
Wellington Regional Council

# Groundwater Quality Protection Zones for the Lower Hutt Valley

Resource Investigations Department
Technical Report

THE REGIONAL COUNCIL

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# Executive Summary

The groundwater resources of the Lower Hutt Valley are an extremely valuable water resource to the Wellington Region. Currently between 25 to 35 percent of the municipal supply requirements of the greater Wellington area are derived from this resource. Forecast increases in demand and the imposition of higher minimum flow requirements in the major surface water catchments in the Wellington area will place increased pressure on this resource to cover any shortfalls in supply.

Present groundwater quality in the Lower Hutt Groundwater Zone is very high and water abstracted from the Waiwhetu Artesian Aquifer is able to be utilised for municipal supply after minimal treatment for pH correction and fluoridation. While this aquifer is protected from direct contamination by a low permeability confining layer, it remains vulnerable to contamination originating from land use and activities in the recharge zone and to the movement of sea water into the coastal margin due to excessive abstraction.

This report proposes three groundwater quality protection zones for the Lower Hutt Groundwater Zone to form the basis for the development of a comprehensive groundwater quality protection strategy. The protection zones encompass the confined aquifer system, the confined/unconfined aquifer margin and the recharge zone respectively. Management objectives range from the prevention of saline intrusion in the confined aquifer system to the avoidance of chemical and microbial groundwater contamination in the recharge zone. The report also identifies methods such as zoning and codes of practice which may be developed and implemented by both a regional and local authorities.

# 1. Introduction

While the need for quantitative management of groundwater resources has long been recognised, management of groundwater quality in New Zealand aquifer systems has received little attention. It is now recognised that effective management of an aquifer system requires integrated management of both the quantity and quality of the resource.

The objective of groundwater quality management is to protect groundwater resources from contamination which may have an adverse effect on existing and future uses of that resource. In contrast to surface water pollution, groundwater contamination is often not immediately evident; may be extremely difficult, if not impossible, to control or remediate; and may persist for years or decades. Contamination of groundwater used for public supply, in addition to posing a potential threat to public health, may require very expensive treatment programmes or development of alternative water sources.

The purpose of this report is to compile existing information to form the basis for the development of a comprehensive groundwater quality management programme for the Lower Hutt Groundwater Zone. The development of a proactive approach to the management of the quality of this resource will seek to maintain or enhance current groundwater quality and limit the potential for future groundwater contamination. Submissions on the Proposed Regional Freshwater Plan support the designation of the Lower Hutt Groundwater Zone as a water body with water quality to be managed for public water supply purposes.

## 1.1 The Lower Hutt Groundwater Zone

The alluvial filled Lower Hutt basin forms an unconfined/confined aquifer system which is known as the Lower Hutt Groundwater Zone. The aquifer system extends from the confines of Taita Gorge in the north, out into Wellington Harbour. The aquifer system is bounded by the Eastern Hutt Hills to the east and the Wellington Fault to the west. The southern extent of the aquifer system occurs along a poorly defined margin between Somes Island and the entrance to Wellington Harbour. Figure 1 shows some of the salient features of the Lower Hutt Groundwater Zone.

The groundwater resources of the Lower Hutt Groundwater Zone are an extremely valuable water resource to the Wellington Region. Currently between 25-35 percent of the municipal supply requirements of the greater Wellington area are derived from this aquifer system. The Waterloo wellfield supplies between 40 to 70 million litres per day (ML/day) for municipal supply in Lower Hutt, and the Gear Island wellfield is used to supplement supply to Wellington City during periods of high demand. In addition, 21 private users utilise groundwater from this resource for cooling, process water, fire protection or irrigation requirements.

