision timeframes out to the 2090s (2090-2099), a **base** value sea level rise of **0.5 m relative to the 1980-1999 average** should be used to assess vulnerability;
- a further assessment needs to be made of the greater risk resulting from a possible higher sea level rise of **0.9 m** by the 2090s **relative to the 1980-1999 average**.

  This could have significant implications for decisions around important or vulnerable infrastructure such as hospitals, schools, key sub-stations etc;
- for planning and decision timeframes beyond 2100 where, as a result of the particular decision, future adaptation options will be limited, an allowance for sea level rise of **10 mm/year beyond 2100** is recommended (in addition to the above recommendation).

However, for the purposes of this document and taking into consideration regional plan (10 year) and consent (up to 35 year) duration periods, it would seem reasonable to consider potential changes out to 2040, which are estimated to be generally in the range of 0.1-0.2 m. Using a value at the top end of the estimated range of +0.2 m would seem reasonable, recognising the shorter term variations that also affect sea levels.

MfE (2008) note that climate change will have an impact on the present day balance between fresh water and salt water at the coastal margin in the following ways:

- sea level rise will cause salty water to encroach further up rivers and creeks;
- longer dry or drought periods in eastern areas will lead to reduced river flows, which in turn will enable salty water to advance further up river;
- sea level rise causing higher water levels at the coast, within estuaries and lower parts of rivers, will exert a higher hydraulic head of saline water on adjacent groundwater aquifers.

In addition, it can be expected that the longer dry periods in the east will contribute to some periods of less rainfall recharge which for some aquifers will contribute to lower groundwater levels, flatter hydraulic gradients and a landward movement of the subsurface interface.

Therefore, the effect of sea level rise causes three situations that increase the risk of sea water intrusion:

- an increased sea water level at the coastline;
- an associated migration of surface sea water in a landwards direction
- a lower and flatter freshwater groundwater system.

These factors will change the position of the sub-surface sea water interface in the following ways:

- there will be a higher sea water head at the coastal margin, although in many instances the fresh groundwater head will rise in sympathy to the rising sea level such that the difference between the fresh water/sea water head may not be greatly different;
- the point at which surface sea water sources occur will be further inland, thereby resulting in a subsurface interface that is displaced inland by an equal distance;
- for some aquifers there will be a reduced groundwater barrier to the subsurface location of saline water.

Werner and Simmons (2009) consider two extreme conceptual scenarios to determine the potential inland movement of the toe of the salt water interface that might result from sea level rise.  Their conceptual model is shown in Figure 10.

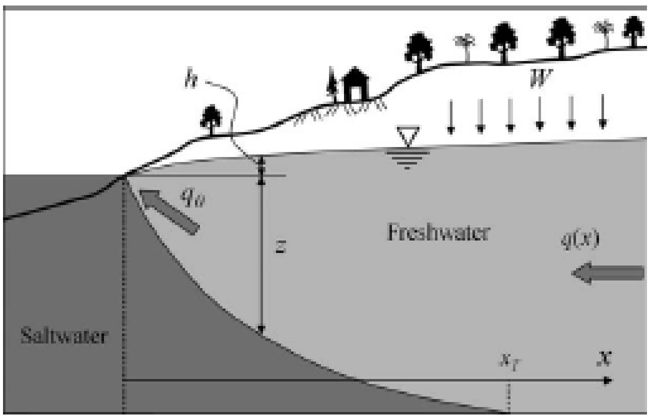


**Figure 10: Conceptual model of sea water fresh water interface for analysis with the Werner and Simmons equations (2009).**

One end point for their calculations is a constant flux scenario, which assumes that the fresh groundwater recharge q(x) at some point inland of the interface remains constant. The other end point is a constant head scenario where the fresh groundwater head at some point inland of the interface remains fixed and does not rise along with the sea level, resulting in a decreasing hydraulic gradient and fresh water through-flow as sea level rises.  The cause of this constant head scenario could be a surface drainage network that intersects the groundwater and maintains constant heads, or a constant head pumping situation.

The analysis in this paper presents modifications of Glover's equation that includes a term for aquifer recharge in the coastal margin (W).  The analysis involves the definition of parameters which must fit three equations which define the position of the toe of the interface ($x_T$) and the fresh water head at that location as it is approached from both the coastal and the landward directions.  The three equations are solved iteratively using the parameters defined in Figure 10.

Firstly, the fresh water head in the zone of the salt water interface, h ($0 < x < x_T$), is defined as:

$$h = \sqrt{\frac{2q_0 x - Wx^2}{K(1+\Delta\rho)}} \qquad \textit{Equation 11}$$

Where:

x: is the distance inland from the position of the coastline (and $x_T$ is the inland extent of the toe of the salt water interface at the base of the aquifer);

$q_0$: is the discharge of fresh groundwater into the sea per unit length of coastline;

W: is the surface recharge to the aquifer;

K: is the hydraulic conductivity of the aquifer.

Secondly, the toe of the salt water-fresh water interface intersects the base of the aquifer at an inland distance, $x_T$, which is defined as:

$$x_T = \frac{q_0}{W} - \sqrt{\frac{{q_0}^2}{W^2} - \frac{K(1+\Delta\rho){z_0}^2}{W(\Delta\rho)^2}} \qquad \textit{Equation 12}$$

Where:

$z_0$: is the depth below mean sea level to the base of the aquifer. Because the reference point for this parameter is mean sea level, it actually increases as sea level rises.

Thirdly, the solution must also fit the definition of the fresh water head on the inland side of the toe of the salt water-fresh water interface, h ($x > x_T$), which is defined as:

$$h = \sqrt{\left(\frac{2}{K}(x - x_T)\left(q_0 - \frac{W}{2}(x + x_T)\right) + (h_T + z_0)^2\right)} \qquad \textit{Equation 13}$$

These three equations do not define a realistic inland position of the fresh water head, in fact a water table mound is created at a distance that can be defined as:

$x_m = \dfrac{q_0}{W}$, at which point q ($x_m$) = 0.

However, the area of interest for this solution is the area between the coast and the inland distance $x_T$. Therefore, the parameters used in equations 11, 12 and 13 must always ensure that:

$$x_m > x_T$$

and this is achieved by ensuring that:

$$q > q_{\min}$$

where

$$q_{\min} = \sqrt{\frac{WK(1+\Delta\rho){z_0}^2}{(\Delta\rho)^2}} \qquad \textit{Equation 14}$$

Provided these constraints are adhered to, equations 11, 12 and 13 can be solved iteratively to define how the position of the toe of the salt water interface could change as a result of sea level rise.

Werner and Simmons have carried out sensitivity analyses for various combinations of aquifer parameters which are presented in Figure 11 and were calculated for a 0.88 m rise in sea level. They show how the various parameters influence the calculated response of the interface to sea level rise, as summarised below.

| **Parameter** | **Response in Constant Flux Scenario** | **Response in Constant Head Scenario** |
|---|---|---|
| Throughflow ($q_0$) | Larger inland movement of the interface as $q_0$ decreases towards $q_{min}$ | $q_0$ is not specified for the constant flux scenario |
| Hydraulic conductivity (K) | Larger inland movement of the interface with higher values of K | |
| Depth of aquifer ($z_0$) | Larger inland movement of the interface with thicker aquifers | |
| Recharge rate (W) | Larger inland movement of the interface with increasing recharge | Larger inland movement of the interface with decreasing recharge |
| Inland head ($h_i$) | $h_i$ is not specified for the constant flux scenario | Larger inland movement of the interface with decreasing inland head |

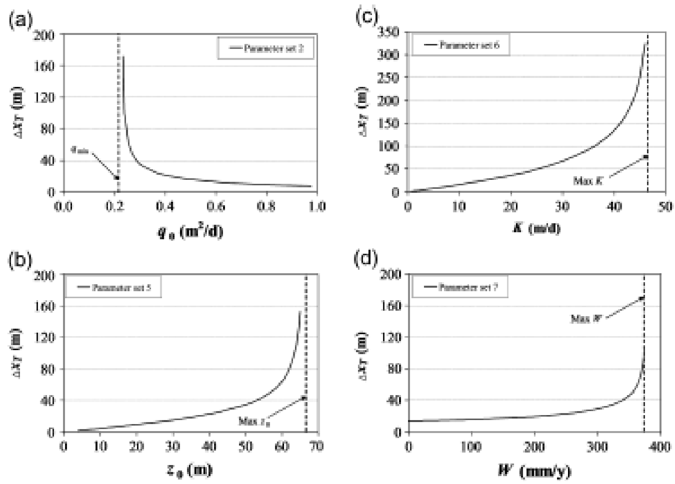


**Figure 11a: Illustrative examples (a to d) of parameter sensitivity analyses for constant flux case.**

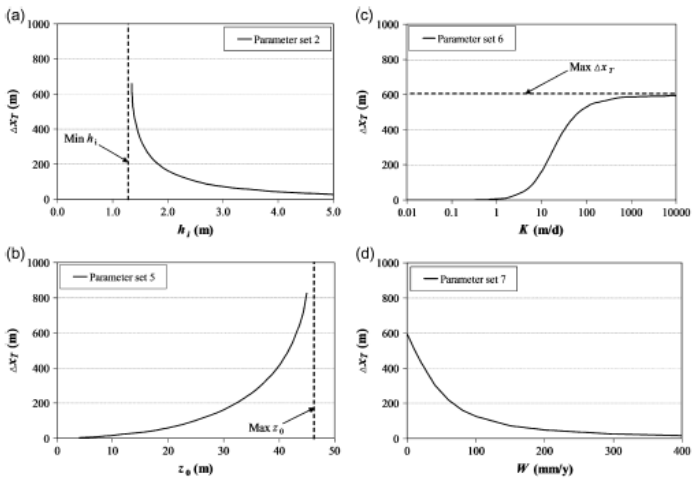


**Figure 11b: Illustrative examples (a to d) of parameter sensitivity analyses for constant head case.**

| Parameter Set | $z_0$ (m) | $W$ (mm/year) | $K$ (m/d) | $q_0$ ($m^2$/d) | Conditions Producing Interface Limits |
|---|---|---|---|---|---|
| 1 | 30 | 40 | 10 | 0.16–0.87 | $q_{min} = 0.159$ $m^2$/d |
| 2 | 30 | 80 | 10 | 0.23–0.98 | $q_{min} = 0.225$ $m^2$/d |
| 3 | 30 | 120 | 10 | 0.28–1.08 | $q_{min} = 0.275$ $m^2$/d |
| 4 | 50 | 80 | 10 | 0.39–1.38 | $q_{min} = 0.375$ $m^2$/d |
| 5 | 4–65 | 80 | 10 | 0.50[2] | $z_0$[1] = 66.7 m |
| 6 | 30 | 80 | 0.01–46 | 0.50[2] | $K$[1] = 46.7 m/d |
| 7 | 30 | 0–374 | 10 | 0.50[2] | $W$[1] = 374 mm/year |

[1]Maximum allowable values. [2] For constant head scenario $h_i$ is set at 2 m at a location 2 km from the coast

**Parameter sets used in sensitivity analyses.**

**Figure 11: Sensitivity analyses for some land rise calculations by Werner and Simmons (2009).**

The use of these equations also show a significantly larger inland movement of the interface (often >100 m) for the constant head scenario compared to the relatively small movements (typically <50 m) that occur in the constant flux scenario. Therefore, it is important to understand the conceptual hydrogeological setting and the dominant factors in groundwater movement when assessing sea level rise effects.

An example of the type of changes that might occur from a 0.2 m rise in sea level (e.g. in the period between 2010 and 2040) is shown in Figure 12 for the following parameters:

- aquifer thickness ($z_o$) = 20 m;
- distance to inland boundary (L) = 2,000 m;
- recharge rate (W) = 300 mm/year;
- aquifer through-flow at inland boundary ($q_o$) = 1 $m^2$/day, for constant flux scenario;
- constant head at inland body ($h_i$) = 1 m, for constant head scenario.

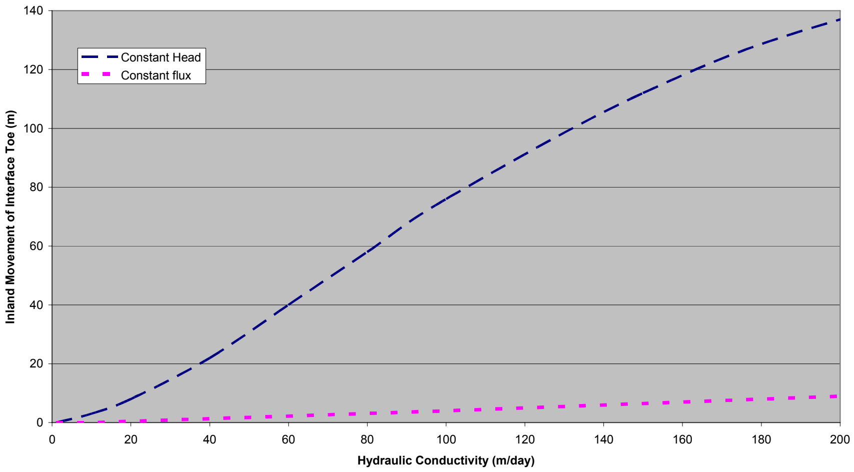


**Figure 12: Simulation of possible inland movement of the interface for a 0.2 m rise in sea level.**

The results show the variable outcomes that occur depending on the hydraulic conductivity value for the aquifer and the type of model that is chosen.

It is important to recognise that the distances for the toe position ($\chi\tau$) defined by the use of equations 11 12 and 13 only calculate changes due to the vertical change in sea level. Therefore, the toe will be displaced further inland by an amount equivalent to any landward shift of the sea water fresh water boundary in the surface environment. In many cases, this surface effect may prove to be more significant than the subsurface changes described above.

It is also important to refer back to the guiding comments in Section 5.5, which are equally applicable to these sea level rise equations. In particular, the equations are for a steady-state situation in a homogeneous, isotropic aquifer with a permeable hydraulic connection between the fresh groundwater and the sea. These factors must be borne in mind when choosing parameters for input to the equations and/or when interpreting the results of the calculations.

## 8.0 Monitoring Strategy

As with all groundwater activities, it is not practical to fully characterise or predict the aquifer conditions and the movement of the fresh water/sea water interface based on theoretical calculations or numerical models, which can only provide a general understanding of what might occur. Therefore, based on the information presented in Sections 1-7, the implementation of a monitoring strategy is essential to assess the current risks posed by sea water intrusion on coastal aquifers and to provide a basis for developing and implementing appropriate management strategies.

Monitoring can occur at two levels. Firstly an **investigation level of monitoring** can be undertaken to understand the likely position of the sea water/fresh water interface. This is very useful for benchmarking the interface at a particular point in time and can be achieved by:

- direct observation by sampling existing groundwater bores for areas in close proximity to sea water;
- piezometric surveys, pumping tests, slug tests and aquifer water balance assessments to determine the parameters that are required to estimate the theoretical position of the sea water/fresh water interface, either through the equations describe in Section 5 of this report, or through more sophisticated numerical modelling exercises;
- remote observation via geophysical surveys, particularly resistivity surveys, given the significant contrast in electrical conductivity between fresh water and sea water. However, any such remote surveys must be calibrated to direct measurements of groundwater levels and groundwater quality in boreholes.

Such field monitoring is best repeated at intervals that correspond to periods of significant changes in the water resource, e.g. significant changes to the water balance due to groundwater abstractions; groundwater discharges, land use changes and/or changes in climatic conditions; or changes due to the position of the saline surface water boundary.

Secondly, monitoring can be undertaken to determine changes over time via direct measurements of **dedicated monitoring boreholes** in close proximity to sea water. As a minimum, such monitoring should involve combined measurements of both groundwater levels and groundwater quality. Groundwater quality can be based around measurements of electrical conductivity, with occasional measurements of a more complete water chemistry analysis to determine any changes to the main contributors that cause the conductivity values. Electronic dataloggers that measure both water pressure and electrical conductivity can provide a particularly detailed record of changes that occur on both a short-term (e.g. 15 minute intervals) and long-term basis. Such data often provides a very useful understanding of the factors that are influencing the groundwater system at the coastal margin.

The location and screen placement of monitoring bores requires careful judgement to provide the best indication of sea water intrusion issues.

In addition to coastal groundwater monitoring, some monitoring of groundwater levels in the range of 1-5 km further inland is also useful to provide comparative observations and to allow a calculation of the fresh water gradient towards the coastline.

These approaches to monitoring can be applied in both a regional groundwater monitoring context and in a consent specific context, as described below. The monitoring data can directly determine appropriate aquifer management strategies for fast responding aquifer systems, although a more cautious and interpretive approach to monitoring and management will be required in groundwater systems that respond very slowly to changes in the groundwater system.

## 8.1 Regional Monitoring

Regional monitoring refers to the implementation of groundwater monitoring to provide a general indication of groundwater conditions near the coastal margin. It is not practical to carry out detailed monitoring along the entire coastal margin, and therefore the monitoring should be focused on areas where sea water intrusion is most likely to occur and cause adverse consequences. The following matrix provides a basis for a relative ranking of potential locations where regional monitoring could be most beneficial.

**Table 4: Ranking Matrix for Considering Regional Monitoring Sites**

| **Ranking Parameter** | **Ranking Criteria** | **Score** |
|---|---|---|
| *A. Risk* | | *1 = Low*<br>*5 = High* |
| 1. What is the quantity of groundwater abstraction within 2 km of the coast relative to the estimated rate of groundwater throughflow, for a fixed section of coastline where higher densities of abstraction occur. | High abstraction relative to aquifer throughflow rank highest. | |
| 2. What is the fresh water head at the potential monitoring location? | Lower heads rank highest. | |
| 3. What is the expected hydraulic connection between the aquifer and the sea at the potential monitoring location? | Permeable connections rank highest, including the risk of old boreholes providing a pathway for sea water to enter the aquifer. | |
| 4. How much further inland is surface sea water likely to extend due to climate change induced sea level rise at the potential monitoring location? | The further inland the higher the ranking. | |
| 5. Is climate change likely to reduce aquifer throughflow at the potential monitoring location? | Larger reductions in throughflow rank higher. | |
| *B. Consequences* | | *1 = Low*<br>*5 = High* |
| 1. What are the consequences of sea water intrusion occurring at the potential monitoring location? | Greater consequences rank higher. | |

Ranking criteria such as this can be adjusted to add other relevant criteria for local situations and the scoring system can be weighted to make adjustments for particular circumstances. The purpose of regional monitoring can be:

- to provide an indication of the sea water intrusion situation within an area for comparison with monitoring that may be undertaken for consent monitoring purposes;
- to provide a sentinel function to indicate groundwater quality changes at either a more coastal location and/or at a greater depth than areas of abstractive groundwater use;
- to monitor changes in coastal groundwater conditions related to activities that are not controlled by consents i.e. changes caused by permitted activities for groundwater takes and discharges and sea level rise effects.

Regional monitoring can take the form of investigative monitoring (as described in Section 8.0) and/or the installation of dedicated monitoring bores. It should focus on areas that show the highest ranking of risk and consequences as defined by the ranking matrix in Table 4. Exactly how much regional monitoring is undertaken depends on the results of the monitoring and the available budget. Regional monitoring could be implemented progressively, with those sites likely to show the biggest effect implemented first. If the ranking is done correctly and monitoring at the highest ranked sites shows no adverse effects, then there may be a lesser requirement to undertake monitoring at any lower ranked sites.

For those councils without monitoring bores that are dedicated specifically for the purpose of assessing sea water intrusion, it is still prudent to periodically review the results of general water quality monitoring for changes in water levels and/or electrical conductivity that would indicate if a higher risk situation is developing.

## 8.2 Consent Monitoring

Monitoring of sea water intrusion issues is important for a wide range of consents in the coastal environment, including:

- groundwater abstraction consents that will lower groundwater levels and reduce the hydraulic gradient in the coastal area;
- land use consents for excavations that will allow the landward movement of sea water to occur, such as the construction of inland waterways;
- consents for management of wastewater discharge that may alter the hydraulic head and/or the rate of groundwater throughflow towards the coast;
- bore permits to construct new bores require a high standard of construction to avoid creating migration pathways into an aquifer;
- bore permits to decommission bores must be rigorously enforced to ensure that proper grouting and sealing is undertaken so that potential migration pathways are sealed up.

Because these consented activities relate to site specific effects that can be of greater magnitude than other smaller or more widespread effects, they will often warrant site specific monitoring requirements. In particular, large coastal groundwater abstractions may create the lowest point in the piezometric surface and the greatest gradient reversal from the sea and as a result may be the first location to see the effects of sea water intrusion. If consents for such activities are granted, it may be appropriate to require continuous monitoring of groundwater pressures and electrical conductivity within the abstraction bore, in addition to flow metering of the abstraction rate. In addition, monitoring of water levels and water quality at a sentinel well located closer to the sea water and/or deeper in the aquifer may also be required.

For other changes arising from excavation or discharge permits, dedicated monitoring of groundwater pressures and groundwater quality may be required in the areas of potential effects.

Bore construction and decommissioning issues require monitoring site visits to ensure the necessary site works have been completed to a suitably high standard.

Consent conditions could include the following requirements:

- monitoring of abstraction rates and volumes from each abstraction bore;
- establishment of a sentinel monitoring bore;
- monitoring of groundwater levels and electrical conductivity in the abstraction bore (and a monitoring bore if one is specified) on a continuous basis or at weekly intervals during higher risk periods of high pumping rates (e.g. during the irrigation season) and monthly intervals during other times of the year;
- groundwater quality sampling twice a year e.g. August (prior to summer abstraction seasons) and February (towards the end of peak abstraction period) or if there is an electrical conductivity change of more than 25% or 10 mS/m (whichever is greater) from the August value;
- supply of all groundwater level and groundwater quality data to the Regional Council within seven days of it being recorded;
- imposition of restricted abstraction rates if groundwater levels fall below, and electrical conductivity increase above, specified threshold values;
- review conditions if there is evidence of a deteriorating situation, as evidenced by progressively declining groundwater levels and/or increasing electrical conductivity.

# 9.0 Management Strategy

Management of the sea water intrusion issue, as defined in water resource planning documents, can range from statements of general intent to avoid adverse effects arising from the risk of sea water intrusion through to specific limits on activities related to discrete monitoring thresholds.

It is desirable that effective management strategies are developed through the combined input of groundwater scientists and RMA planners.

## 9.1 Generic Management Goals

It is important that all regional water plans covering aquifers with a coastal boundary identify and describe sea water intrusion effects and this issue should receive special mention in policies and rules.

A reasonable approach to management of the sea water intrusion issue is to have a generic policy similar to the following:

> *"To minimise the risk of adverse effects arising from a landward shift of the sea water/fresh water interface in groundwater".*

It is considered inappropriate to have a management approach to "prevent the landward shift of the interface" because:

- the interface can naturally be present at an inland location;
- such an approach could be interpreted as prohibiting any groundwater abstraction, because all groundwater abstractions contribute in varying degrees to a landward movement of the interface;
- the interface may migrate landward irrespective of any groundwater abstraction activities due to climatic changes in the amount of aquifer recharge and/or sea level rise issues, thereby making the management goal unachievable.

Similarly, it is considered preferable to seek to "minimise the risk of adverse effects" rather than "prevent adverse effects", because our knowledge of groundwater issues is never perfect and management is largely based around judgements of risk rather than having absolute control over natural processes.

Other factors that could be considered in planning documents to address sea water intrusion risks are the imposition of more stringent requirements within a certain distance of the coastal marine area, which could include:

- a requirement to locate and operate abstraction bores in a way that minimises the risk of drawing sea water inland;
- a requirement to undertake a specific assessment of sea water intrusion effects for consent applications to abstract groundwater and/or consent applications to carry out land use activities that will allow surface sea water to move in a landwards direction;
- increased monitoring requirements of groundwater chemistry involving regular monitoring of the electrical conductivity of groundwater, with occasional sampling to characterise the chemical make-up of the groundwater – for both the regional groundwater monitoring network and large groundwater abstractions near the coast;
- more stringent constraints on Permitted Activity allowances;

- specification of sustainable limits based on abstraction rates, groundwater pressures and electrical conductivity values to be maintained at coastal monitoring bores.

The inland distance over which such special requirements should apply should be based on measurements of drawdown effects and/or land use activities causing changes that create a situation where sea water intrusion could theoretically occur.

Given the uncertainties associated with groundwater effects and the increasing knowledge that occurs over time with increased monitoring information, it may be unwise to have absolute limits specified in plans unless there is a very good understanding of the saline interface boundary as demonstrated by monitoring. As an alternative, the planning documents can focus on qualitative goals and minimisation of risks.

## 9.2 Specific Management Approaches

In many cases, the description of the generic management goal will be a sufficient basis for dealing with sea water intrusion issues. However, in some well monitored situations, more specific controls are appropriate. These controls may involve:

- requirements for more intensive monitoring;
- reductions in groundwater abstraction rates and/or pumping durations and volumes, based on monitoring data;
- tighter controls on land use activities.

The criteria that may be used to define where and when such additional controls apply may include:

(i) definition of a zone within a fixed distance of surface sea water bodies. Based on the information in Section 3 and Appendix A, such distances could be on the order of 500-1,000 m for unconfined aquifers and 2-5 km for confined aquifers, based on the potential drawdown effects that abstractions might cause at the location of the subsurface sea water/fresh water interface;

(ii) implementation of stricter controls during times when groundwater levels and/or the hydraulic gradient fall below certain trigger level values, based on the equations in Section 5;

(iii) implementation of stricter controls during times when groundwater quality starts to worsen above certain trigger levels, based on a change relative to background values and/or relative to water quality guideline criteria that are relevant to the use of the groundwater.

It is often useful to have trigger levels for both groundwater levels and groundwater quality because, unless monitoring data confirms an adverse trend occurring under particular groundwater level conditions, there is a significant degree of uncertainty as to whether the cause is sea water intrusion and whether the extra management controls are warranted. Similarly, the period of time over which a trigger is breached is a relevant consideration, particularly if there is some low permeability impedance between the groundwater and the sea water. Short-term declines in water levels below the theoretical trigger levels defined by the equations in Section 5 of this report may be perfectly acceptable, because those equations are based on steady-state equations for groundwater that has a completely unimpeded hydraulic connection to the sea. Therefore, monitoring of water quality trends at key locations is the best indicator on which to base the imposition of additional management controls.

The most precise management of this effect is achieved in aquifer systems that show a fast response to changes in the water balance, where monitoring at key indicator wells shows slight (but not adverse) water quality changes that can be rectified by feasible control of abstraction, discharge and land use activities which do not significantly impact on those activities.

However, a more cautious and conservative management approach may be required for groundwater systems that respond slowly to changes in aquifer stress.

## 9.3 Management of Situations Where Adverse Effects Occur

Where adverse effects from sea water intrusion do occur, then a more active and urgent management approach is required.

A consideration of the hydraulic balance to assess the position of the saltwater interface (as described in Section 5) also provides the rationale for solving saltwater intrusion problems. Typical approaches to solving the problem are:

i. modifying pumping practice in the coastal zone (i.e. reduced pumping rates or relocation of wells);
ii. inland artificial recharge (to increase the rate of freshwater throughflow);
iii. land reclamation (to increase the separation distance to the saltwater);
iv. freshwater injection barriers (to raise the freshwater head at the coast);
v. extraction of saline and brackish groundwater (to lower the saltwater head in the aquifer);
vi. creation of physical barriers in the lower part of an aquifer via sheet piles, grout injection.

In New Zealand, the reduction of abstraction rates and/or relocation of abstraction wells (item (i)) are the main approaches to rectify sea water intrusion problems that have occurred, and has generally proved an effective methodology. Artificial aquifer recharge (item (ii)) is also practiced in some areas, although not specifically to address sea water intrusion problems. However, it does provide a feasible means of enhancing the fresh water gradient in a seawards direction. Land reclamation (item (iii)) is another activity that is undertaken in New Zealand, primarily for the purpose of increasing coastal land availability, but it also has the effect of shifting the sea water interface. The remaining items in the list (items (iv), (v) and (vi)) are more expensive engineering solutions and not commonly practiced in New Zealand.

## 10.0 Conclusion

The occurrence of sea water in groundwater is a natural situation that is always present in the coastal environment. A number of different activities can cause this saline subsurface water to migrate in a landward direction and contaminate fresh groundwater sources, such as:

- increased groundwater abstraction;
- landward movement of surface sea water bodies;
- changes to discharges into groundwater;
- management of the construction and/or decommissioning of bores.

Therefore, special management of these activities is required to minimise the risk of adverse groundwater quality effects.

Our understanding of the strata and movement of groundwater at the coastal margin is never precise. Analytical equations are available to indicate situations where sea water intrusion problems might arise, but these are typically based on steady-state situations with a perfect hydraulic connection between the fresh groundwater and the sea. Numerical models allow a more sophisticated representation of subsurface conditions, but the characterisation of the necessary modelling parameters is relatively imprecise. Therefore, such calculations cannot be relied upon to provide precise predictions of the interface location. Instead, the analytical equations and numerical models are best used to provide guidance for a monitoring regime to indicate the actual occurrence of groundwater quality patterns at key locations along the coastal margin. Such monitoring can take the form of occasional investigations to indicate the position of the interface and/or regular monitoring to demonstrate transient changes in both groundwater levels and groundwater quality (as indicated by electrical conductivity and occasional more detailed water quality analyses).

The results of such monitoring provides a sound basis for the implementation of robust and defensible management criteria. The management approach will need to be more conservative in groundwater systems that respond slowly to changes in the groundwater balance.

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## 12.0 Acknowledgement

Many of the examples contained in this report have been provided by Regional Council groundwater staff from throughout New Zealand. They have a good awareness of the sea-water intrusion issue and have incorporated this knowledge into their water resources planning and management systems. It is largely through their skill and commitment that New Zealand has experienced relatively few significant issues arising from sea-water intrusion problems. We are grateful for their contribution to this report and trust that the tools described in the report assist in their ongoing management of New Zealand's groundwater resources.

# Appendix A Examples of Management and Monitoring from Regional Councils (as practiced in mid-2010)

This Appendix presents a summary of the management and monitoring approach to sea-water intrusion that is currently taking place in New Zealand. A summary table and map show the locations of two groups of wells.

Firstly there are wells where saline groundwater has been observed that has been suspected of being due to a current sea-water intrusion origin. However, it must be acknowledged that not all these situations are confirmed instances of sea water intrusion effects caused by human activities, recognising that saline groundwater is a natural component of all coastal groundwater systems. Furthermore, many of the occurrences that are listed are historical and have been successfully addressed by appropriate management responses.

The second grouping of wells show monitoring locations that have sea-water intrusion risks as a particular focus for their monitoring, although no definitely confirmed occurrences of saline intrusion have been observed to date.

It is important to note that in all regions there are a number of other groundwater monitoring bores, some of which occur near coastal locations, however they are used for more general groundwater management purposes rather than having a particular focus on current sea water intrusion risks.

The pages following the map provide a summary of the management and monitoring approach implemented by each of the regional councils and unitary authorities throughout New Zealand.

**Table A: Summary of Locations Which Are a Focus of Sea Water Intrusion Monitoring and Management**

| Region | Main locations where saline groundwater has been observed that have been attributed to a current sea water source [1] | Locations where sea water intrusion has not occurred, but are a focus of special monitoring and management |
|---|---|---|
| Northland | Ruawai, Pataua North, Cable Bay | Mangawhai Heads east, Mangawhai Heads west, Mangawhai Village, Sandy Bay, Taupo Bay, Tauranga Bay, Te Ngaire Bay, Tapeka Point, Whananaki Bay, Taiharuru Bay, Ngunguru, Whangaumu Beach, Matapouri Bay, Oakura Bay, Bland Bay, Coopers Beach, Waipapakauri Beach, Waipapakauri East, Houhora, Taipa, Russell |
| Auckland | Waiwera, Whangaparoa Peninsula | Karaka, Middlemore, Omaha, Parakai |
| Waikato | Opoutere, Whangamata | Cooks Beach, Hahei, Pauanui |
| Bay of Plenty | Papamoa Beach | Tauranga |
| Gisborne | - | - |
| Hawkes Bay | - | Esk/Bayview, Wairoa-Mahia |
| Taranaki | Patea, Waitara | - |
| Manawatu-Wanganui | - | Manawatu coastline between Rangitkei River and Manawatu River |
| Wellington | - | Lower Hutt, Kapiti Coast |
| Tasman and Nelson City | Hau Zone, Waimea Plains, Tangmere (Takaka) | - |
| Marlborough | Havelock | Coastal margin of Wairau Plain |
| West Coast | - | - |
| Canterbury | Woolston/Heathcote, Makikihi | Eastern Canterbury Plains coastline from Waipara River to Waitaki River |
| Otago | South Dunedin | Kakanui River Mouth |
| Southland | - | Tiwai Point |

Note 1. Many of these are historical occurrences which have subsequently been addressed by appropriate management responses and saline groundwater is no longer occurring and monitoring may no longer be undertaken.


**Figure A: Main Locations of Sea Water Intrusion Monitoring in New Zealand**

**Figure A: Main Locations of Sea Water Intrusion Monitoring in New Zealand**

# A1: Northland

(Information from Ananda Hapu, Northland Regional Council)

## A1.1 Management Approach

### A1.1.1 Planning

**Regional Water and Soil Plan for Northland**

In section 10.3: Issues of Part 4 of the Plan (Resource Policy), the following issue is identified: *The potential contamination of groundwater from…….(e) Excessive pumping of coastal aquifers allowing the freshwater/saltwater interface to move inland.*

The first policy in section 10.5: Policies is *Sustainable Use and Development*:

*1. To ensure the sustainable use of groundwater resources, by avoiding groundwater takes that exceed recharge which result in any of the following: (a) Saltwater intrusion or reduced groundwater quality…..*

In Section 10.6 - Methods of Implementation, it is stated that the Council will undertake or direct the following work for Policy 1 that is related to salt water intrusion:

- *Continue to monitor the groundwater levels, spring flows (where relevant) and associated rainfall data for a number of aquifer systems;*
- *To monitor the salinity of groundwater in the shallow gravel aquifer at Russell and the shallow sand aquifer at Taipa on a regular basis and to monitor the quality of other, at risk coastal aquifers, (listed in Schedule B) as frequently as required to identify any trends;*
- *Identify other coastal aquifers where the demand for groundwater supply is increasing by assessing the number of bores being constructed and to provide information to the district councils regarding the potential risk of saltwater intrusion and faecal contamination.*

Aquifers listed in Schedule B of the Regional Water and Soil Plan for Northland are considered to be at risk from saltwater intrusion, particularly if large amounts of water are taken without the consideration of environmental effects. It is stated in the plan that *"The shallow coastal aquifers listed in Schedule B are currently being used for individual water supplies in existing settlements. These aquifers are at risk of contamination by saltwater intrusion should development continue."*

*Section 25 of Part 5 of the Plan (Rules)* sets out the Rules for the Taking, Use and Diverting of Groundwater (Including Geothermal Water). Part C of Section 25 states that a groundwater take for reasonable domestic needs or animal drinking water needs will be considered likely to cause an adverse effect on the environment in terms of Section 14(3)(b) of the RMA where it:

- Is from an aquifer listed in Schedule B and is a take for animal drinking water purposes;

- Is from an aquifer listed in Schedule B and is a take for domestic needs where the take is greater than 1 $m^3$ per day;

Except for this allowance for 1 $m^3$ per day for domestic needs, the taking of groundwater from an aquifer listed in Schedule B is a discretionary activity under the Plan (with some exceptions for bore testing, development and dewatering). In other parts of the region, the permitted activity rule allows groundwater to be taken at amounts up to 10 $m^3$ per day. The reason for the reduced allowance in Schedule B aquifers (those identified as at risk from salt water intrusion) is to enable greater control on the level of abstraction from these aquifers to prevent saltwater intrusion.

One of the criteria in Section 36.2.6: Assessment Criteria for Groundwater Takes is:

*(c) The proximity to the freshwater/seawater interface and the likelihood of any seawater intrusion affecting groundwater users.*

One of the environmental results anticipated under Section 39 of the Plan is *"No movement of the freshwater/seawater interface into shallow coastal aquifers as a result of groundwater takes."*

### A1.1.2 Consent Conditions

Conditions related to sea water intrusion are placed on abstraction consents near the coast that could increase the risk of sea water intrusion. The general condition applied reads as follows:

*"To prevent saline contamination, the Regional Council reserves the right to require the Consent Holder to cease the taking of groundwater from any or all the bore/s at such times as the chloride concentration in water delivered by any of the bores is measured by standard methods to be greater than x grams per cubic metre."*

NB: 'x' in this condition is either 200, 220 or 250 depending on the location.

## A1.2 Monitoring Results

### A1.2.1 Results from Regional Monitoring

The Council monitors wells through the National Groundwater Monitoring Programme and has its own State of the Environment (SoE) groundwater monitoring programme. Twenty-two of the thirty eight wells sampled every three months are located in coastal aquifers. The wells along the coastal margin can be seen in Figure A1.1.

The 2007-2008 Annual Groundwater Monitoring Report states that wells located in the following coastal areas are monitored:

Mangawhai Heads east, Mangawhai Heads west, Mangawhai Village, Sandy Bay, Taupo Bay, Tauranga Bay, Te Ngaire Bay, Tapeka Point, Pataua Bay, Whananaki Bay, Taiharuru

Bay, Ngunguru, Whangaumu Beach, Matapouri Bay, Oakura Bay, Bland Bay, Cable/Mangonui Bay, Coopers Beach, Waipapakauri Beach, Waipapakauri East, Houhora

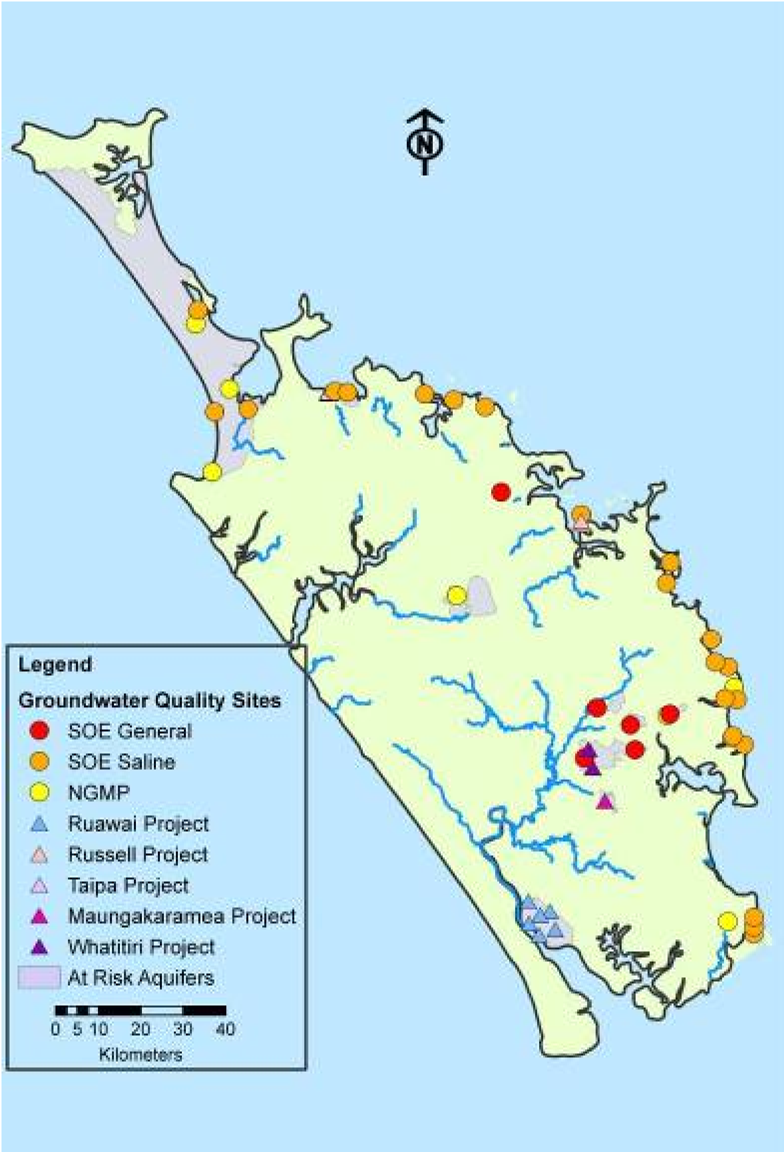


**Figure A1.1: Groundwater Quality Monitoring Sites in Northland**

Elevated electrical conductivity values have been recorded at one site in the Ruāwai area, which is discussed in section 1.3 below. Bores monitored in Pataua North and Cable Bay, which are very close to the coast, have also registered elevated chloride concentrations. However, NRC staff have noted that the bores located further inland do not show elevated chloride concentrations. It is considered that the chloride concentrations in these coastal bores are naturally occurring and there are no increasing trends that indicate that the freshwater/sea water interface is migrating inland.

The Council undertakes a specific groundwater investigation where a potential issue has been identified, such as an increased risk of salt water intrusion. The aquifers in Northland that are subject to specific investigation for salt water intrusion are Ruāwai, Taipa and Russell.

### A1.2.2 Results from Consent Monitoring

Around 46 consents currently have monitoring conditions related to sea water intrusion monitoring.

## A1.3 Cause of Sea Water Intrusion Problems and the Response to Them

**Ruāwai Monitoring Results**

The Ruāwai area, located approximately 15 kilometres south of Dargaville, is predominantly an alluvial flood plain consisting mainly of mud, sands and peat. One of the issues in the area is groundwater abstractions resulting in saline (saltwater) intrusion.

The 2008-2009 Annual Groundwater Monitoring Report states that the test results from 6 bores at Ruāwai show that saltwater intrusion is occurring on the south-eastern zone but that there are no significant increasing trends. The following graph of conductivity data from 6 monitoring wells illustrates this.

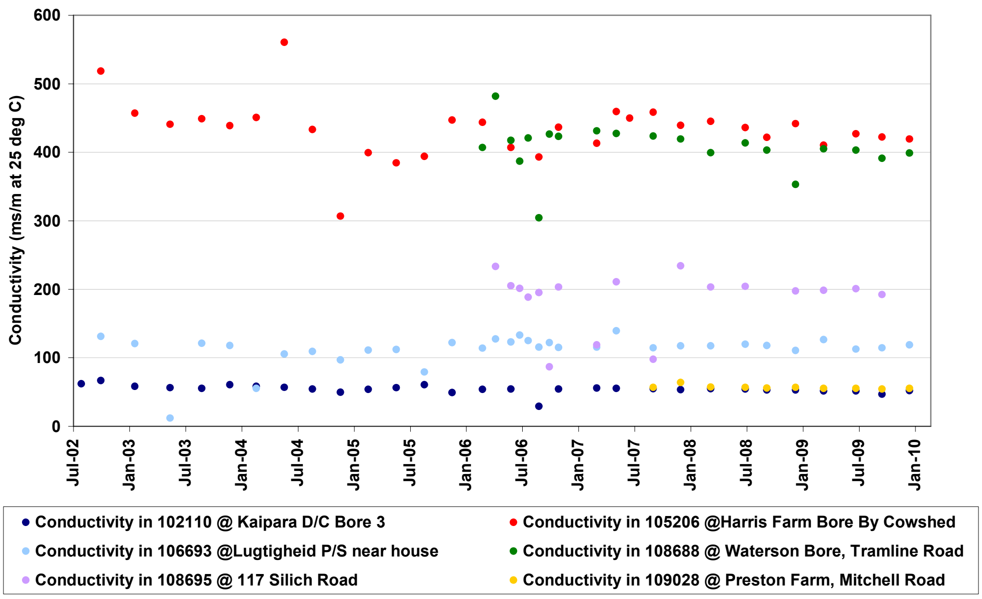


**Figure A1.2: Groundwater Quality Data from Sites at Ru□wai**

**Taipa Monitoring Results**

Taipa is a coastal aquifer with a saline boundary on the northern and eastern edge of the aquifer. The Taipa aquifer has similar groundwater issues to Ruāwai, including potential for saline intrusion.