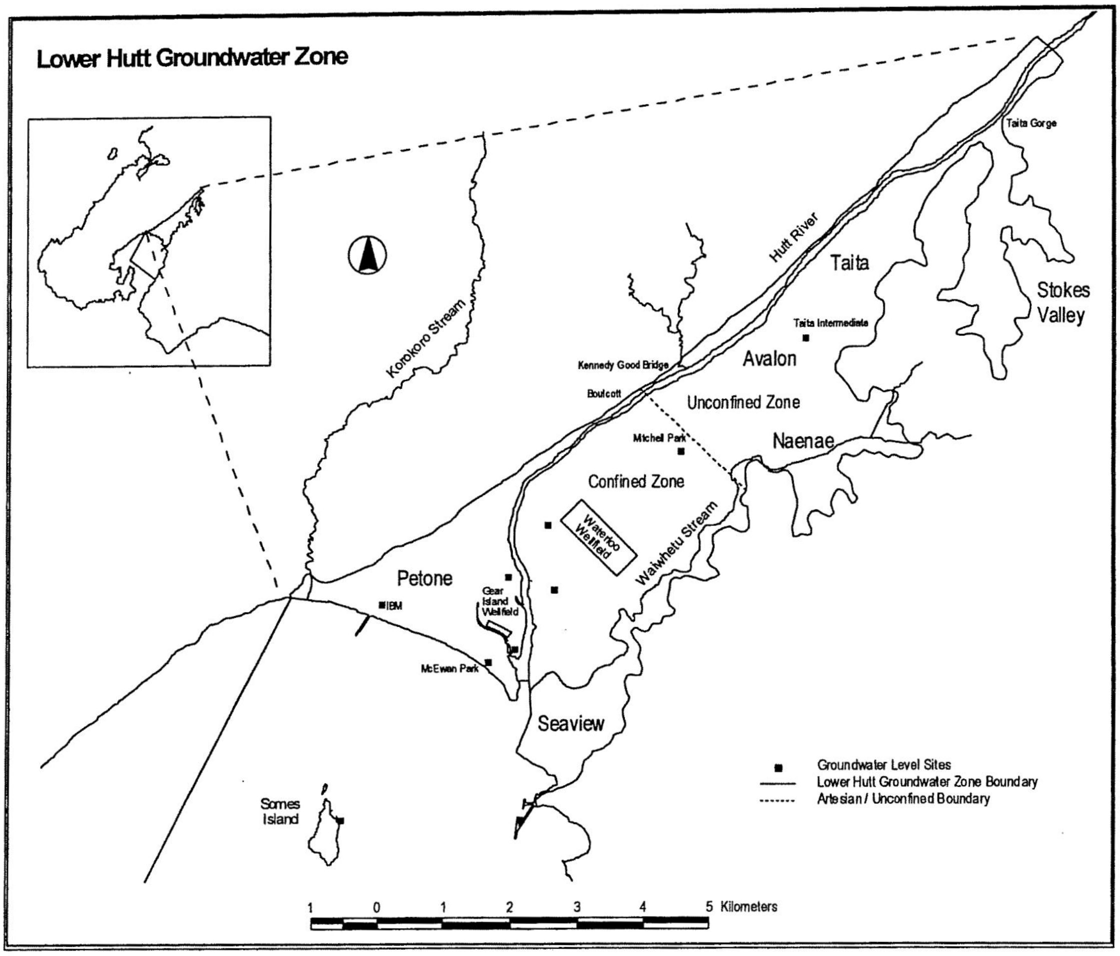


**Figure 1: Location map of the Lower Hutt Groundwater Zone**

The volume of groundwater abstracted from the Lower Hutt Groundwater Zone for municipal supply has been increasing steadily over the past five years to a current average of approximately 70 ML/day. It is likely that the level of groundwater abstraction will increase in the near future in response to increasing demand and the implementation of the Proposed Regional Freshwater Plan. Under policies contained in this plan, the volume of water available for municipal supply from intakes on the Hutt, Wainuiomata and Orongorongo Rivers is likely to be reduced during drought periods to preserve the life supporting capacity of these waterways. Consequently, demand on groundwater resources in the Lower Hutt Valley is likely to increase to cover any shortfall in supply. Resource consent applications currently lodged with the Wellington Regional Council propose an increase in the maximum allowed groundwater abstraction rate to 120 ML/day for up to three months in any 12 month period

Present groundwater quality in the Lower Hutt Groundwater Zone is generally very high and the water is able to be used for public supply after minimal treatment for pH correction and fluoridation. The Waiwhetu Artesian aquifer which extends throughout the southern half of the Lower Hutt Basin is the major water producing unit used for municipal and industrial supply. This aquifer is protected from localised contamination by a low permeability confining layer. However, the quality of this resource may be affected by contamination originating in the recharge area, or by seawater intrusion into the coastal margin. The Waiwhetu Artesian Aquifer is recharged from the unconfined aquifer which in turn receives recharge from the Hutt River and rainfall recharge.

The catchment areas of the major rivers used for water supply in the Wellington Region, e.g., the Hutt and Wainuiomata Rivers, have been managed since initial development to ensure water quality is not affected by land use activities. As a result, these catchment areas remain relatively pristine. In contrast, the entire Hutt Valley is highly urbanised with a considerable amount of urban development in the recharge area for the artesian aquifer system. The urban development in this area increases the potential for contamination of one of the Region's major water resources. A proactive approach is required to develop a groundwater quality management strategy to safeguard this regionally significant resource.

## 1.2 Responsibility for Groundwater Quality Management

The responsibility for the management of groundwater quality under the Resource Management Act 1991 is shared between regional councils and territorial authorities (district and city councils). Under the Act, regional councils have a responsibility to control discharges to avoid adverse environmental effects and ensure the quality and quantity of groundwater resources remain suitable for potential future use. This is achieved by the requirement for Resource Consent to be obtained from the Regional Council for groundwater abstraction or specific discharges which may affect groundwater quality.