The 2007-2008 Annual Groundwater Monitoring Report states that over the monitoring period, there had been no significant variation in chloride levels in bores adjacent to the foreshore. Two extreme outliers have historically been observed at the Greer House well, however their isolated occurrence suggests they may be related to an equipment malfunction or sample contamination. The following graph of conductivity data from 4 monitoring wells illustrates the observed results.

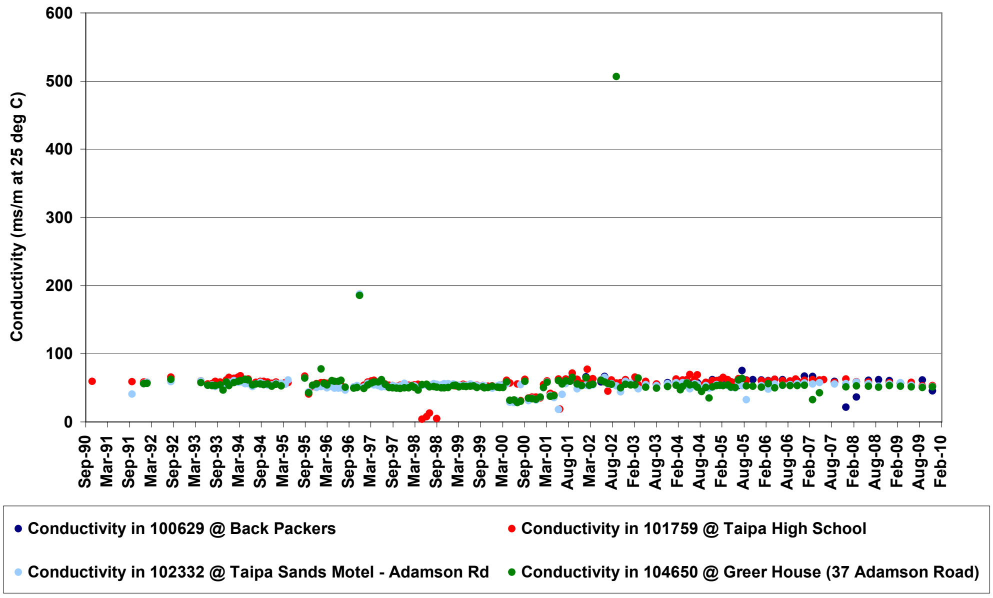


**Figure A1.3: Groundwater Quality Data from Sites at Taipa**

**Russell Monitoring Results**

The groundwater resource at Russell consists of a gravel and fractured greywacke system located close to the coast. There are many bores in the area that abstract water for domestic use. The main concern for the Russell aquifer is that reduced recharge due to wastewater reticulation, and increased groundwater use, will lead to an increased risk of saline (saltwater) intrusion. Previous groundwater modelling suggests that the reticulation of wastewater will significantly increase the risk of saltwater contamination during prolonged periods of dry weather. There are currently four monitoring bores in Russell and Matauwhi Bay. These bores are sampled and analysed for saline indicators on a quarterly basis. A new bore has been installed at the Russell foreshore to regularly record groundwater level and conductivity. This data is logged every 15 minutes and transmitted to the NRC office via a telemetry system to enable direct access to these monitoring results. This system provides an early warning of any increase in saltwater contamination in the aquifer.

The 2008-2009 Annual Groundwater Monitoring Report states that the test results from four bores at Russell showed no increase in saltwater intrusion. The following graph of conductivity data from 4 monitoring wells shows stable conductivity values.

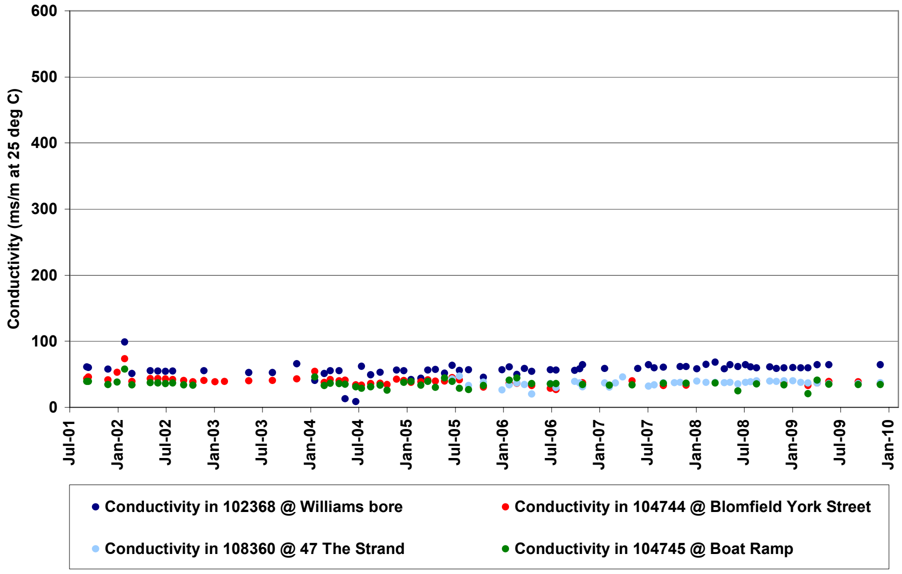


**Figure A1.4: Groundwater Quality Data from Sites at Russell**

**Monitoring Results from Other Coastal Bores**

Other coastal bores have had some elevated chloride concentrations recorded. Bores monitored in Pataua North and Cable Bay registered elevated chloride concentrations during a period of low groundwater levels in the summer of 2007-08, which was attributed to the influence of saltwater. As noted previously in section A1.2.1, this is considered to be a natural occurrence of saline groundwater.

# A2: Auckland

(Information from Nick Hazard, Sharon Vujnovich, Greg Murphy and Naveen Kumar, Auckland Regional Council)

## A2.1 Management Approach

### A2.1.1 Planning

**Proposed Auckland Regional Plan: Air, Land and Water**

In Section 2.0.4 - Rivers and Streams of Chapter 2 - Values of the Proposed Auckland Regional Plan: Air, Land and Water, it is stated that *"salt-water intrusion is another threat from over abstraction take, which will affect the ability to use the water from that aquifer."*

In Section 6.1.3.6 of Chapter 6 – Water Allocation, the effects of taking groundwater are outlined. This includes *"Changed water level and flow regimes in aquifers caused by the taking of groundwater may lead to……the degradation of water quality through saltwater intrusion……. Such changes can result in reduced water availability, both for present and future generations."*

In Section 6.1.3.7, the selection criteria for a bore location to minimise the effects of bore drilling are outlined. These include *"ensuring that the potential for saline intrusion is minimised*."

Issue 6.2.6 identifies that "*Abstracting water from aquifers, especially those in High Use Aquifer Management Areas, can reduce water levels, especially in summer when demand is generally at its peak. This can lead to……saltwater intrusion into the aquifer."*

Policy 6.4.26 states that the *"The maximum amount of water that can sustainably be allocated from an aquifer (the water availability) shall be determined by taking into account: (c) Outflow requirements of the aquifer, including (i) flow at the coast, to prevent saltwater intrusion and (iv) in the case of geothermal aquifers, water levels or outflow to prevent cold groundwater or seawater intrusion and reduction in aquifer temperatures;"*

Policy 6.4.30 is: *"In aquifers where monitoring shows that outflow requirements are not being met (as indicated by, for example, the occurrence of saltwater intrusion…………), adverse effects on the environment shall be avoided, remedied or mitigated by: (a) Ceasing any further allocation of groundwater; (b) Temporarily restricting the taking of water by the issuing of a water shortage direction under Section 329 of the RMA; (c) Reviewing the conditions of existing consents in accordance with General Policy 6.4.12."*

Policy 6.4.33 is: *"Any proposal to take and use groundwater for which a resource consent is required shall demonstrate that: (d) The taking of groundwater will not cause saltwater intrusion…..;"*

Policy 6.4.35 is *"Any proposal to take and use geothermal water for which a resource consent is required shall demonstrate that: (a) Aquifer water levels and pressures will be managed to avoid, remedy or mitigate: (i) cold groundwater or seawater intrusion"*

The Anticipated Environment Result 6.7.2 is that *"Aquifer water level regimes and quality are maintained sufficient to avoid any adverse effects from ……the degradation of water quality through saltwater intrusion"*

**Regional Policy Statement**

In Chapter 9 – Water Conservation and Allocation of the RPS, Objective 9.3-2 is *"To maintain water levels and flows of aquifers in the long term so as to ….. prevent seawater intrusion at the coast"*

Policy 9.4.4 is *"The availability of water in water bodies and coastal water for taking, use, damming or diversion shall be determined on the following basis:….. (g) maintenance of outflow from aquifers at the coast to prevent salt-water intrusion"*

### A2.1.2 Consent Conditions

Conditions related to sea water intrusion are placed on abstraction consents near the coast that could increase the risk of sea water intrusion. Historically, consent conditions have been based on monitoring requirements for electrical conductivity and chloride concentrations in a bore, in combination with groundwater level monitoring.

ARC staff have provided the conditions to several consents as an example. An example of the type of consent conditions includes the following:

- Measurement and recording of water levels in specified monitoring bores.
- Collection, analysis and recording of the results of water samples from the monitoring bores.
- That the exercising of the consent be subject to the maintenance of aquifer conditions which do not indicate initiation of saline water ingress from the coast. The conditions state that a programme of emergency response will be initiated by the consent holder if the aquifer conditions in any of the four saline intrusion monitoring bores, as indicated by standing water level and chloride concentrations, deteriorate from a predetermined trigger level.
- The emergency response programme consists of a number of steps to be implemented. These include (1) review of all of the available data for groundwater levels, groundwater use and groundwater quality to assess why the trigger level has been exceeded, (2) increase the frequency of monitoring of the bores (3) if after 3 consecutive samples the initiation of saline intrusion cannot be discounted, a series of reductions in the pumped volume from the deep and shallow bores to be implemented.

- The trigger level in the saline intrusion monitoring bores is reached when the chloride concentration of the groundwater in the monitoring bores is greater than double the mean value of the chloride measurements established by baseline sampling, and the standing water level in these bores have fallen below mean sea level. If the calculated doubled mean value is greater than 250 mg/L, the trigger level is to be set by the Director Environmental Management, Auckland Regional Council, in consultation with the consent holder and local representatives, based on a review of the groundwater quality data from bores in the local area.

## A2.2 Monitoring Results

### A2.2.1 Results from Regional Monitoring

Two of the major aquifers in the Auckalnd region: The Kaawa Aquifer and the Waitemata Group sandstones extend to the coast.

The Council monitors twenty four sites through their State of the Environment (SoE) groundwater monitoring programme (ARC, 2007). These sites have been sampled every three months since September 1996.

These wells are as shown in the Figure A2.1. Several of the wells are located close to the coast. The State of the Auckland Region report 2010 – Chapter 4-3 Freshwater did not identify any indicators of the occurrence of seawater intrusion.

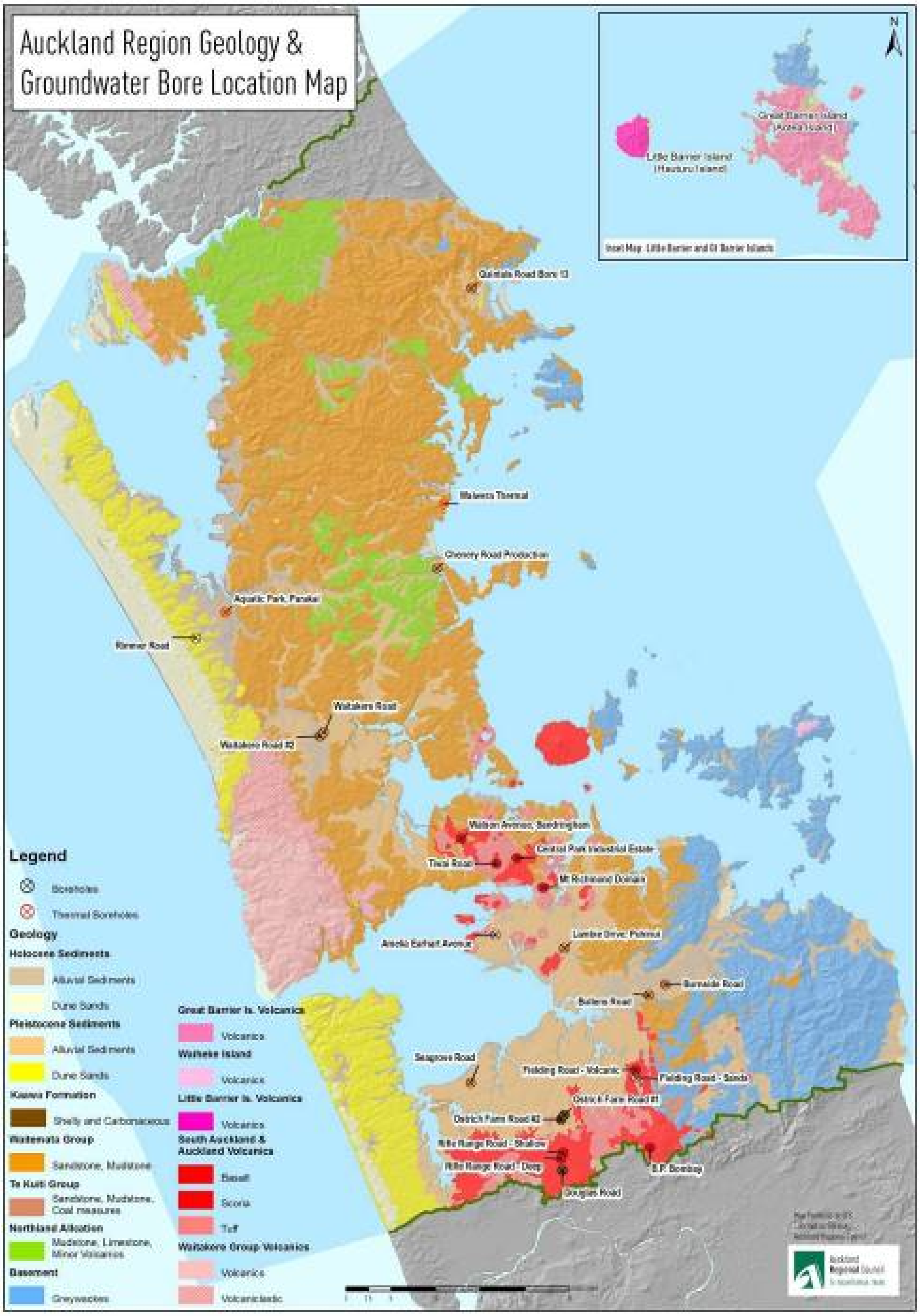


**Figure A2.1: Groundwater Quality Sites**

(NB: This map is being updated by the ARC in July 2010. Amelia Earhart should be labelled Kaawa and Douglas Rd should be labelled S. Auckland Volcanics)

### A2.2.2 Results from Consent Monitoring

Around 58 consents currently have monitoring conditions related to sea water intrusion monitoring.

Monitoring results from a consented groundwater abstraction at Karaka have been provided by ARC. Figure A2.2 below shows a time series of groundwater levels measured in four monitoring wells at the site with a general declining trend in groundwater levels being evident.

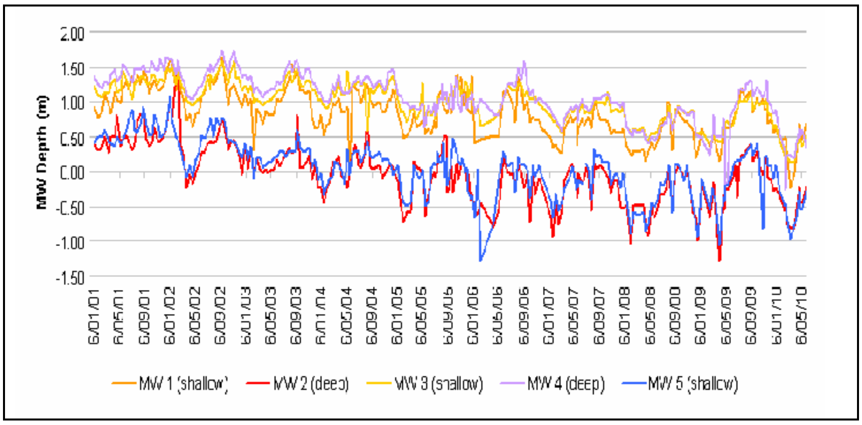


**Figure A2.2: Time Series of Groundwater Levels at Karaka**

Due to some residual uncertainty in the sustainability of the allocation, the Environment Court issued a stepped increase to the allocation, with monitoring requirements and contingency plan provisions already discussed in section A2.1.2. Water level records in Figure A2.2 are a response to this stepped increase, and show a general declining trend in groundwater levels. Monitoring bores MW1-MW4 cover groundwater conditions at shallow and deeper depths in two directions.

Figure A2.3 below shows a time series of chloride and sulphate concentrations in one of the monitoring wells at the site.

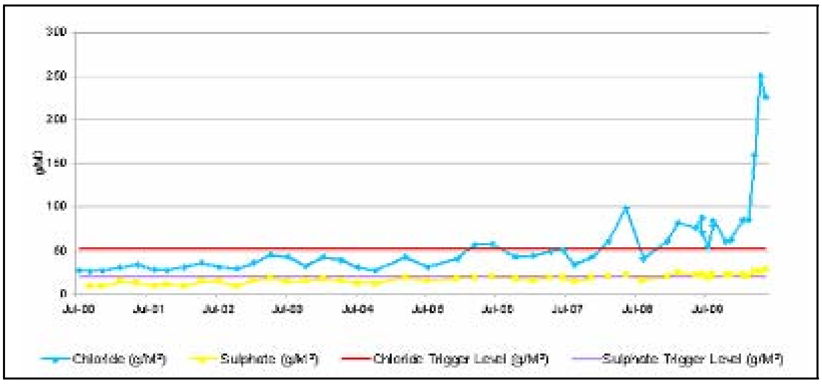


**Figure A2.3: Time Series of Chloride and Sulphate Concentrations in a Monitoring Bore at Karaka**

It is evident in Figure A2.3 that chloride concentrations in this well have increased since 2000 to the point where in more recent years they have been consistently above the consent trigger level guideline. Sulphate concentrations show a small increasing trend but remain below the guideline trigger level. One other well at the site shows some instances where the trigger level for chloride is exceeded, however the other two monitoring wells at the site show stable concentrations of chloride and sulphate.

Other large abstraction consents include monitoring for seawater intrusion, such as Fonterra at Papakura and NZ Steel at Glenbrook, although no problems have been reported. Similarly a water supply abstraction at Orewa was observed to draw water levels down to 30 metres below mean sea level with no observed intrusion problems.

Conversely some smaller abstractions at the end of the Whangaparoa Peninsula and at Waiheke Island have result in localised sea water intrusion effects

## A2.3 Cause of Sea Water Intrusion Problems and the Response to Them

The risk of seawater intrusion has been identified for a number of areas and is managed carefully through determination of appropriately conservative groundwater availabilities which maintain a head of groundwater at the coast, and through consent monitoring.

The Auckland Volcanic Aquifers are managed to maintain aquifer water quality but are generally not close to the coast, so saline intrusion is typically not an issue.

The Parakai Geothermal Resource is an area where a limit has been set to maintain aquifer water levels sufficient to avoid cold landward groundwater or seawater intrusion, which could result in a reduction in aquifer temperature. Therefore, whilst the key management issue is maintaining temperature, it is necessary to avoid seawater intrusion to achieve that objective.

At Omaha there is an ARC monitoring bore and abstractions are managed to maintain a management groundwater level. Groundwater availability limits have statutory status due to their specification in the regional plan and there is monitoring of actual use compared to allocations. Any individual consent applications adjacent to the coast are carefully considered relative to an estimate of availability – taking into account the risk of seawater intrusion.

The rapid population growth in the Orewa/Whangaparoa Peninsula saw the establishment of local borefields to provide a reticulated water supply. ARC (2002) notes that this resulted in rapidly declining water levels. In many places, groundwater levels declined below sea level and saline intrusion become a problem. This was addressed in 1995 when the local borefields ceased pumping when the source of supply was changed to the Watercare Services network.

A limit has also been set for groundwater at Middlemore. ARC (2002) states that at Middlemore groundwater demand is for irrigation water for Auckland Golf Club and Grange Golf Club. Both golf courses have coastal boundaries and the greatest risk to the groundwater resource is from saline intrusion. ARC (2002) note that the proximity to the coast also means that the golf club bores will be the first to detect salt-water intrusion and elevated chloride and sodium will have an adverse effect on the courses. It is concluded that it is in the best interests of the consent holders, therefore, to keep within the allocations granted.

There is a site in the Karaka area where there is ongoing monitoring of both water levels and chemistry (there has been the occasional elevated chloride concentration). As with Auckland Golf Club and Grange Golf Club, the proximity to the coast means that consented takes with monitoring requirements will be the first to detect salt-water intrusion and it is in their best interests to manage their abstractions to avoid any adverse effects occurring.

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# A3: Waikato

(Information from Ed Brown and John Hadfield, Environment Waikato.)