Responsibility for the control of land use is shared between regional and territorial authorities. However, in practice, this is function is generally undertaken by territorial authorities. District plans developed by territorial authorities include land use zoning or controls on activities within certain areas. As a result, the control of activities or land uses which may impact on groundwater quality is primarily a territorial authority function.

**Table 1: Methods Available for Managing Groundwater Quality in New Zealand**

| Authority | Activities Controlled | Method |
|---|---|---|
| Regional Councils | Discharges | Resource consents |
| | Abstraction | Regional Plans |
| Territorial Authorities | Land Use | District Plans |
| | | • Land use zoning |
| | | • Codes of practice |

The Local Government Act 1974 also contains provisions relevant to the implementation of groundwater quality protection measures. This legislation empowers local authorities to construct or purchase any waterworks for the supply of pure water and makes it an offence to directly or indirectly pollute the water supply, or watershed, of any district in such a manner as to make the water a danger to human health or offensive; or allow livestock to trespass onto any waterworks (section 392).

Public health authorities have a responsibility for improving, promoting and protecting public health under the Health Act 1956. Part of this responsibility includes ensuring private and public water supplies are of an adequate standard. This is generally achieved by ensuring municipal supplies are adequately treated and reticulation systems are of an acceptable standard. Monitoring of the quality of public water supplies in New Zealand is achieved by a system of voluntary compliance. The Health Act 1956 also contains provisions whereby the Governor General can, by Order in Council, declare any water supply source, whether publicly or privately owned and operated, to be under the control of a territorial authority if this is necessary in the interests of public health (section 61(2)). The Health Act also makes it an offence to create a nuisance or allow a nuisance to continue (section 30) including allowing a water source to be offensive, liable to contamination, or hazardous to health (section 29).

In the absence of any statutory requirements, groundwater users do not have any direct responsibility for the management of groundwater quality. However, users of a groundwater resource have a vested interest in ensuring the quality of a groundwater resource remains suitable for the intended use. In the case of public water supply utilities, the economics of groundwater quality protection clearly outweighs the costs of treatment and development of new water supplies as a result of the contamination of groundwater resources.

## 1.3 Regional Plans

The value of water resources to the community is recognised by the Resource Management Act 1991. This legislation makes a trade-off between human needs and environmental impacts with a goal of enabling sustainable management of natural resources.

The WRC Regional Policy Statement provides for the management of natural resources in the Wellington Region. Section 5 of this document covers the management of freshwater resources including surface and groundwater. The plan lists a number of issues related to the quality and quantity of water resources and outlines the Regional Council's objectives for water resource management. The plan then specifies a number of policies and methods to be used to attain the stated objectives. A number of the objectives, policies and methods contained in this section are directly relevant to the development of a groundwater quality management strategy for the Lower Hutt Groundwater Zone.

For example, Objective 2 of the Freshwater section of the plan requires that:

> *The quality of fresh water meets the range of uses and values for which it is required, safeguards its life supporting capacity, and has the potential to meet the reasonably foreseeable needs of future generations.*

Policies developed in the plan which are specifically related to this objective and are relevant to the management of groundwater quality in the Lower Hutt Groundwater Zone include:

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.;*

Policy 4: *To maintain and protect the quality of freshwater so that it is available for a range of uses and values, and;*

*(1) Its life supporting capacity is safeguarded; and*

*(2) Its potential to meet the reasonably foreseeable needs of future generations is sustained, and;*

*(3) For surface water, any adverse effects on aquatic and riparian ecosystems are avoided, remedied, or mitigated.*

Policy 6: *To ensure that the effects of contaminants contained in point source discharges on the quality of fresh water and aquatic ecosystems are avoided, remedied, or mitigated and allowing for reasonable mixing:*

*(1) Do not render any fresh water unsuitable for any purpose specified in any regional plan for that water.*

*(2) Do not prevent the receiving fresh water from meeting any standards established in any regional plan for that water.*

*(3) Do not render any water in the coastal marine area unsuitable for any purpose specified in a regional coastal plan for the Wellington Region.*

Policy 7: *To avoid, remedy, or mitigate adverse effects on water quality and aquatic ecosystems of contaminants contained in non-point source discharges.*

Policy 12: *To avoid remedy, or mitigate any adverse effects of any new or existing use and development where these effects impact on the natural character of wetlands, lakes, rivers, and other water bodies, and their margins.*

Policy 15: *To protect water resources used for public water supply from abstractions of water and discharges of contaminants which may affect the suitability of those water for water supply purposes.*