## A3.1 Management Approach

### A3.1.1 Planning

**Variation 6 of the Waikato Regional Plan**

| | |
|---|---|
| Policy 2 | Establish and set sustainable yields from groundwater resources which are to be used when assessing authorised water takes and resource consent applications and that:<br>a) protects the groundwater resource from salt intrusion;<br>b)-i) |
| Policy 9 | Consent Application Assessment Criteria for groundwater takes includes having regard to the potential for salt water intrusion from individual and cumulative abstraction effects. |
| Rule 3.3.4.9 | Permitted Activity takes, limited to 1.5 $m^3$/day within 600 m of the coastal marine area, compared to 15 $m^3$/day further inland. In both cases, the activity is permitted provided that (amongst other things) the activity shall not result in salt water intrusion. |

The 1.5 $m^3$/day within 600 m of the coast criteria is explained in the Section 32A report as follows:

*In the coastal aquifers of the Region depending on aquifer characteristics (i.e. transmissivity of 10 $m^2d^{-1}$ and storativity of 0.001 to 0.0001) a single permitted take of 15 $m^3$/d after 30 days of operation (potential duration of use over peak summer period) could cause a drawdown in water levels of between 350 mm and 100 mm at a distance of 600 metres from the well. This drawdown would be accentuated if there is more than one permitted user nearby in the same aquifer and if the users are located closer to the costal marine area. The permitted take of 1.5 $m^3$/d allows enough water for domestic use and the lower level of cumulative drawdown effects on the coastal aquifers will reduce the likelihood of saline intrusion. In the situations of properties requiring more water for stock, this can be obtained via RMA s14(3)(b).*

### A3.1.2 Consents

Consent conditions related to sea water intrusion are placed on consents on a case-by-case basis. They generally involve drawdown constraints and conductivity triggers.

## A3.2 Monitoring Results

### A3.2.1 Results from Regional Monitoring

Coastal aquifer monitoring is carried out at Hahei, Cooks Beach, Whangamata and Opoutere as part of the Coromandel coastal aquifer management project. Some of these wells are also part of the larger regional monitoring network.

### A3.2.2 Results from Consent Monitoring

The Waikato region spans the width of the North Island. The western coastal boundary is an area of relatively little groundwater use and as such, there is no indication of sea water intrusion issues . In contrast, the east coast Coromandel Peninsula has many coastal communities which experience large increases in population (and water demand) during summer holiday periods. These water supplies tend to be drawn from either fractured volcanic rock aquifers or from localised, shallow, sand aquifers via consented or individual permitted takes.

Isolated instances of sea water intrusion have arisen from these small coastal abstractions, and are being monitored and investigated by EW, including the sites shown in Figure A3.1 and discussed below.


**Figure A3.1: Waikato Locations Monitored for Sea Water Intrusion Effects**

**Opoutere**

The Opoutere Motor Camp groundwater supply was drawn from a 19.5 m deep bore with a consented abstraction of 48 m³/day from a shallow sand aquifer bounded to the east by the Pacific Ocean and to the south by the Wharekawa estuary. The sand aquifer is not extensive, being bounded to the west by fractured rhyolite, as indicated by the schematic cross-section in Figure A3.2.

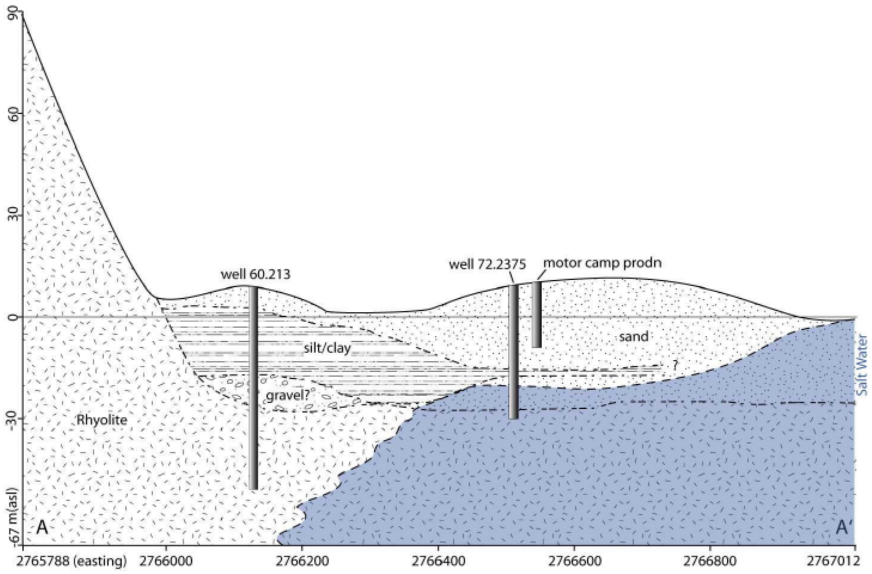


**Figure A3.2: Stylised East-West Hydrogeologic Cross-Section Indicating the Likely Saltwater Wedge Distribution**

Background chloride concentrations in this aquifer are typically around 25-30 g/m$^3$, but since 1998 chloride concentrations in the motor camp bore have typically been above 100 g/m$^3$ and occasionally above the aesthetic guideline value of 250 g/m$^3$. As a result, in 2001 the bore was considered an unsustainable source of water supply, and the motor camp has reverted to a roof water supply for drinking water, with the well only used for non-potable purposes.

A resistivity survey was undertaken to investigate the location of saline water, but the results were not definitive and drilling investigations were preferred.

An investigative monitoring well drilled just to the north of the motor camp bore shows the presence of a fairly sharp saline interface at a depth of 28 m, as shown in Figure A3.3. Static water levels in the area have been measured to occur at an elevation of around 0.4-1.1 m above mean sea level.

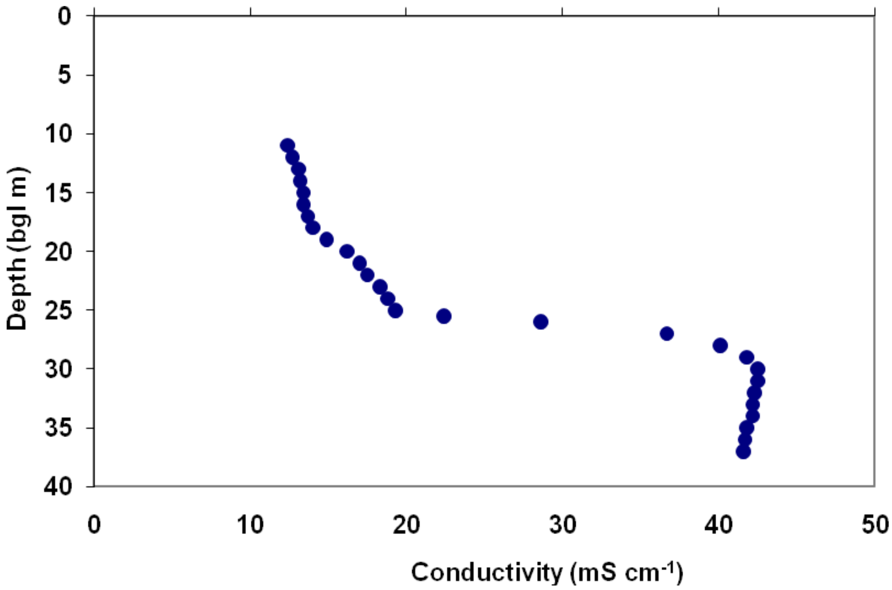


**Figure A3.3: Conductivity Profile of Well 72.2375 (11/6/5)**

**Cooks Beach**

Cooks Beach is located on the east coast of the Coromandel Peninsula and is underlain by a shallow sand aquifer around 6 m deep. This aquifer is underlain by estuarine silts and rhyolite at a depth of around 8-15 m.

On-site household wastewater disposal systems have been replaced by a reticulated sewer system which has removed a component of the local water balance and increased the risk of sea water intrusion. Sentinel wells have been installed to monitor water levels and salinity, but no problems have arisen to date.

**Hahei**

Hahei is a small beachside community located near Cooks Beach that derives its water supply from 50-100 m deep bores drilled into fractured rhyolite aquifers. The total consented abstraction is small (~640 $m^3$/day), but the low transmissivity of the strata (13 $m^2$/day) leads to large drawdown of groundwater levels below sea level, which extends to the coast, creating a risk of sea water intrusion. A deep sentinel well has been established at the coast and groundwater levels and quality are monitored at this and existing wells. Consented takes have groundwater level and conductivity constraints.

**Pauanui**

The eastern Coromandel settlement of Pauanui is underlain by a sand barrier aquifer system that is used both for water supply and subsurface wastewater disposal. The water table over much of this sand lens is less than a metre above mean sea level.

Hydraulic conductivity of the strata is reported to range from 10-80 m/day and consented abstractions total 1,400 $m^3$/day. This creates a high risk of sea water intrusion.

Consent conditions limit the maximum amount of drawdown to avoid sea water intrusion, and set an electrical conductivity trigger level of 150 mS/m for potential cessation of pumping.

**Whangamata**

Whangamata has a permanent population of 4,000 and a summer peak of 30,000. Water supply is from wells tapping fractured rhyolite and andesitic aquifers. Temporary drawdown below mean sea level occurs at most well-fields and creates a risk of sea water intrusion. Consents to take groundwater at Whangamata have conditions including conductivity triggers. One water supply well has been shut down because of an increasing conductivity trend which has exceeded the trigger.

## A3.3 Cause of Sea Water Intrusion Problems and Response to Them

The occurrence of sea water intrusion at Opoutere appears to have have arisen primarily from upconing due to pumping of a small sand aquifer bounded on two sides by surface saline water. The motor camp water supply well has been abandoned and replaced by roof water for potable use. This situation has led to increased monitoring and investigations at Opoutere and other Coromandel coastal settings where groundwater is considered vulnerable to sea-water intrusion.

# A4: Bay of Plenty

(Information from Jonathan Freeman, Reuben Fraser and Helen Creagh (Environment Bay of Plenty)

## A4.1 Management Approach

### A4.1.1 Planning

There are no specific policies or rules relating to sea water intrusion within the Bay of Plenty Regional Water and Land Plan.

### A4.1.2 Consents

Bay of Plenty Regional Council has confirmed that there are several consents in the area that require monitoring with specific regard to risk of salt water intrusion. In general the conditions of most of these consents require the monitoring of chloride concentrations similar to the example below.

The consent holder shall take a water sample from the bore delivery pipe during September each year.

The water sample shall by analysed for chloride.

The water analysis shall be carried out as set out in the latest edition of "Standard Methods for the Examination of Water and Wastewater" ALPHA-AWWA-WEF or such other method as may be approved in writing by the Chief Executive of the Regional Council or delegate.

The consent holder shall measure and record the temperature of bore water from the delivery pipe during September each year.

The chloride analysis results and temperature records for the year ending 30 September shall be sent to the Regional Council by 31 October each year.

The consent holder shall maintain adequate access to the head of the bore and to all reticulation, for monitoring purposes, to the satisfaction of the Chief Executive of the Regional Council or delegate.

An example of a more detailed consent condition relating to dewatering of a quarry pit and intended specifically to manage a potential sea water intrusion risk is given below. We understand that these conditions are currently under appeal.

**Monitoring for Salt Water Intrusion**

Where the Regional Council considers that, based on the monitoring information provided by the applicant and/or Regional Council monitoring, that the dewatering operation at both quarry pits is causing salt water intrusion then the dewatering operation shall cease.

No less than 6 months prior to dewatering groundwater from the quarry pits the consent holder shall submit to the Chief Executive of the Regional Council or delegate, for approval construction details for groundwater monitoring bores for salt water intrusion, this proposal shall include, as a minimum, the following:

- proposed location and access to the bores;
- construction details and depth;
- at least 3 monitoring bores into the Rotoiti Pyroclastic unit;
- maintenance requirements and programme.

No less than 6 months prior to dewatering groundwater from the quarry pits the consent holder shall submit to the Chief Executive of the Regional Council or delegate, for approval a groundwater monitoring regime for salt water intrusion, this proposal shall include, as a minimum, the following:

- method and system of water level measurement;
- method and system for water quality sampling;
- method of ground water quality analysis;
- will include measurement of water levels and water quality analysis of monitoring bores prior to dewatering commencing;
- the frequency of monitoring and reporting to the regional council;
- how the data will be provided to the regional council;
- how the data will be analysed by the consent holder;
- analysis required shall be carried out by an IANZ registered laboratory.

Once the Chief Executive of the Regional Council or delegate has provided approval for the monitoring system as required under condition 10.2, and prior to any dewatering of the quarry pits, the consent holder shall install and monitor the groundwater monitoring system for saltwater intrusion.

## A4.2 Monitoring Results

### A4.2.1 Results from Regional Monitoring

There is currently no specific sea water intrusion monitoring programme in place in the region, however as discussed in Section 1.3 a proposal for a monitoring programme has been developed.

Groundwater levels are reported to potentially be below or close to sea level in 19 wells in the region and therefore some wells may be at risk from salt water intrusion. However there is some uncertainty regarding accuracy of ground level estimates in the area. The wells identified as being at risk from sea water intrusion are shown in the following Figure.A4.1

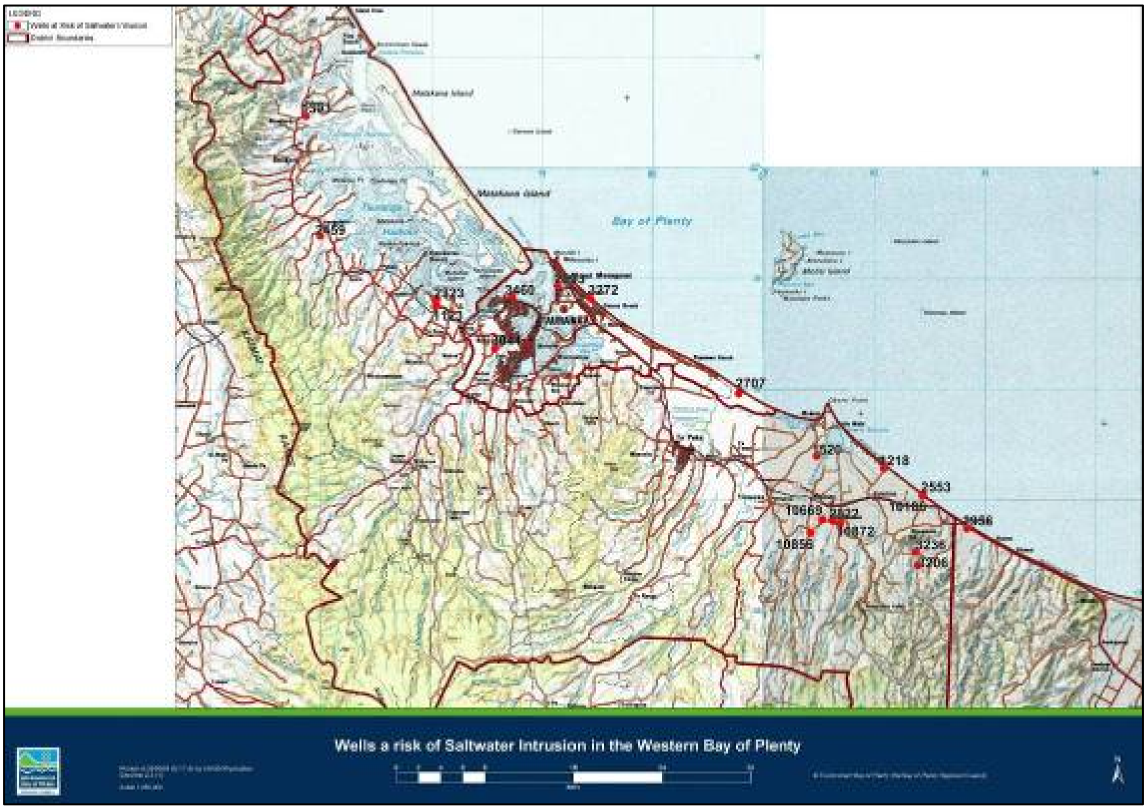


**Figure A4.1: Supplied by Bay of Plenty Regional Council**

While there are several wells near the coast which have been identified as having high concentrations of conductivity, sodium and chloride, a cause relating to saltwater intrusion is considered certain in only one of these wells. This well is 2707 located at Papamoa Beach. It is reported that based on proximity to the coast, shallow depth, relatively cold temperatures (ruling out a geothermal cause) and constant increase in multiple variables such as sodium and chloride, it is likely that well 2707 (shown in the Figure above) shows evidence of sea water intrusion. This well is used for domestic purposes and therefore the abstraction rate is low and the activity is permitted under the regional plan. Figure A4.2 below shows a time series of conductivity and chloride concentrations measured in the well between 1991 and 2009. While there is a general increasing trend in conductivity and chloride concentrations during the monitoring period, the lower concentrations measured in 2006 and 2009 are in contrast to the general trend.

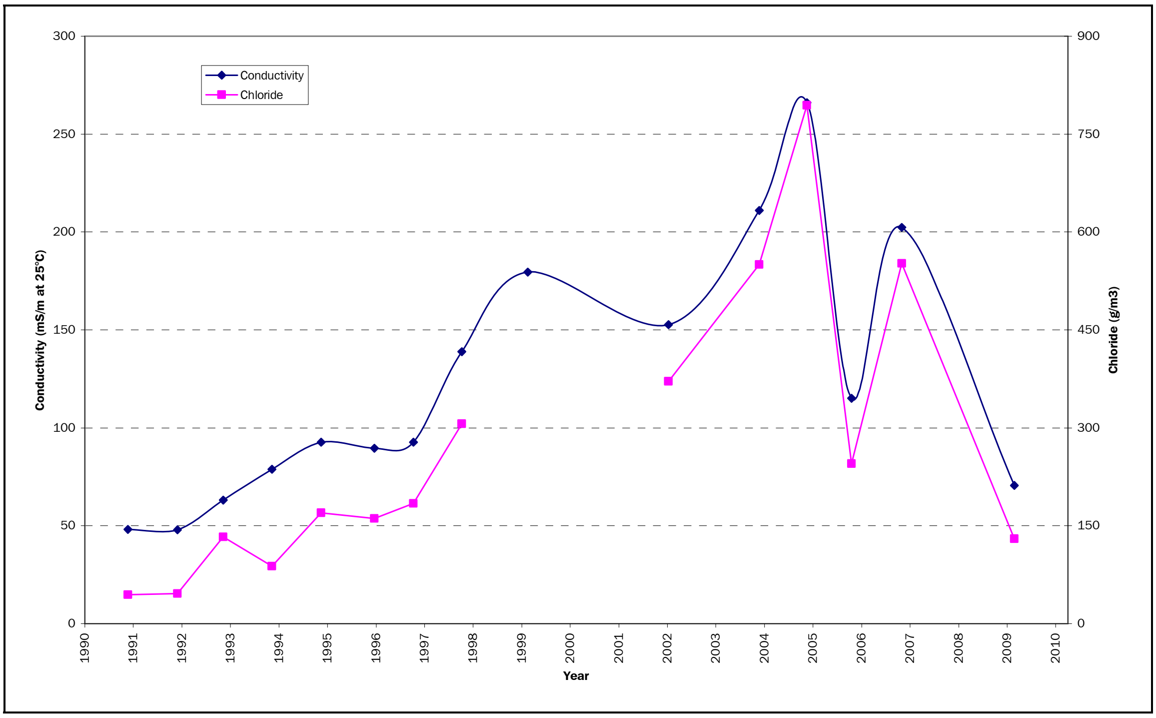


**Figure A4.2: Monitoring Data from Well 2707**

### A4.2.2 Results from Consent Monitoring

No results from consent monitoring are currently available.

## A4.3 Cause of Sea Water Intrusion Problems and the Response to Them

Further in-depth monitoring is required in order to confirm water level and chemistry results. It has been recommended that risks of saltwater intrusion are assessed when setting groundwater allocation limits and that information should be obtained on wells at risk from sea water intrusion. It has also been recommended that water levels near the coast should not be allowed to decline below sea level and that water quality data should be obtained from at risk wells.

Based on that investigation, Jonathan Freeman (Bay of Plenty Regional Council Environmental Scientist) has proposed a regional scale monitoring programme aimed at advising the Regional Council to identify long term quantitative and qualitative salinity trends.

It appears that most existing bores are not deemed suitable for physical monitoring and it is therefore proposed that new bores/piezometers are installed at suitable coastal locations. The approximate location of priority monitoring bores is shown in the Figure A4.3 below. Resistivity studies indicated in this proposed investigation/ monitoring approach may not be implemented based on cost.

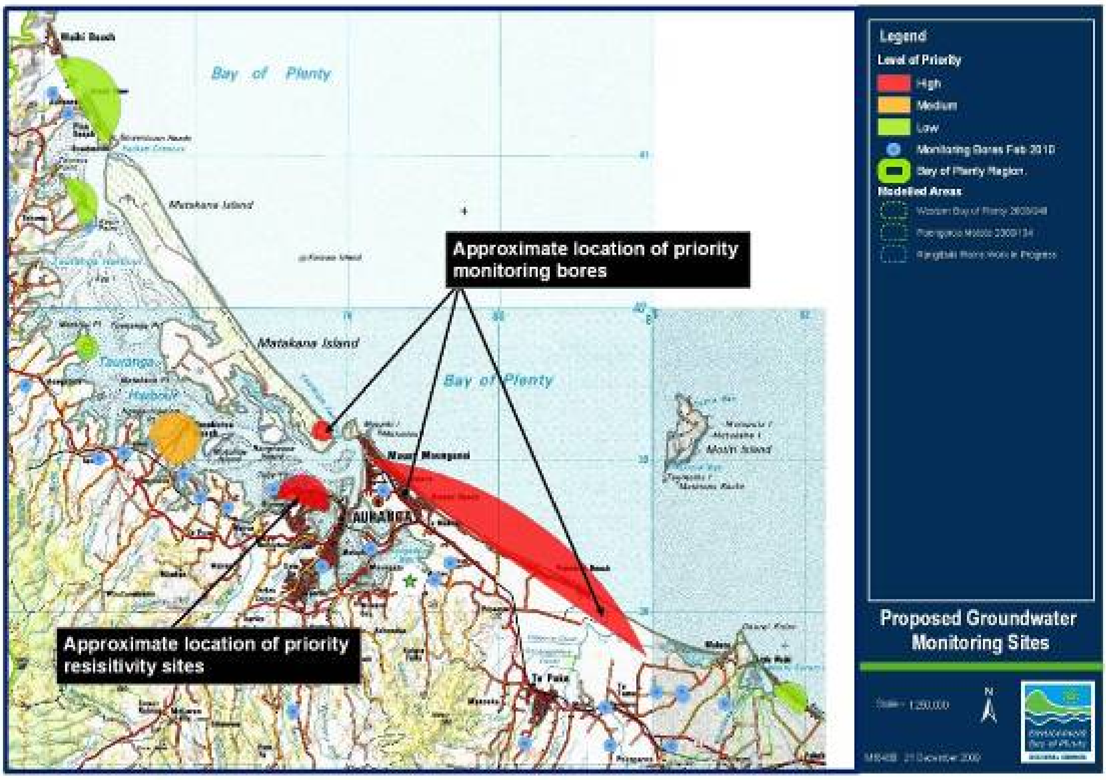


**Figure A4.3: Supplied by Bay of Plenty Regional Council**

The location of these priority sites is consistent with those areas/aquifers under pressure from abstraction. At each location an ideal proposed monitoring strategy would involve the installation of two piezometers, the first to intercept the freshwater table and the second to extend to near the base of the aquifer. Three major aquifer units are identified in the region within which monitoring is recommended, these being the Tauranga Group Sediments, Waiteariki Ignimbrite and Aongatete Ignimbrite.

Ideally automated monitoring of water levels is proposed using pressure transducers set to log at 15 minute intervals. The primary focus for water quality monitoring is the influx of salt. Chloride concentration and conductivity measurements are the main focus of proposed water quality monitoring.

It is expected that a better understanding of the cause and required response to cases of sea water intrusion will be gained by the regional council's proposed monitoring programme.

# A5: Gisborne

(Information from Dennis Crone, Gisborne District Council)

## A5.1 Management Approach

### A5.1.1 Planning

Gisborne District Council does not currently have a Water Plan and is operating under a Transitional Regional Plan. The TRP does not contain any specific references to sea water intrusion issues.

### A5.1.2 Consents

There are no specific standardised consent conditions that are used related to sea water intrusion issues. If any issues arose, they would be judged on a case-by-case basis.

## A5.2 Monitoring Results

### A5.2.1 Results from Regional Monitoring

GDC operate a network of 88 monitoring bores which are used for groundwater level monitoring and groundwater quality sampling. Around 12 of these bores are located within 2 km of the sea coast, but none have shown any effects of sea water intrusion.

### A5.2.2 Results from Consent Monitoring

No monitoring required by resource consents has shown any sea water intrusion issues. A GDC bore that was used for washing milliscreens at the Gisborne wastewater treatment plant was located at the beachfront is now no longer used because of salinity issues.

## A5.3 Cause of Sea Water Intrusion Problems and the Response to Them

The main salinity issue faced by GDC is the movement of the surface water saltwater interface in rivers and its potential effect on surface water abstractions. This tidal effect exists up to 6.0 km inland.

In some instances, it is possible that bores have been drilled at coastal properties and encountered saline groundwater. These bores are likely to have penetrated local shallow gravel lenses that have closer connection to saline water than the preferred Te Hapara Sand aquifer. It is expected that in those situations the bore is simply relocated to a different location further away from the saltwater source.

# A6: Hawkes Bay

(Information coordinated by Dougall Gordon, Hawkes Bay Regional Council.)

## A6.1 Management Approach

### A6.1.1 Planning

**Hawkes Bay Regional Resource Management Plan**

*POL 17 Decision Making Criteria – Activities Affecting Groundwater Quality*

3.8.15 To manage the effects of activities that may affect the quality of groundwater in accordance with the following approach:

(c) to consider the effects of the taking of groundwater on the quality of groundwater, including the potential for salt water intrusion.

*POL 29 Decision Making Criteria – Aquifer Dewatering and Salt Water Intrusion*

3.9.20 To avoid any significant long-term reduction in the groundwater level or piezometric pressure in aquifers, and any landward movement of the sea water/groundwater interface, as a result of groundwater takes.

Explanation and Reasons

3.9.21 Policy 29 recognises the importance of avoiding a long-term lowering of groundwater levels, and salt water intrusion in aquifers near the coastal margin.

| Anticipated Environmental Result | Indicator | Data Source |
|---|---|---|
| Avoidance of localised interference with other users and of salt water intrusion into groundwater | Number of complaints | Complaints register |

*POL 77 Environmental Guidelines – Groundwater Quantity*

**Table 11. Environmental Guidelines – Groundwater Quantity Guidelines That Apply Across the Entire Hawkes Bay Region**

| Issue | Guideline |
|---|---|
| 2. Effects on takes of water quality. | Takes should not contribute to the intrusion of salt water into fresh water aquifers. |

**Proposed HB Regional Coastal Environment Plan**

| | | | |
|---|---|---|---|
| *Rule 136* Small scale removal of sand or gravel | The removal of sand or gravel for non-commercial purposes from the foreshore. | Permitted | a) Sand or gravel may only be removed using a hand-held, non-mechanical device (for example a shovel).<br>b) The sand or gravel must not be removed from the foreshore of an estuary or lagoon.<br>c) The sand or gravel must not be removed from, or areas within 200 m of, coastal protection works or natural barriers (including sand dunes).<br>d) The quantity of sand or gravel removed by any person must not exceed:<br>i) 0.25 $m^3$ on any single day;<br>ii) 1 $m^3$ over any 12 month period. |

*[Rule 136 extract included as indirect reference to conditions managing vulnerability of estuaries to weakened barriers and exacerbation of intrusion.]*

*1.54* *Coastal Hazard Zone 1 (CHZ1)*

means an area seaward of the CHZ1 boundary identified on the planning maps which land assessed as being subject to storm erosion, short-term fluctuations and dune instability and includes river mouth and stream mouth areas susceptible to both erosion and inundation due to hydraulic forcing of river or estuary systems. For the purposes of this Plan, it extends a distance of 200 m seaward from its inland boundary.

*[CHZ1 definition extra included as indirect reference to highlight recognition that potential intrusion is addressed in managing coastal erosion risks.]*

### A6.1.2 Consents

Assessed on a case-by-case basis for proposed takes from wells that are close to the coast, such as in Bay View or Awatoto, Te Awanga and Haumoana ( as shown in Figure A6.1). An assessment of effects would generally be required to be provided which would consider this issue.

The following conditions on groundwater take permits is used where saline intrusion may be an issue:

1. The consent holder shall sample the well annually during the month of March and have the sample analysed for NH4-N, Alkalinity, Ca, $HCO_3$, $CO_3$, Cl, electrical conductivity, dissolved reactive phosphorous ($PO_4$), Fe, Mg, Mn, $NO_3$-N, pH, K, $SiO_2$, Na, $SO_4$, Total Dissolved Solids, hardness (CaCO3), Total Organic Carbon, ion balance (as % or total anions plus total cations). The results of the analysis shall be provided to the Council (Environmental Regulation Section) no later than 7 April each year. The consent holder shall meet the costs of this monitoring and ensure that there is a point established where a water sample can be obtained.

In some cases, conditions are imposed requiring water level monitoring and subsequent ceasing of the take when water levels drop to a certain level relative to sea level.

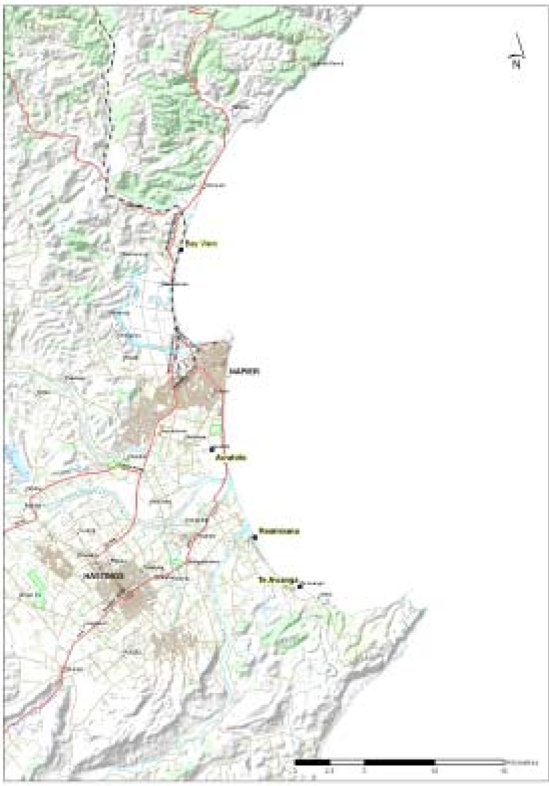


**Figure A6.1: Hawkes Bay Location Where Sea Water Intrusion Risks are Assessed**

## A6.2 Monitoring Results

### A6.2.1 Results from Regional Monitoring

Along the coast of the Heretaunga Plains, the piezometric pressure is about 8-9 m above MSL in the main aquifer system. The fresh/sea water interface in the aquifer is considered to be several kilometres offshore and therefore risk of intrusion is considered to be low under the present allocation in the aquifer, so no specific sea water intrusion monitoring is undertaken in that area.

A programme of consent monitoring has been implemented for the Esk/Bay View area, which contains a shallow unconfined aquifer used by bores that are around 10 m deep. Four monitoring wells have been installed near the coast. The wells have been monitored for electrical conductivity and water level three times per year since 2004. The results show elevated electrical conductivity values, with average values in each well in the range of 97-483 mS/m. These values are relatively stable and show no significant trend or variation with changing water levels. Therefore it is unclear whether this saline water is due to sea water intrusion.

In the Wairoa-Mahia area, elevated chloride concentrations (up to 500 mg/L) occur, which may be related to the dissolution of natural minerals or the intrusion of sea water. In Wairoa, the expected cause is due to tidal effects in the Wairoa River. In some wells, the Na/Cl ratios (in moles) are higher than in sea water, which suggests an enrichment of sodium as a result of exchange of magnesium and/or calcium ions between the sea water and the clay minerals.

### A6.2.2 Results from Consent Monitoring

The monitoring from consent conditions has not shown any indication of sea water intrusion problems.

## A6.3 Cause of Sea Water Intrusion Problems and Response to Them

There are no obvious areas of active sea water intrusion where the sea water interface is changing in response to groundwater abstraction and/or changing groundwater levels. The monitoring to date has identified areas where saline groundwater is present.

# A7: Taranaki Regional Council

(Information from Andres Jaramillo, Taranaki Regional Council and Peter Cook, South Taranaki District Council)

## A7.1 Management Approach

### A7.1.1 Planning

**Regional Fresh Water Plan for Taranaki**

Policy 6.4.2 includes *"the Taranaki Regional Council will take into account the need to:*

*(c) avoid saltwater intrusion into aquifers;"*

Rule 48 allows for the abstraction of small quantities of groundwater to occur as a permitted activity, however the conditions of this rule include:

*"The bore shall be located not less than 500 m from the sea…"*

*"The well shall be located not less than 25 m from the sea…"*

The main distinction between bore and well in the plan is that a well is 20 m below ground level and less compared with a bore that is defined as being greater than 20 m below ground level, however these terms are used interchangeably and do not have any difference in terms of regulatory issues.

Rule 49 allows for larger abstractions of groundwater to occur as a controlled activity and includes the following condition:

*"The abstraction shall not cause the intrusion of saltwater into any fresh water aquifer."*

**Regional Policy Statement for Taranaki**

Groundwater Policy 2 relates to taking and use of groundwater and includes the following:

*Groundwater allocations will be made having regard to:*

*(f) the need to avoid saltwater intrusion into aquifers;*

Policy 6.4.2 states that the groundwater resources of Taranaki will be managed on a sustainable yield basis. The concept of sustainable yield applies to both the quantity and quality aspects of groundwater. With respect to quantity, sustainable yield means ensuring that the abstraction rate does not cause long-term depletion of the groundwater resource. Similarly, sustainable yield is the rate at which groundwater may be abstracted without resulting in a decline in water quality by the influx of poor quality water or saltwater into the aquifer.

### A7.1.2 Consents

Taranaki Regional Council uses a standard condition for all bores located in close proximity to the coast (3 – 6 km) that reads, "The taking shall not cause the intrusion of salt water into any freshwater aquifer." Furthermore, periodic monitoring of chloride and conductivity levels is recommended as a consent condition for groundwater abstractions near the coast.

For irrigation bores chloride monitoring is only required over the irrigation season and the general approach is that the last sample for the season should be collected 7 to 10 days after irrigation ceases.

For bores used by South Taranaki District Council for water supply there is a requirement that data is supplied to the regional council from any hydraulic or chemical testing carried out on the water supply bores. These consents are currently being renewed and a new condition is proposed which requires water chemistry monitoring.

## A7.2 Monitoring Results

### A7.2.1 Results from Regional Monitoring

There is currently no specific saltwater intrusion monitoring being carried out in the region. Taranaki Regional Council has commented that groundwater use is generally low in areas where there is a high risk of saltwater intrusion.

An investigation by South Taranaki District Council identifies that Whenuakura Aquifer 1 and Whenuakura Aquifer 2 near Patea are at high risk from potential saltwater intrusion and recommended that a 'sentinel' bore be established and monitored for salinity.

Sea water contamination can potentially enter the deeper Whenuakura aquifers, where they are in direct contact with overlying unconfined aquifers and/or where the Whenuakura aquifers are exposed in the stream channels to the east of Patea. The upper Whenuakura Formation aquifers in the Patea area are also vulnerable to sea water contamination due to their shallow depth, close proximity to the coast, and hydraulic connection to the surface. The upper aquifers appear to be hydraulically connected due to permeable pathways in the intervening sediment.

In addition, two shallow bores constructed during the 1930s at the Patea Freezing Works were found to be affected by sea water intrusion and were decommissioned.

A 1996 Taranaki Regional Council report entitled "Groundwater Resources of the Taranaki Region" notes that in Waitara, the Affco freezing works had a 125 m deep bore located 1.5 kilometres from the coast. This groundwater was used for washdown purposes at the plant at a rate of 96 $m^3$/day (1 litre/second). Despite the relatively low abstraction from the aquifer (Matemateaonga Formation), by 1980 the aquifer had been intruded by salt water. A June 1980 water analysis from the bore encountered chloride at 1,210 mg/L and sodium at 1,000 mg/L.

### A7.2.2 Results from Consent Monitoring

No results from individual consent monitoring are available.

## A7.3 Cause of Sea Water Intrusion Problems and the Response to Them

During the 1990's elevated chloride levels were detected in the water supply bores for Patea. Investigations in 1997 concluded that the problem was due to pumping induced saline intrusion of the aquifer caused by operation of wells in close proximity of the Patea River mouth, which is tidal for some distance beyond the Patea township.

Subsequently the township supply is now sourced from three bores located at greater distance from the Patea River mouth.

A schematic diagram of the Patea Water supply is shown in Figure A7.1 below. Bores G, H, I and J, K, L are the previous town water supply bores affected by saline intrusion and the current water supply bores are labelled as No 1, No 2 and No 3.

Bore K is reported to have shown chloride concentrations of up to 6,500 mg/L, although this reduced to 23 mg/L when the pumping rate decreased.

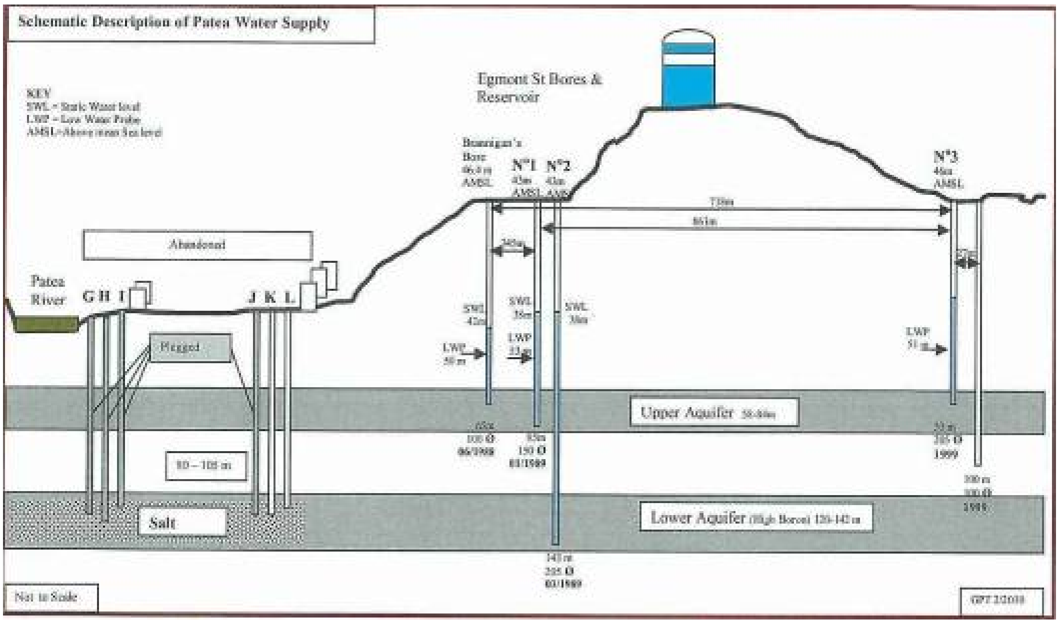


**Figure A 7.1: Supplied by South Taranaki District Council**

For the Waitara situation, the standing water level of the Affco bore that was affected by sea water intrusion is only 1.8 to 3.4 metres deep, while the ground elevation is only 1.5 metres above sea level. These observations suggest that the Matemateaonga Formation aquifer may be equilibrating with sea level along the north Taranaki coast and the area is considered to be particularly susceptible to saltwater intrusion. The bore has now been decommissioned so is no longer an issue of concern for any abstractive users.

# A8: Manawatu-Wanganui Region

(Information from Hisham Zarour, Horizons Regional Council.)

## A8.1 Management Approach

### A8.1.1 Planning

**Proposed One Plan**

**Policy 15-2D Saltwater Intrusion**

- consent applicants within 5 km of the coast must carry out pumping tests to assess their drawdown effect and its contribution to increasing the risk of sea water intrusion;
- restrictions on (or decline of) consent applications to manage the risk of sea water intrusion;
- consents to take groundwater within 5 km of the coast must contain conditions relating to the monitoring of electrical conductivity and restriction on abstractions if specified electrical conductivity thresholds are breached. These thresholds are determined on a case-by-case basis.

### A8.1.2 Consents

Consent conditions related to sea water intrusion monitoring are placed on abstraction consents located within 5 km of the western coast, in areas of large consented groundwater abstractions and increasing groundwater demand.

## A8.2 Monitoring Results

### A8.2.1 Results from Regional Monitoring

The Manawatu Wanganui region extends from the west coast to the east coast across the central lower portion of the North Island.

Sea water intrusion is not considered a potential risk in the eastern coastal area of the Region. This eastern coastal area is predominantly covered by low permeability strata, which is not favourable for groundwater resource development. Hence there are very few wells and no consented takes in that part of the region. As a result, the sea water-groundwater interface in this area is expected to occur in its natural position, unaffected by the minor human activity in the area.

In contrast, the groundwater system in the western coastal areas of the region are widely utilised for abstraction purposes and the demand on the groundwater resource in this area is increasing. Hence, sea water intrusion is identified as a risk in those western coastal areas of the region where the highest levels of abstraction occur.

To safeguard against sea water intrusion in the coastal zone, Horizons has set up a monitoring network to provide advanced warning against this risk (Figure A8.1).

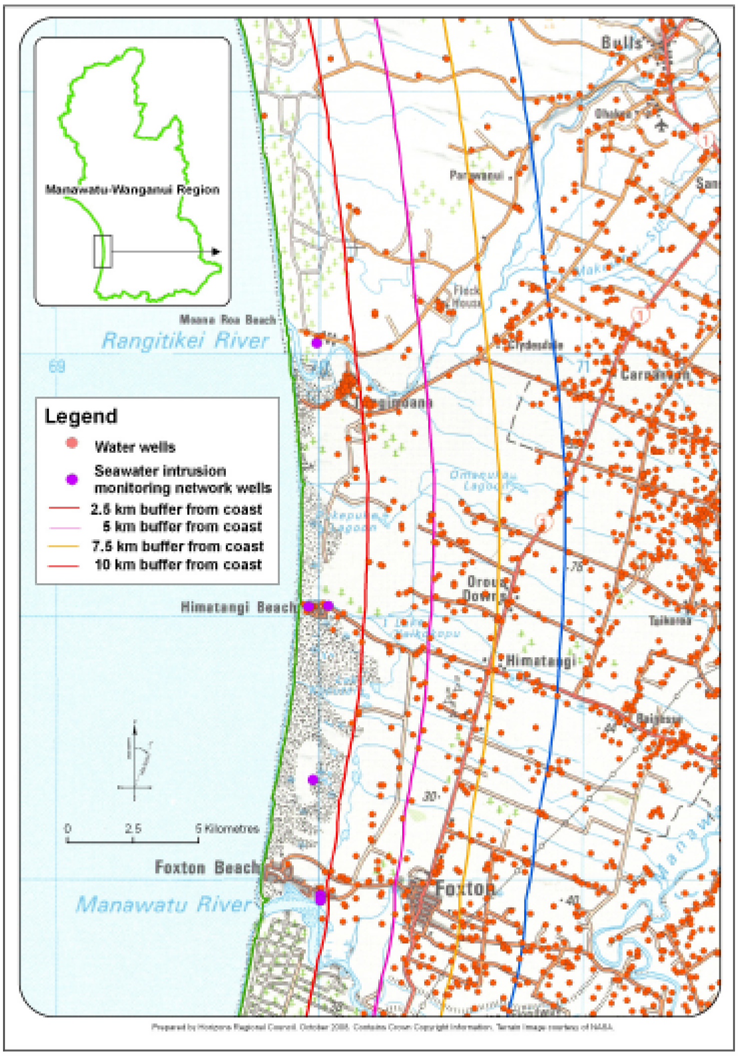


**Figure A8.1: Horizons Regional Council Seawater Intrusion Monitoring Network**

There is no evidence of inland sea water intrusion occurring to date. To the contrary, the electrical conductivity of the groundwater tends to change in direct proportionality to the groundwater levels, i.e. when groundwater level drops due to pumping, water salinity drops too (Figure A8.2). This is expected to be due to the effect of groundwater inducing the movement of less conductive inland groundwater into the coastal area.

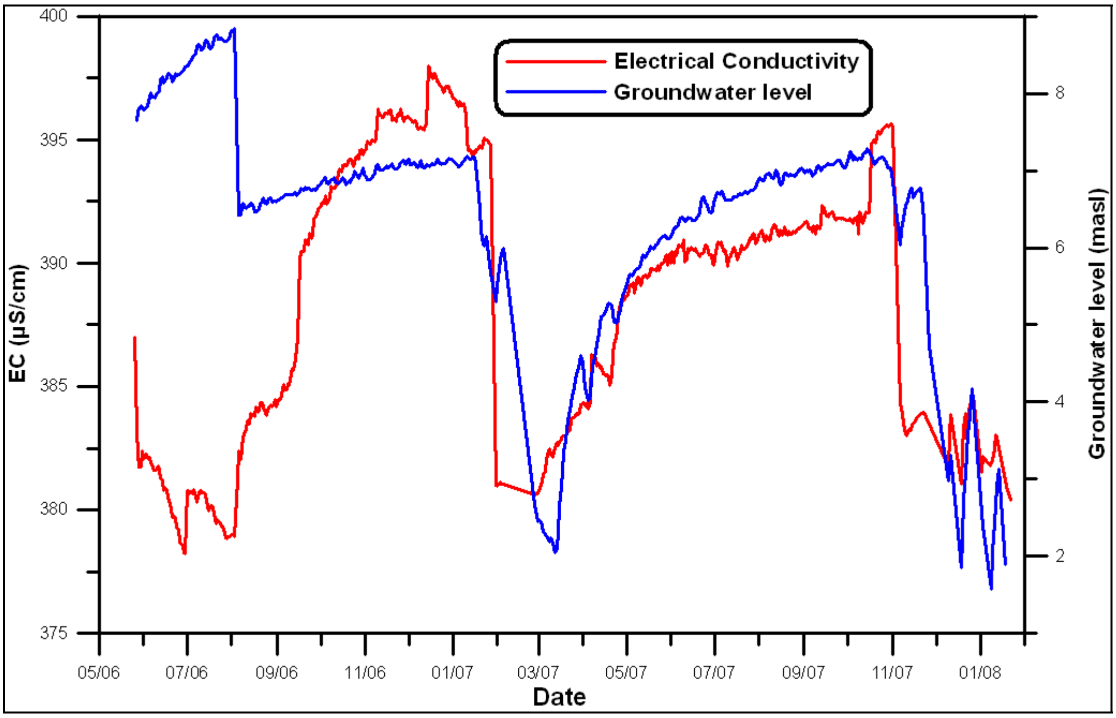


**Figure A8.2: Example on Seawater Intrusion Monitoring Data from Well 342107**

### A8.2.2 Results from Consent Monitoring

No adverse effect is shown from consent monitoring to date.

## A8.3 Cause of Sea Water Intrusion Problems and Response to Them

No known sea water intrusion situations have arisen.

No planning or consent response has been required because no known problems have occurred to date.

# A9: Wellington

(Information from Amy Holden and Sheree Tidswell, Greater Wellington Regional Council.)

## A9.1 Management Approach

### A9.1.1 Planning

**Regional Policy Statement (RPS)**

The RPS outlines the resource management issues of significance to the region and provides a framework for managing the natural and physical resources of the region in a sustainable manner. Further to this, the RPS identifies objectives, policies and methods which are designed to achieve integrated management of the natural and physical resources of the whole region.

*Chapter 5* – Freshwater in particular contains objectives, policies and methods that address water quantity and quality concerns. Issue 8 and Policy 3 make specific mention of sea water intrusion.

*Issue 8* – S.6 and 7 of the Act require consideration to be given to the protection of various aspects of fresh water, including quality, natural character, and any scenic, cultural, recreational, fisheries, or other amenity values. There is currently little formal protection for rivers, lakes and streams, or parts thereof that are highly valued by the community (e.g., the aquifer under the Hutt Valley). Only some water bodies are protected in any way by the Wellington Regional Council. This includes limiting access to water supply catchments, preserving the Lake Wairarapa wetland system through a national water conservation order, and maintaining the quality of the Hutt aquifer from saline intrusion. As well as protection, there are also public demands for the enhancement of water quality.

*Policy 3* – To control the use and allocation of groundwater so that it is not depleted in the long-term and sea water intrusion is minimised.

*Groundwater is a valuable resource currently used for public water supply (rural areas, Lower Hutt and Otaki), industrial uses (cooling water in Lower Hutt City and Upper Hutt City), and the irrigation of horticultural crops (grapes, kiwi fruit, pip fruit) and pasture. Iwi regard it as important for its spiritual qualities and its purity.*

*The resource needs to be managed so that abstractions are sustainable both in the short and long-terms (i.e., that groundwater levels do not decline over time) and that adverse effects from human activities, such as ground sinking, interference between wells, and springs drying up are minimised.*

*Aquifers that connect with the sea must be protected against over extraction to prevent sea water flowing into them. This can render them unusable for many years.*

**Proposed Regional Policy Statement**

At the time of writing this report, the appeals period for Greater Wellington's PRPS has closed. There have been 8 appeals on the various sections of the PRPS which need to be worked through before it can be made operative.

Policy 12: *Allocating water – regional plans* states that *"Regional plans shall include policies and/or rules that…(b) establish allocation limits for the total amount of water that can be taken from groundwater, taking into account the aquatic ecosystem health of rivers, lakes and wetlands, and preventing saltwater intrusion."*

In the explanation it is stated that "*Groundwater allocation limits must safeguard the needs of dependent ecosystems in groundwater-fed streams and wetlands, and prevent saltwater intrusion."*

**Regional Freshwater Plan**

The RFP contains objectives, policies and rules seeking to avoid, remedy or mitigate the potential adverse effects of the use and development of water bodies including discharges of contaminants to water.

Issue 2.6.3 in section 2: Issues, is as follows:

*"The excessive abstraction of groundwater can lead to lower groundwater quality, land subsidence, or adverse effects on nearby users."*

The explanation for this issue includes the following:

*"In the Hutt Valley, groundwater is an important source of water for municipal use. The Lower Hutt Groundwater Zone supplies approximately 25 percent of water used in the Wellington metropolitan area as well as a number of industrial uses. It is vital that the use of this source of water is managed so the amount available for abstraction does not diminish, and that there is no salt-water intrusion because of its overuse."*

Rule 20 in the plan is a minimum operating level for the Lower Hutt Groundwater Zone. This rule reads as follow:

*"The abstraction of groundwater from the Lower Hutt Groundwater Zone (Taita Alluvium/Waiwhetu aquifers) shall cease when the 24 hour mean groundwater level of the aquifer at McEwan Park falls below 1.4 metres above mean sea level."*

This level has been set to prevent saltwater intrusion from occurring.

One of the environmental results anticipated under Section 10 of the Plan is *"The quantity and quality of groundwater in the Region is at least maintained because: (3) The rate of groundwater abstraction does not cause salt water intrusion…"*

### A9.1.2 Consent Conditions

Conditions related to sea water intrusion are placed on abstraction consents near the coast that could increase the risk of sea water intrusion. The type of consent conditions that the Greater Wellington Regional Council (GWRC) places on consents is relative to the risk of saline intrusion.

Water takes in the Lower Hutt Groundwater Zone (22 takes) have to comply with the following consent condition:

*"'In the event that the pressure in the Waiwhetu Artesian Aquifer drops to an average, over a 24 hour period, of +2.3 metres above datum, as measured at the McEwan Park (site number 1428009) water level monitoring station, or any other official Wellington Regional Council water level monitoring station in the Petone and Seaview area, the permit holder shall comply with all abstraction restrictions and/or rostering as directed by the Manager, Environmental Regulation, Wellington Regional Council."*

The water levels of the groundwater zone are monitored by the GWRC Environmental Monitoring and Investigation team at the Ewan Park water level monitoring station and analysed by the GWRC groundwater scientist.

As the water supply department's consent is for 92% of this groundwater zone's allocation, that consent holder has slightly different conditions which require them to monitor and control their takes to minimise the occurrence of low water levels. This is as follows:

*"The permit holder shall monitor and control the combined take for Waterloo and Gear Island Water Treatment Plants at all times to ensure that the 24 hour mean groundwater level at McEwan Park (site number 1428009) water level monitoring station, or any other official Wellington Regional Council water level monitoring station in the Petone and Seaview areas, does not fall below +2.3m relative to mean sea level (except where allowed by condition 8)*

*If the 24 hour mean groundwater level at McEwan Park (site number 1428009) water level monitoring station, or any other official Wellington Regional Council water level monitoring station in the Petone and Seaview areas, is less than +2.3m relative to mean sea level, the permit holder may only abstract water at the discretion of the Manager, Consents Management, Wellington Regional Council. The permit holder shall notify the Manager, Consents Management immediately if the 24 hour mean 2.3m level is reached.*

*'The permit holder shall ensure that the combined take from the Waterloo and Gear Island Water Treatment Plants is limited to ensure that the 24 hour mean groundwater level at McEwan Park (site number 1428009) water level monitoring station, or any other official Wellington Regional Council water level monitoring station in the Petone and Seaview areas, does not fall below +2.0m relative to mean sea level."*

There is one other consent (WGN100150) that is known to have a condition related to the risk of saline intrusion. This is for a take from a bore located approximately 310 m from the coast. Assessments carried out as part of the consent application showed that there may be a slight landward movement of the sea water interface. Due to the potentially high impacts and consequences of sea water intrusion, it was decided that regular monitoring of the conductivity of the bore discharge during the summer months for the first year of the consent would be undertaken. The condition is as follows:

*“The permit holder shall measure the electrical conductivity of the abstracted water on a weekly basis after periods of water use during each irrigation season.*

*The weekly conductivity measurements shall be compared against the rolling mean and if conductivity increases by more than 25% the permit holder shall notify the Manager, Environmental Regulation, Wellington Regional Council.*

*A suitably qualified person shall provide an assessment of the monitoring results. This assessment and the records shall be submitted to the Manager, Environmental Regulation, Wellington Regional Council in an electronic spreadsheet format by the 10 July each year the monitoring is undertaken.*

*The frequency of the conductivity monitoring will be reviewed and may be reduced at the discretion of the Manager, Environmental Regulation, Wellington Regional Council, following the assessment of the first irrigation season’s results.”*

This condition has only recently been granted so no monitoring results are available as yet.

## A9.2 Monitoring Results

### A9.2.1 Results from Regional Monitoring

The Annual Groundwater Monitoring Report for the Wellington Region 2008/09 identifies three principal groundwater areas in the Wellington region: the Lower Hutt Valley, the Kapiti Coast and the Wairarapa Valley. Secondary groundwater areas include Upper Hutt, Mangaroa valley, Wainuiomata valley and sections of the eastern Wairarapa coastline. Aquifers in all of these areas are found in unconsolidated alluvial, aeolian (wind-blown) and beach sediments of varying grain size. Minor aquifers are also found in limestone and fractured greywacke in some areas of the region.

The Council monitors a core groundwater quality monitoring network of 71 boreholes as part of their State of the Environment (SoE) groundwater monitoring programme. The sites are sampled every three months. The groundwater level network currently consists of 75 automatic and 72 manually dipped wells. There are nine telemetered sites containing conductivity probes which monitor for saline intrusion. The monitoring wells are shown in Figure A9.1.

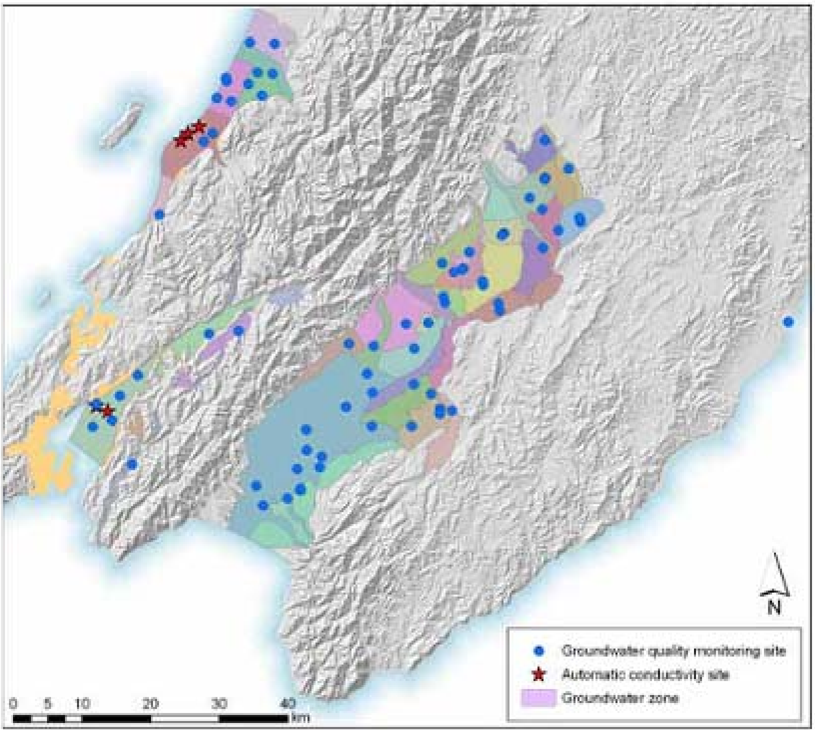


**Figure A9.1: Location of Existing Routine Groundwater Quality Monitoring Sites in the Wellington Region.** Automated saline intrusion groundwater monitoring sites are also shown.

The nine telemetered sites containing conductivity probes are located in Lower Hutt and the Kapiti Coast. There are no saline intrusion monitoring sites on the Wairarapa east coast or down in the Lower Valley as water abstraction in these areas is low.

Conductivity measurements from the nine monitoring bores are not precise, the conductivity is monitored more to see a relative change rather than to detect actual conductivity.

The Annual Groundwater Monitoring Report for the Wellington Region 2008/09 did not identify any indicators of the occurrence of sea water intrusion.

### A9.2.2 Results from Consent Monitoring

There have been no indications of adverse effects from the monitoring of the wells in the Lower Hutt area. Consents in this area and the newly granted consent WGN100150 (see Section A9.1.2) are currently the only consents with conditions requiring sea water intrusion monitoring.

## A9.3 Cause of Sea Water Intrusion Problems and the Response to Them

**Lower Hutt Groundwater Zone (Taita Alluvium/Waiwhetu aquifers)**

An investigation of the Waiwhetu Aquifer has considered its vulnerability to saline intrusion. The Waiwhetu aquifer is the main source for the greater Wellington water supply system. The following tiered foreshore aquifer management levels were recommended (24 hour means):

- Warning level: 2.5m amsl
- Critical level: 2.3m amsl
- Minimum allowable foreshore level: 2.0m amsl (2.4 mamsl in the Lower Waiwhetu Aquifer)

The above levels apply to the Upper Waiwhetu Aquifer and are used for monitoring of the shallow bore at McEwan Park. Alarms are set for each of the aquifer management levels and if the conductivity reaches 250 uS/cm, which is about a 20% increase above a stable background fluctuating range of 190-205 uS/cm. This is a conservative trigger level that reflects the significant consequences that would arise if contamination were to occur. If an alarm is triggered, a member of the Wellington water group is alerted. At this stage it is only the shallow bore at McEwan Park that has an automated alarm system.

The Annual Groundwater Monitoring Report for the Wellington Region 2008/09 states that an average year in terms of groundwater levels occurred in the Lower Hutt aquifer system and that levels were well above warning levels for saline intrusion.

**Figure A9.2: Location of Coastal Monitoring Wells in the Waiwhetu Aquifer**

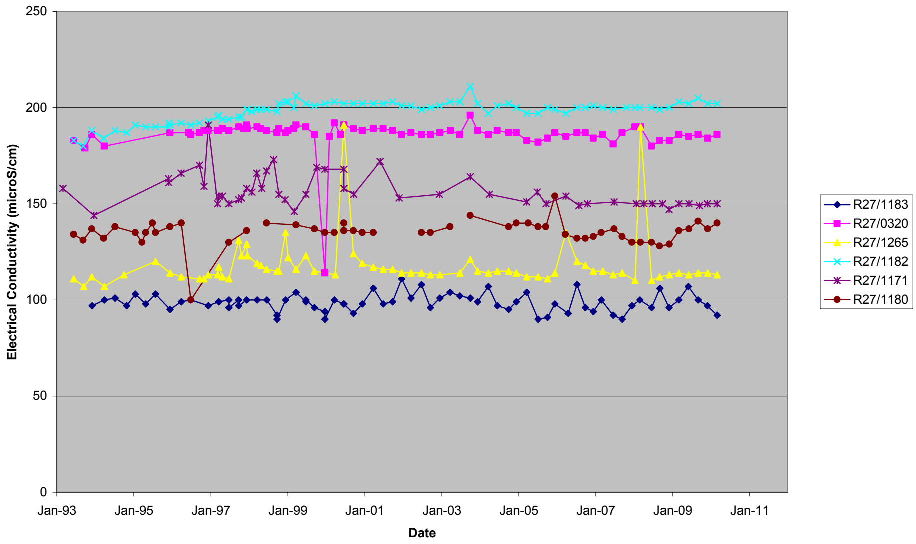


**Figure A9.3: Electrical Conductivity Measurements from the Waiwhetu Aquifer**

**Kapiti Coast Shallow Groundwater Resource**

The Wellington Regional Council Investigations Department Technical Report *"Annual Environmental Incident Report 2001"* stated that groundwater management had emerged as a significant resource management issue on the Kapiti Coast in 2000-2001. This was due to many property owners installing shallow bores to draw water for irrigation and recreation as a result of water shortage issues in Kapiti. This had prompted concern that unchecked bore drilling and groundwater extraction could result in lowering of the Kapiti shallow groundwater aquifer and subsequently cause saltwater intrusion.

A requirement for a resource consent for all bore construction in the Wellington region was introduced in 2002.

Further work was carried out to investigate the effect of un-monitored abstraction on the Kapiti Coast (Raumati, Paraparaumu and Waikanae). They concluded that the saline intrusion risk relating to garden well abstraction is negligible.

The Annual Groundwater Monitoring Report for the Wellington Region 2008/09 reported that groundwater levels were generally above average on the Kapiti Coast. No issues associated with sea water intrusion were reported.

# A10: Tasman Region and Nelson City

(Information from Joseph Thomas, Tasman District Council.)

## A10.1 Management Approach

### A10.1.1 Planning

*Tasman Resource Management Plan*

*Policy 30.1.4*

To establish the sustainable yield of aquifers, taking into account … potential contamination of the aquifer by sea water intrusion; … to avoid … irreversible sea water contamination of the aquifer.

*Policy 30.1.6A*

To adopt a water allocation limit for the groundwater of the Motueka Plains aquifers, based on the sustainable yield of the aquifer that takes into account …

(b) the cumulative effect of takes in the Central Plains Zone on the potential for sea water intrusion, especially in the Hau Zone; …

(f) the potential for mitigating adverse effect of localised salt water intrusion in the coastal margin of the Hau Zone, including through provision of alternative water supplies for existing users …

and to review the allocation limit if further monitoring and investigation confirms that the Hau Zone sea water intrusion trigger for rationing is not affected by water abstraction in the adjacent zones.

*Policy 30.1.9*

When assessing resource consent applications to take water, to take into account cumulative effects that might cause sea water intrusion.

### A10.1.2 Consents

No specific standardised consent conditions are used, but planning rules allow restrictions on consents to prevent sea water intrusion occurring.

## A10.2 Monitoring Results

### A10.2.1 Regional Monitoring

A network of three automated monitoring wells are established in the Hau Zone of the Motueka Plains aquifers, where historical sea water intrusion problems have occurred.

A network of a dozen manually monitored wells are established in the coastal Waimea Plains, which are monitored if flows in the Waimea River and/or groundwater levels are particularly low. This is based on the experience of an occurrence of saline intrusion into the unconfined Waimea Plains aquifer during the 2000-01 irrigation season.

### A10.2.2 Results from Consent Monitoring

Sentinel wells were established in the area of Tangmere Road (near the mouth of the Takaka River) in Golden Bay to monitor the occurrence of sea water intrusion induced by shallow 5 m deep irrigation wells in the late 1990s.

## A10.3 Cause of Sea Water Intrusion Problems and the Response to Them

Three main areas of sea water intrusion problems have occurred:

*(a) Hau Zone, Motueka Plains*

In the early 1990s, seasonal sea water intrusion was experienced in a shallow coastal aquifer due to coastal pumping wells (typically around 9 m deep) and surface sea water being introduced into stormwater drainage channels via flap gates that were not tightly sealed. Groundwaters of New Zealand (2001) reports that in 1990 groundwater level drawdown below sea level induced sea water intrusion onto an area of approximately 1.5 km by 0.4 km, and this disrupted orchard irrigation. The contamination problem was reversed once pumping ceased and water levels rose during water recharge.

This seasonal sea water contamination problem has been addressed by the provision of the Lower Moutere Water Scheme into the area and pumping from wells located further inland. These measures were identified in the Tasman Resource Management Plan, which includes the following references to mitigation measures:

> *30.2.13*
> *To work together with water users in the Hau Plains Zone, particularly the users of the Lower Moutere Water Scheme to ensure that domestic water users in the coastal margin of the Hau Plains Zone are periodically supplied with alternative water supplies so as to avoid rationing caused by sea water intrusion into those domestic bores.*
>
> *The Council will work with the Lower Moutere Water Scheme and other water users in the Hau Plains Zone to ensure that domestic water users, who might otherwise have been affected by sea water intrusion are periodically provided with an alternative water supply to avoid adverse effects of sea water intrusion. This means that domestic users will continue to have water while irrigators can avoid triggering rationing for longer.*

As a result, coastal groundwater pumping wells are no longer in use. Irrigation wells near the coast were replaced with wells approximately 2 km inland. Since that time (mid-1990s) the sentinel monitoring wells have not shown any problems.

*(b) Waimea Plains*

During the 2000-01 drought, the Waimea River experienced very low flows (causing surface sea water effects to move further up the river), and groundwater pumping caused very low groundwater levels, resulting in sea water intrusion moving further inland into the Appleby Gravel Unconfined Aquifer. The extent of the change in the interface is shown in Figure A10.1.

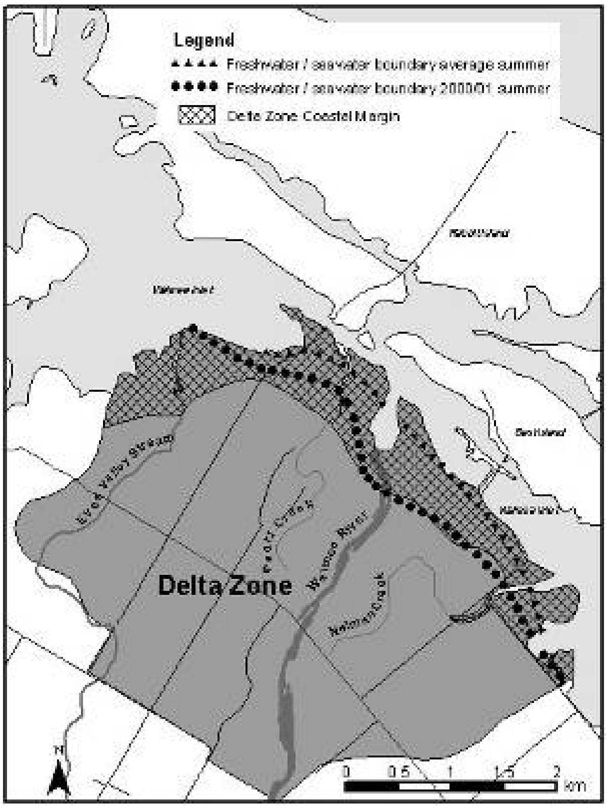


**Figure 10.1: Sea Water Intruded Areas – Delta Zone, Summer 2000-2001**

Council convened a dry weather task force in late January to assess, monitor and coordinate management action over the drought period. This group consisted of councillors, water resources and water supply staff. This group met weekly to assess all weather, flow, water use, groundwater level and salinity data and made decisions on restrictions that were to be implemented the following week. Regular public meetings with water user groups, irrigators, industry, public and the fire authority were held from late February through until the drought broke. This was to ensure that the management actions were understood and had public support. Regular weekly water updates were also published in the paper, with the notification of the management action for each zone with advice/suggestions for best watering practices and methods. Council also published weekly soil moisture monitoring data to help irrigators better manage irrigation.

The water supply authority used the radio media to inform the public on water conservation measures, as well as distributing water conservation pamphlets to all households. Lawn watering bans were imposed, with industrial users requested to minimise water use. At the height of the drought, cutbacks of 60% of water use were implemented on the unconfined aquifers (including the Delta Zone), with the confined aquifers cut by 35%. Water rationing compliance was monitored by requiring weekly water meter returns to Council, with Council further checking this by random monitoring of meters. To avoid sea water intrusion into the main Delta well field for urban supply the water supply authority shut down the usage of two wells closest to the sea (Figure A10.2) and replenished storage to the holding tanks by programming pumpage to periods when the tide was out. The water supply authority also used the LCA supply as a back up supply to meet flow requirements, as this source was subjected to a lower rationing level.

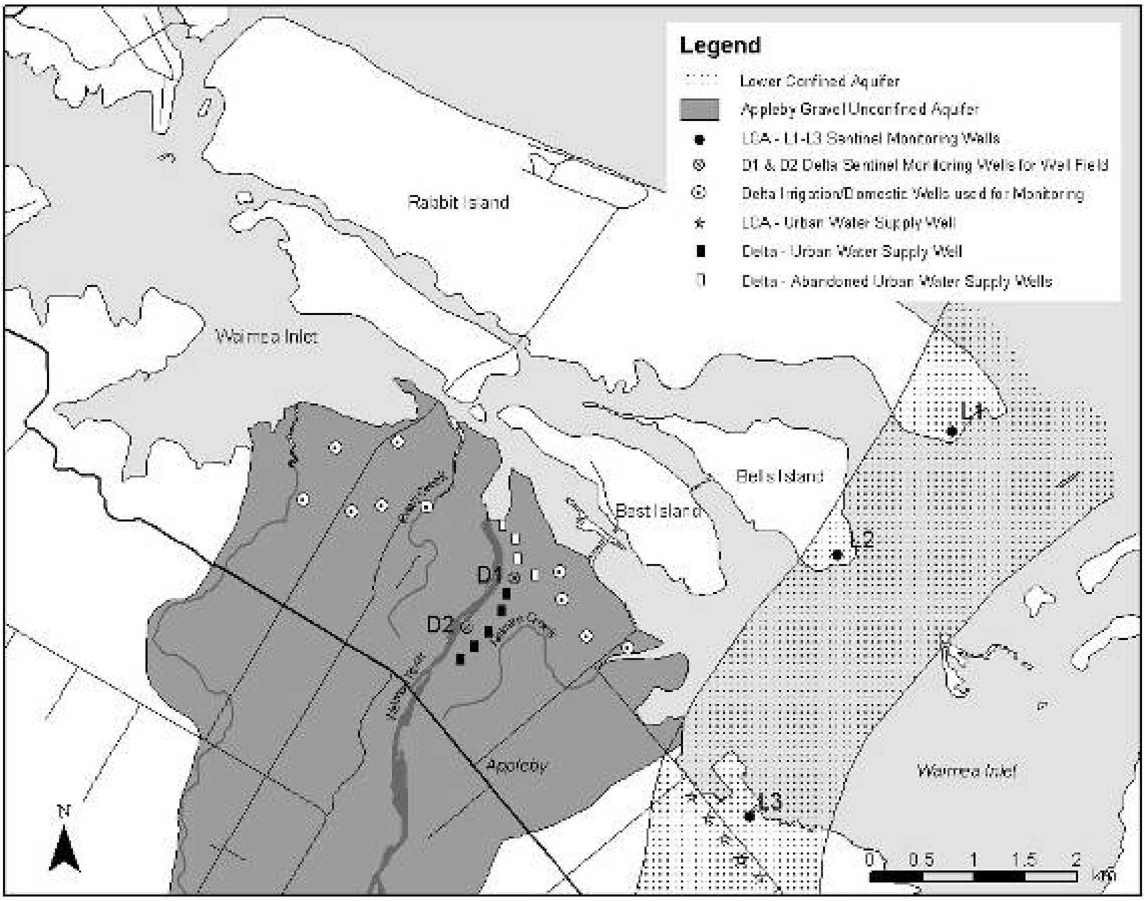


**Figure A10.2: Location of Water Supply Wells and Sentinel Monitoring Wells – Delta Zone and LCA**

The change in conductivity in one of the monitoring wells is shown in Figure A10.3. The sea water intrusion problem was corrected when river flows and groundwater levels returned to normal due to late autumn-winter rainfall. The Lower Confined Aquifer that extends out under the Waimea Inlet was not affected.

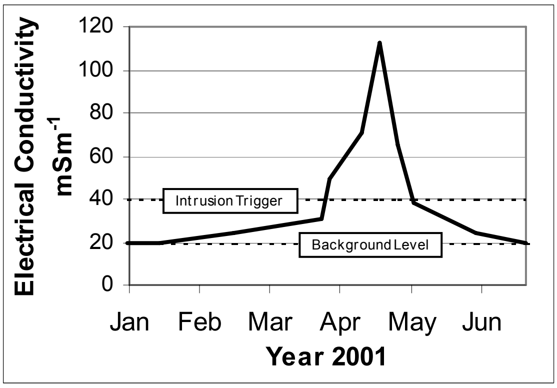


**Figure A10.3: Electrical Conductivity, Sentinel Monitoring Well D1 – Delta Zone**

A monitoring network of a dozen coastal wells has been established in response to this incident, as shown in Figure A10.2. These are measured manually during times when river levels and/or groundwater levels approach the levels that occurred in 2000-01.

The management response to prevent this situation occurring again has been:

- re-assessment of sustainable abstraction limits and of minimum flows in the Waimea River, the Wairoa River, the Wai-iti River and a coastal spring-fed stream;
- creating a coastal margin zone within the Delta Zone where no new water permits would be granted;
- salinity trigger for commencement of take rationing is based on an electrical conductivity exceeding 40 $mSm^{-1}$ in any used coastal well;
- explicit provisions for stepped rationing each zone when trigger flows or water levels or salinity are breached;
- requirement for all consented abstractions to have water meters, with water meter returns required fortnightly through the summer.

There has been no repeat of the 2000-01 sea water intrusion problems since these measures have been in place.

*(c) Tangmere, Golden Bay*

Sea water intrusion occurred in a shallow coastal aquifer due to the pumping of 5 m deep bores for irrigation in the late 1990s. Two monitoring wells were established to manage abstraction rates to prevent the sea water intrusion becoming problematic.

Since that date, the land use has changed and coastal pumping no longer occurs.

(d) As an aside, groundwater of New Zealand reports another situation of sea water effects which occurs at Waikoropupu Springs. These are the largest springs in New Zealand and emerge from the Arthur Marble Aquifer at a mean flow of 13.2 m³/s. The spring water has a sea water content of about 0.5-0.7%. As the flow at the springs increases, so does the concentration of sea water, which may indicate some sort of venturi mixing with water from the deepest cave levels of the aquifer, which are believed to be filled by sea water.

The location of all these areas that have shown sea water intrusion issues is presented in Figure A10.4 below.


**Figure A10.4: Occurrence of Sea Water Intrusion in Tasman**

# A11: Marlborough

(Information from Peter Davidson and Stuart Donaldson, Marlborough District Council.)

## A11.1 Management Approach

### A11.1.1 Planning

**Wairau/Awatere Resource Management Plan**

| | |
|---|---|
| Policy 1.3 and 1.7 | Establish groundwater Sustainable Flow Regimes (SFRs) to prevent a landward shift of the sea water/fresh water interface, e.g. Rarangi Shallow Aquifer. |
| Rule 1.1.3 | Maximum Total Abstractions for Ground Water Resources |
| 1.1.3.2 | Class A permits will allow water to be taken from groundwater resources when the aquifer water level is above a set low level.<br>Class B and C permits will allow water to be taken from groundwater resources when the aquifer level is above a specified level, which is higher than the A and B levels respectively. These levels will be determined on the basis of an appropriate combination of five factors, one of which is:<br>- prevent a landward shift of the sea water/fresh water interface, e.g. Rarangi Shallow Aquifer. |

### A11.1.2 Consents

Consent conditions related to sea water intrusion monitoring and associated restrictions if water level declines and electrical conductivity increases occur are placed on consents located within 2 km of the coastline on the Wairau Plain (or where the electrical conductivity values are greater than 20 mS/m.

## A11.2 Monitoring Results

### A11.2.1 Results from Regional Monitoring

The Wairau Plains forms the main water bearing aquifer in Marlborough. Three monitoring wells are located in the confined Wairau Aquifer, covering the northern, central and southern coastal margin of the plains. Five monitoring wells are located on the coastal margin of the unconfined Rarangi Shallow Aquifer. The location of these monitoring wells is shown in Figure A11.1.

**Figure A11.1: MDC Coastal Monitoring Wells**

All monitoring wells are fitted with transducers that record water levels and electrical conductivity, with the information transmitted at 15 minute intervals back to the Council office.

The results show no sign of sea water intrusion problems to date, although the following water quality changes have been observed:

- one monitoring well located on the beach front shows the effects of storm surge impacts on groundwater quality.  This is not a sea water intrusion effect induced by groundwater abstraction, as the electrical conductivity remains stable at times of low groundwater levels;

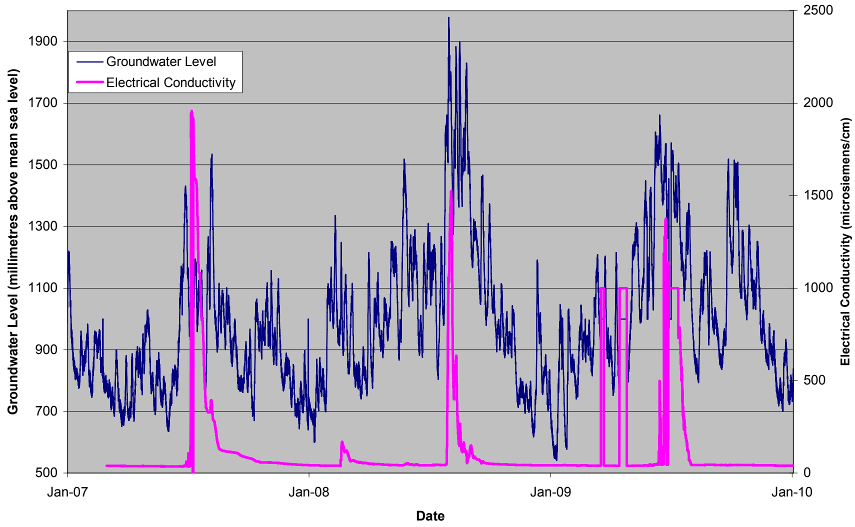


**Figure A11.2: Monitoring Data from Well P28w/4349 in the Unconfined Rarangi Shallow Aquifer**

- one monitoring well shows the effects of surface salts being leached into the aquifer during rainfall recharge, as evidenced by the rise in electrical conductivity coinciding with the rise in water level. This data highlights the importance of monitoring both groundwater levels and groundwater quality together;

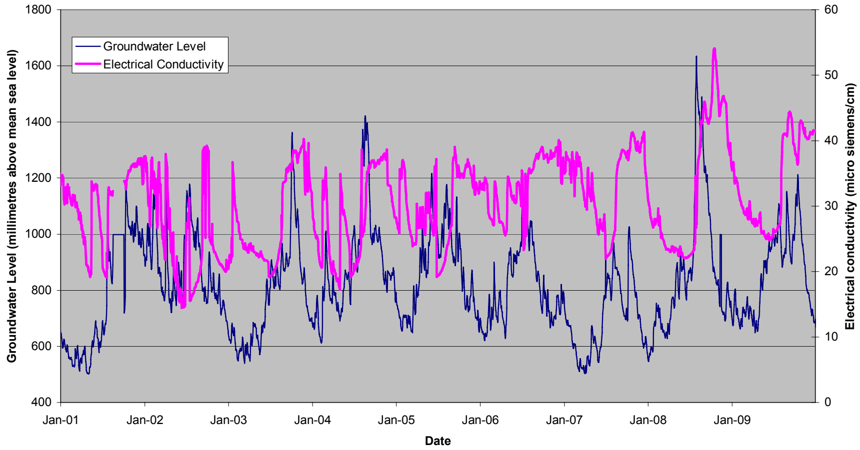


**Figure A11.3: Groundwater Level Monitoring Data in Well P28w/3668 in the Unconfined Rarangi Shallow Aquifer**

- one monitoring well in the confined Wairau Aquifer has shown a steady decrease in electrical conductivity. This is inferred to have been a well that was monitoring groundwater with a natural salinity derived from the surrounding sediments, some of which have been deposited in a marine environment. The increase in groundwater abstraction in the area is thought to have induced the movement of lower salinity groundwater into the area, causing an improvement in groundwater quality.

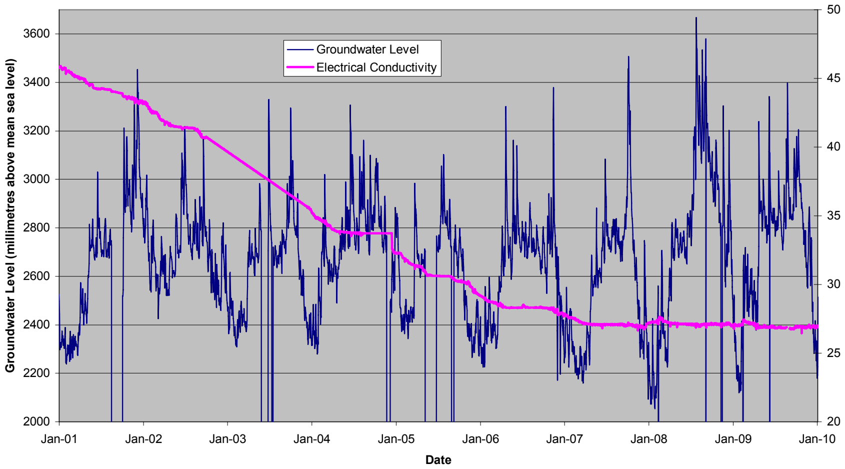


**Figure A11.4: Groundwater Monitoring Data from Bore P28w/3667 in the Confined Wairau Aquifer**

Beyond the Wairau Plain, monitoring of sea water intrusion effects also occurs at Havelock. At the sea coast old well casings and piling to support wharf structures are expected to provide a pathway for sea water to enter a shallow confined aquifer at the coast. The aquifer has a very flat hydraulic gradient and is used by the Havelock water supply wells which are located around 1.3 km south of the coastline. Figure A11.5 shows the pattern of abstraction rate and chloride concentration that have been measured at the water supply wells.

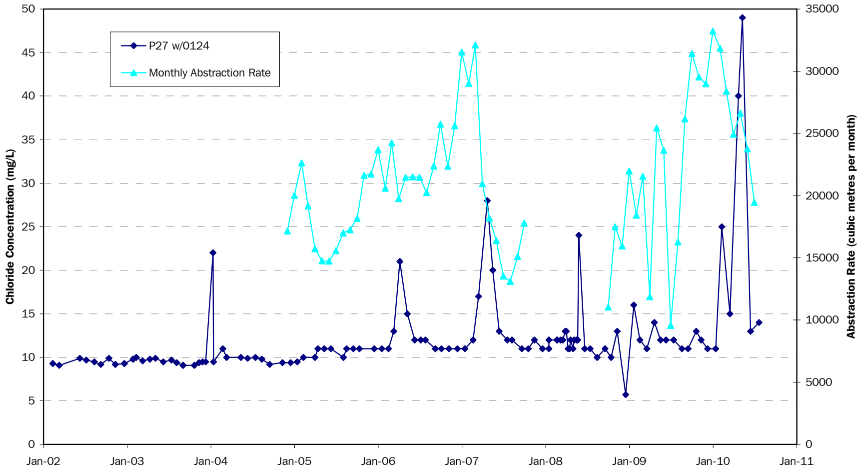


**Figure A11.5: Water Use and Chloride Concentrations Measured at the Havelock Water Supply Wells**

The data indicates that the chloride concentration starts to rise at the time of peak abstraction, but actually peaks after the abstraction rate has started to reduce, which presumably is due to the large separation distance (1.3 km from the sea water source). This monitoring pattern provides an opportunity to manage the effect by controlling the abstraction rate.

### A11.2.2 Results from Consent Monitoring

Monitoring of groundwater levels, electrical conductivity of groundwater and groundwater abstraction rates is implemented for all new consenting of abstractions within 2 km of the coastal margin. No significant changes in groundwater quality have been observed to date.

An example of the consent monitoring from outside the Wairau Plain comes from the Linkwater area where a shallow irrigation well is located around 500 m to the east of the coastline of the Mahakipawa Arm. The monitoring data from that abstraction is shown in Figure A11.6.

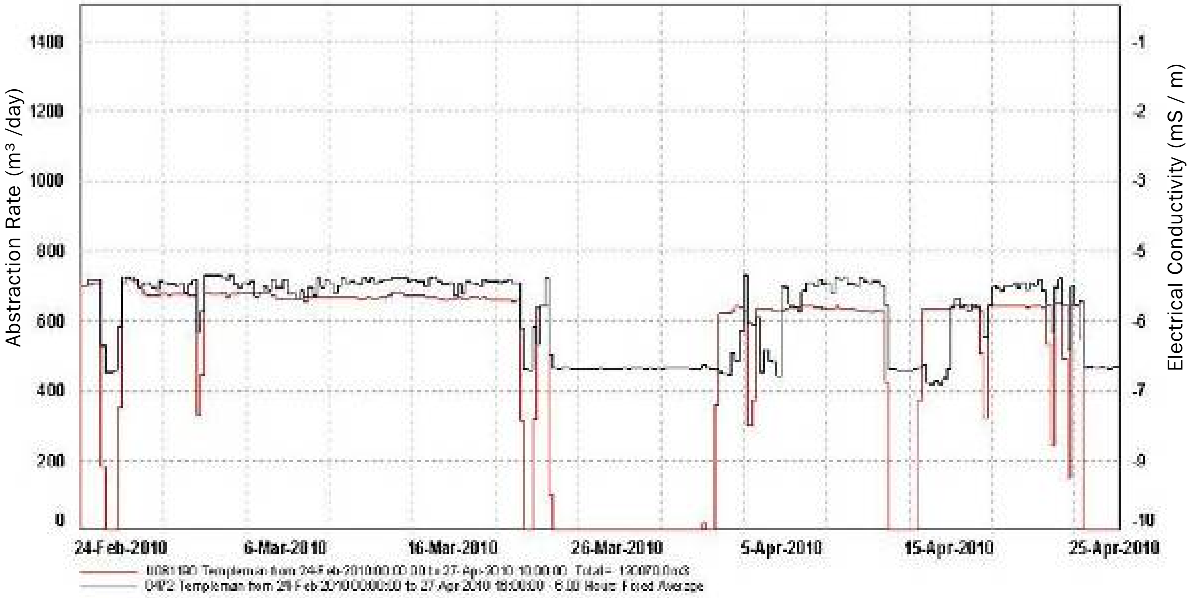


**Figure A11.6: Monitoring Data from Linkwater**

The data indicates that abstraction (red line) actually causes a small decrease in electrical conductivity (black line, plotted on a reverse scale) indicating that better quality inland groundwater is being induced into the well rather than the more coastal saline water.

## A11.3 Cause of Sea Water Intrusion Problems and Response to Them

The only noteworthy issue of actual sea water intrusion has occurred at Havelock. This is a shallow confined aquifer, but sea water is expected to have entered the aquifer at the coastal margin due to pumping from bores for the local mussel processing industry. This will have lowered aquifer pressures in the area, where sea water occurs directly above the aquifer. Sea water would enter the aquifer via leakage through the confining layer or via preferential pathways created by boreholes.

With saline water already present in the coastal margin of the confined aquifer, the pumping of inland wells induces the seasonal movement of salinity in a landwards direction.

Continuous monitoring of abstraction rate, water levels and electrical conductivity is undertaken, with restrictions on abstraction rates if adverse trends occur.

# A12: West Coast

(Information from Stefan Beaumont, West Coast Regional Council)

## A12.1 Management Approach

### A12.1.1 Planning

**Proposed Water Management Plan**

Section 9.4 of Chapter 9 – Groundwater, of the West Coast Regional Council's (WCRC) Proposed Water Management Plan sets out the policies related to groundwater.

Policy 9.4.5 is *"To manage the taking of water from any bore such that groundwater contamination by sea water intrusion is avoided."*

This policy envisages setting minimum water levels when considering resource consent applications to take groundwater from bores near the coast to prevent sea water intrusion.

The taking and use of groundwater is a permitted activity subject to a number of conditions under Rule 12.2.1. These include a condition that any well shall be located not less than 20 metres from the Coastal Marine Area.

The taking and use of groundwater that is not permitted or controlled under Rules 12.2.1 though 12.2.4, is a restricted discretionary activity under rule 12.2.5. In considering any resource consent application under this rule, the WCRC will restrict the exercise of its discretion to a number of factors including whether a minimum water level needs to be applied to the take. This means that the WCRC is able to consider whether a minimum water level needs to be applied to the take to manage the risk of salt water intrusion.

### A12.1.2 Consent Conditions

While the plan envisages placing restrictions on groundwater takes from bores near the coast to prevent sea water intrusion, in general, groundwater takes are not large on the West Coast (usually 2-5 l/s) and there are not many groundwater takes near saline environments (the sea or tidal river systems). Therefore, there has not been a need to place any restrictions on groundwater takes to prevent sea water intrusion to date.

## A12.2 Monitoring Results

### A12.2.1 Results from Regional Monitoring

The WCRC monitors eight sites through the National Groundwater Monitoring Programme. The locations of these are shown in the Figure A12.1. Water quality data has been recorded since September 1998. GNS (2005) state that although the intended sampling frequency was quarterly, there were substantial data gaps and for most wells data were available for only 65% of the quarters involved.

One of the monitored wells is located approximately 300 m from the coast (well HK25, ID#N08) in Hokitika. This well is 13 m deep and is used for commercial water supply. The data presented in GNS (2005) shows that the concentrations of chloride are low (around 10 mg/L) and therefore not indicative that sea water intrusion is occurring at this well.

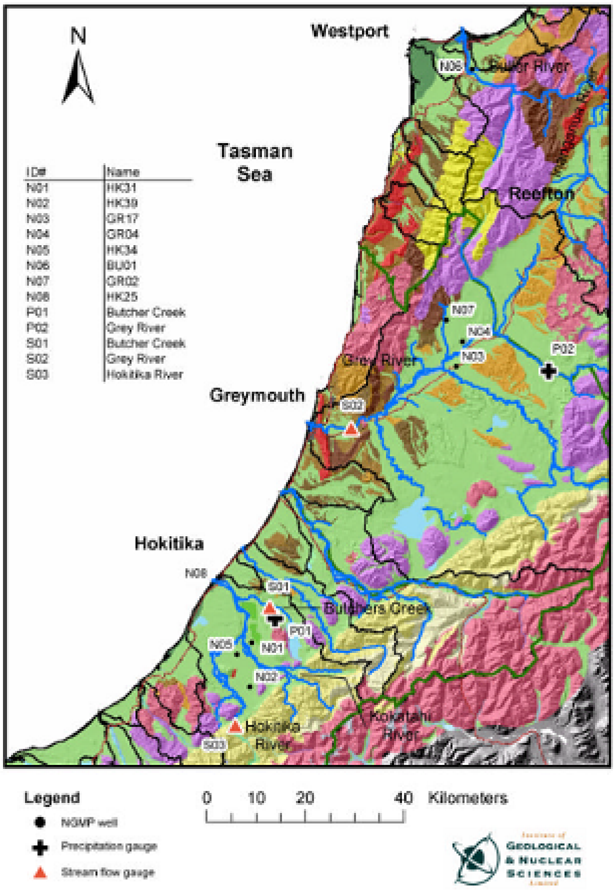


**Figure A12.1: West Coast Region National Groundwater Monitoring Programme Wells**

## A12.3 Cause of Sea Water Intrusion Problems and the Response to Them

There are no known incidences of sea water intrusion on the West Coast to date.

## A12.4 References

Institute of Geological & Nuclear Sciences Limited (GNS). 2005. State of the Environment Technical Report 05004. West Coast Regional Council. October 2005

# A13: Canterbury

(Information from David Scott, Matt Smith and Carl Hanson, Environment Canterbury.)

## A13.1 Management Approach

### A13.1.1 Planning

**Proposed Natural Resources Regional Plan**

**Chapter 5 – Water Quantity**

*Policy WQN11 – Confined Aquifers:*

- control the rate of abstraction to maintain groundwater levels in the shallowest confined aquifer (the default level to be maintained is 1.5 metres above msl);
- for main areas of groundwater use (Ashley to Rakaia Rivers) prevent the use of pumps to abstract groundwater within 1.5 km of the coast;
- control the rate of abstraction to prevent pressure gradient changes that allow movement of contaminants into the aquifer.

*Policy WQN12 – Unconfined Aquifers:*

- control the rate, duration and volume of water pumped from bores to prevent sea water contamination due to landward movement of the fresh water/sea water interface and to prevent contamination from upconing.

### A13.1.2 Consent Conditions

Conditions related to sea water intrusion are placed on abstraction consents near the coast that could increase the risk of sea water intrusion. In general terms, the proposed conditions are:

| Risk | Proposed Conditions |
|---|---|
| Unconfined well with a low risk of upconing/landwards intrusion. | Monthly water level measurements at the well;<br>Monthly water usage measurements at the well;<br>Biannual water quality measurements at the well. |
| Unconfined well with high risk of upconing/landwards intrusion. | Weekly water level measurements at the well;<br>Weekly water usage measurements at the well;<br>Monthly water quality measurements at the well. |
| Confined aquifer well with a calculated drawdown at the coast that will lower the water level below 1.5 m amsl. | Install a sentinel well at the coast;<br>Monthly water level measurements at sentinel well;<br>Measure water quality if water level measurements indicate coastal pressures dropping below 1.5 amsl;<br>Monthly water usage measurements. |

## A13.2 Monitoring Results

### A13.2.1 Results from Regional Monitoring

A network of 24 wells along the coastal margin is sampled twice a year in spring (high groundwater levels) and at the end of the irrigation season (low groundwater levels). Analyses are carried out for common cations and anions. Other coastal wells are also monitored, although are not part of the saltwater intrusion monitoring programme. The location of the wells is shown in Figure A13.1. Two areas have shown elevated salinity effects in groundwater, as described in Section A13.3 The remaining wells do not show any problems.

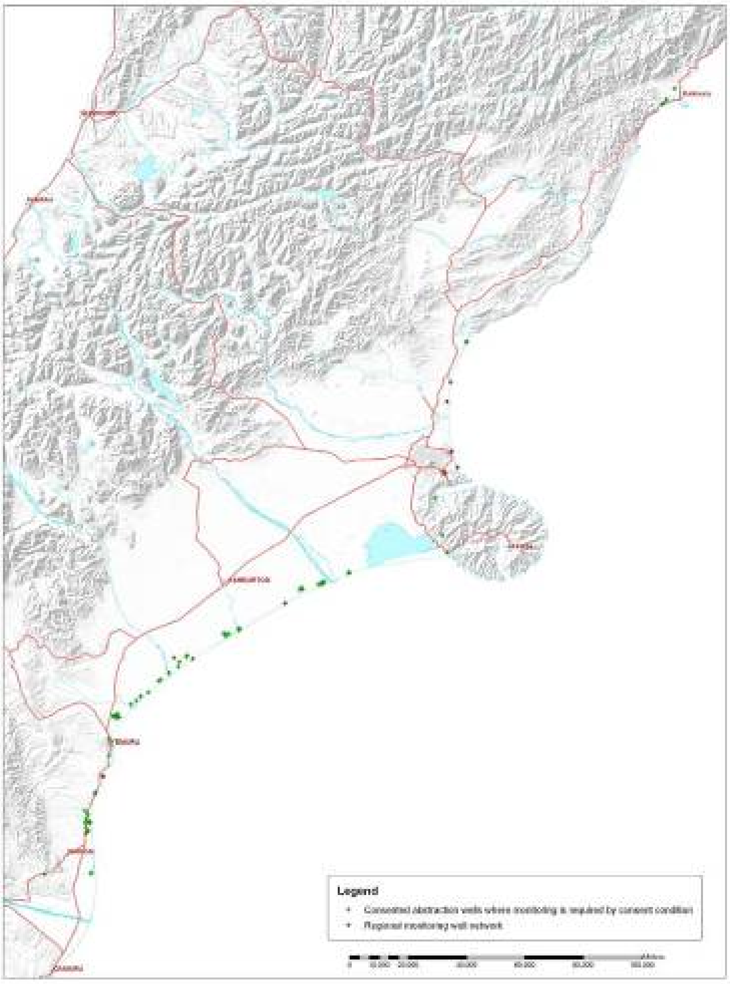


**Figure A13.1: Sea water Intrusion Monitoring in Canterbury**

A13.2.2 Results from Consent Monitoring

Around 100 consents currently have monitoring conditions related to sea water intrusion monitoring. None of these have shown any reported indications of adverse effects.

## A13.3 Cause of Sea Water Intrusion Problems and the Response to Them

*Woolston/Heathcote Confined Aquifer:*

- abstraction has caused prolonged periods of widespread groundwater level decline below mean sea level;
- likely cause of sea water entry into aquifer is downwards seepage through confining aquitard, with the likelihood of preferential inflow via abandoned boreholes.

Six industries, and the Christchurch City Council, pump water from this area. The problem, and remedial options, were discussed by groundwater managers and Woolston/ Heathcote groundwater users.

The response has been to restrict groundwater abstraction in the affected area to maintain groundwater levels above particular target values. This approach is set out in a policy of the NRRP:

*Policy WQN10 NRRP*

- prepare a groundwater management strategy to set allocation limits to maintain an upward hydraulic gradient from the first confined aquifer;
- restrict existing abstractions if time-based groundwater level targets in a monitoring bore are not maintained, i.e.:
  - 1 m above msl as a 365 day moving mean;
  - 0.25 m above msl as a 14 day moving mean;
  - 0.5 m below msl as a 24 hour average;
- no new groundwater consents in the affected area.

The monitoring data shows that this approach has been very effective in causing higher groundwater pressures within the area since it was adopted in the late 1990’s, as shown in Figure A13.2.

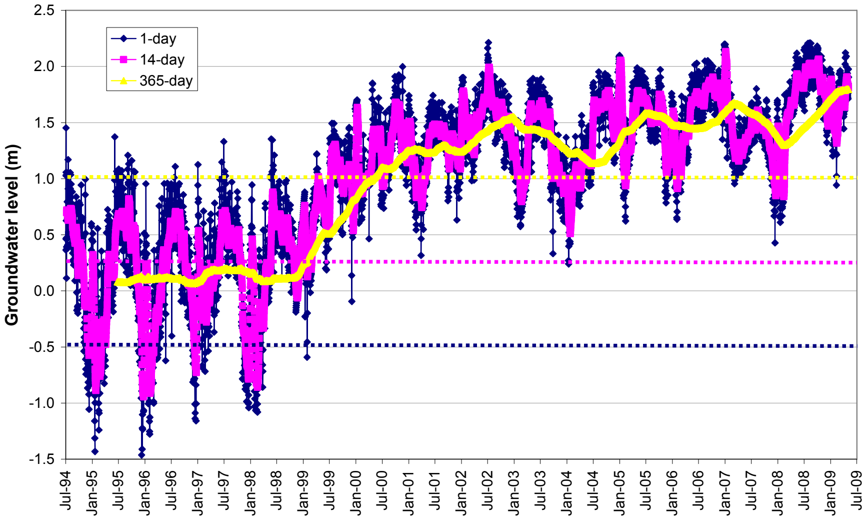


**Figure A13.2: 1-Day, 14-Day and 365-Day Moving Average Groundwater Levels at Scrutton Road (M36/1159)**

The response of chloride concentrations to the higher groundwater pressures has been slower to change, due to the confined aquifer conditions. However, chloride concentrations are gradually decreasing, as shown in Figure A13.3.

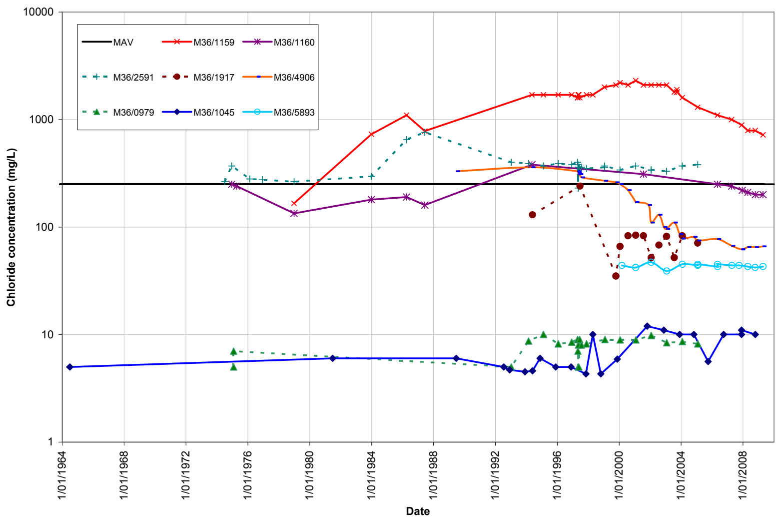


**Figure A13.3: Chloride Concentrations Measured in Wells in and Adjacent to the Woolson/Heathcote Groundwater Management Zones**

The response for consents in the affected area is:

- no new consents issued in areas where sea water intrusion is shown to occur;
- water user groups formed for existing abstractors to limit abstractions and manage water levels to lessen the risk of occurrence.

*Makikihi, South Canterbury:*

- Figure A13.4 shows data from a 7 m deep bore (J39/0042) in an unconfined aquifer 400 m from the coast, showing that elevated electrical conductivity occurs at times of low groundwater levels, although the converse is not always true and there have been times of low groundwater levels without elevated electrical conductivity.

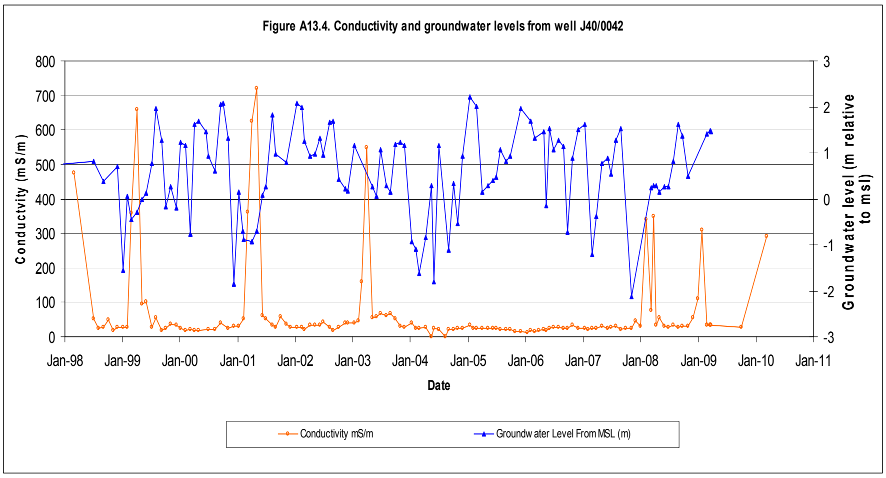


**Figure A13.4. Electrical Conductivity and Groundwater Levels from Well J40/0042**

Other situations of elevated salinity in groundwater have been observed in bores at St Andrew's Golf Course (bore J39/0232), Red Ruth near Timaru (bore J39/0259) near Saltwater Creek and at the Amberley Golf Course. However, in these cases, the data may indicate surface seepage of saline water from a surface water, from aquifer strata and/or sea spray, rather than pumping induced intrusion.

# A14: Otago

(Information from Jens Rekker, Otago Regional Council and Laura McElhone, Dunedin City Council.)

## A14.1 Management Approach

### A14.1.1 Planning

*Regional Plan: Water*

Policy 9.4.10 – To manage the taking of water from any bore such that groundwater contamination by sea water intrusion is avoided.

### A14.1.2 Consent

No standardised approach to consent conditions. Issues are evaluated on a case-by-case basis.

## A14.2 Monitoring Results

### A14.2.1 Results from Regional Monitoring

No regional coastal monitoring wells established.

However, monitoring wells installed to assess groundwater conditions in an area of South Dunedin have shown evidence of sea water intrusion extending around 400 m inland in a shallow unconfined aquifer.

### A14.2.2 Results from Consent Monitoring

No consents have conditions requiring monitoring.

## A14.3 Cause of Sea Water Intrusion Problems and the Response to Them

Leaky stormwater and wastewater pipes placed 1-2 m below ground level in South Dunedin exhibit a drainage effect on the groundwater that appears to have contributed to the landward movement of the sea water interface. The shallow strata has sufficient permeability to be considered an aquifer, although it is not used for abstractive purposes. Groundwater levels are very shallow in the area, and the leaky wastewater and sewer networks are potentially creating a beneficial effect by controlling groundwater levels to avoid inundation of the land surface by a rising water table, albeit at the expense of the landward migration of sea water.

The response to this situation is ongoing monitoring of water levels and water quality to gain an improved understanding of the situation.

As an aside, saline water has also affected wastewater pipes in the Tahuna area to such an extent that under some high tide conditions, the salinity adversely affected the performance of the biologic processes in a pilot plant for a new wastewater treatment plant upgrade. This salinity arises from two sources:

- saline groundwater infiltrating into wastewater pipes located in reclaimed ground a few metres from the harbour;
- sea water inflow into stormwater pipes which have an overflow weir into the wastewater network.

The first of these points relates to an in-situ saline groundwater issue rather than a pumping or drainage induced sea water intrusion problem. That issue is being addressed by re-lining of the sewers. The second point relates to surface sea water and coastal pipe networks but presents another example of how sea water can move inland and in a situation of lowered groundwater could cause an inland source of sea water to an aquifer via exfiltration from a leaky pipe network.

# A15: Southland

(Information from Karen Wilson, Environment Southland.)

## A15.1 Management Approach

### A15.1.1 Planning

There are no specific policies or rules relating to sea water intrusion within the Regional Water Plan for Southland.

### A15.1.2 Consents

It appears that only one groundwater abstraction consent in the region has specific conditions relating to the management of saltwater intrusion effects. The consent is held by New Zealand Aluminium Smelters Ltd (NZAS) at Tiwai Point and allows for the abstraction of up to 4,546 $m^3$/day of groundwater.

Condition 5 of the consent is given below and relates to management of potential saltwater intrusion effects.

> 5. If volumes above 3,500 $m^3$/day are abstracted for three months or longer continuously, the consent holder is to additionally monitor the sentinel wells at monthly intervals. The sentinel wells are located at the outer periphery of the aquifer to monitor possible saltwater intrusion, as identified in the resource consent application.
>
> The consent holder is to monitor and record the following about the sentinel wells:
>
> - the depth of the water levels, and
> - the conductivity level of the water in the wells.
>
> If no effects develop within 12 months, monitoring for this level of abstraction may, with the written approval of the Council's Environmental Compliance Manager, revert to yearly monitoring during summer low ground water conditions.

## A15.2 Monitoring Results

### A15.2.1 Results from Regional Monitoring

Environment Southland does not currently have any regional monitoring bores which are used for monitoring of salt water intrusion effects. Their state of the environment monitoring does not include monitoring for sea water intrusion effects.

### A15.2.2 Results from Consent Monitoring

Environment Southland has commented that based on the 2006, 2007 and 2008 annual reports supplied by NZAS there has been no indication of salt water intrusion. However, an application to renew their water permit in 2005 discussed that seawater had probably entered the peripheral areas of the aquifer but data was not sufficient to determine whether the saltwater occurred before or after pumping commenced. It was concluded that given the nature of the groundwater system it was likely that the saltwater was present prior to the exercising of the consent.

## A15.3 Cause of Sea Water Intrusion Problems and the Response to Them

With respect to the NZAS consent, it appears that salt water is likely to occur in the aquifer naturally and that the exercising of the consent is not causing any increase in saltwater intrusion.

Environment Southland has also commented there was anecdotal evidence that there may be low grade saltwater intrusion occurring on Stewart Island relating to the use of some domestic supply bores. However, as yet Environment Southland's investigations on the island have not been comprehensive enough to determine whether this is the case.