To achieve the stated policy goals, the Regional Policy Statement includes a number of methods which may be used to achieve the management objectives. Listed methods which are relevant to the management of groundwater quality in the Lower Hutt Groundwater Zone include:

*The Wellington Regional Council will:*

Method 17: *Require resource consents for all discharges to water, land or groundwater not allowed for in the Act or in a regional plan.*

Method 26: *Where necessary, develop standards, guidelines and codes of practice (based on nationally recognised codes of practice and in association with territorial authorities, industry and professional groups) for the following activities or effects:*

- *(1) Dairy shed effluent disposal;*
- *(2) Stormwater run-off;*
- *(3) Land clearance;*
- *(4) Subdivision and mass earthworks effects;*
- *(5) Mining;*
- *(6) On-site sewage treatment and disposal (e.g., septic tanks);*
- *(7) Spills of contaminants.*

Method 30: *Identify land based activities which contribute to adverse effects on water bodies and provide advice on ways of minimising those effects through district plans or other means available to territorial authorities.*

Method 51: *Through resource consents, control abstractions and discharges with the potential to detract from the quality or quantity of any water which is used to maintain public water supplies. Conditions may be imposed on existing consents over time where necessary to improve the quantity or availability of water.*

Method 52: *Encourage water supply authorities and other authorities to use the provisions and powers of other acts, regulations and guidelines to protect the quality of water in water bodies and promote public health.*

Methods 30 and 52 are especially relevant to groundwater quality protection in the Lower Hutt Groundwater Zone. Following these policies, groundwater quality management strategies developed by the Regional Council can be implemented by inclusion in district planning provisions by territorial authorities.

In addition, specific policies are included in the Proposed Regional Freshwater Plan for the Wellington Region, and the Proposed Regional Discharges to Land Plan for the Wellington Region which relate directly to the protection and maintenance of groundwater quality throughout the Wellington Region. The Regional Freshwater Plan contains general policies relating to the quality of the Regions water resources while the Regional Discharges to Land Plan regulates specific activities which may have an adverse effect on ground and surface water resources.

For example Policy 7.3.7 of the Freshwater Plan states the policy of the Wellington Regional Council:

> *To manage all groundwater in the Wellington Region so that there are no net adverse affects on its quality as a result of discharges to surface water or groundwater.*

The purpose of this legislation is to manage the fresh water in the Wellington Region (including the groundwater resources) so that wherever possible groundwater quality is maintained or enhanced. The Proposed Regional Freshwater Plan contains a large number of specific policies developed from the more general objectives outlined in the Regional Policy Statement.

# 2. Hydrogeology

This section presents a brief summary of the hydrogeology of the Lower Hutt Groundwater Zone. An expanded description of the hydrogeology of this area is included in Appendix 1. The most comprehensive summary of the surface and groundwater resources of the Hutt Catchment to date is contained in WRC (1995).

## 2.1 Geology

The Lower Hutt Groundwater Zone describes an unconfined/confined aquifer system deposited in an actively developing basin adjacent to the Wellington Fault. The Lower Hutt Basin was formed by downwarping of the greywacke basement during the mid-late Pleistocene period. Basement rock occurs just below the surface at Taita Gorge, and slopes down to in excess of 300 metres below ground level at the Petone foreshore.

During the Quaternary period, relative sea and ground levels around the Wellington area fluctuated considerably as a result of the combination of tectonic activity and climatic oscillations. During warmer interglacial periods, the Hutt River delta extended past the present harbour entrance and extensive areas of alluvial sediments were deposited. During cooler glacial times the sea inundated the Lower Hutt Basin and fine marine sediments were deposited over the alluvial sediments. The layers of fine grained marine sediments now form aquitards which separate alluvial gravel aquifers.

## 2.2 Hydrogeology

The Lower Hutt Groundwater Zone extends from the confines of Taita Gorge in the north, out into Wellington Harbour. The aquifer system is bounded by the Eastern Hutt Hills to the east and the partially buried scarp of the Wellington Fault to the west. The southern extent of the aquifer system occurs along a poorly defined margin between Somes Island and the entrance to Wellington Harbour. The greywacke ridges which define the Lower Hutt Valley effectively act as a hydraulic barriers and confine groundwater flow to the alluvial sediments infilling the valley.

The sediments infilling the northern portion of the Lower Hutt Valley comprise a thick undifferentiated sequence of gravel sand and silt deposited by the Hutt River, which forms an unconfined aquifer. South from a line across the valley in the vicinity of the Hutt Golf Course, the sequence of alluvial material is broken by two layers of low permeability marine and marginal marine sediments. These low permeability layers separate the aquifer system in the lower valley into two confined aquifers overlain by a thin unconfined aquifer.

The Moera Gravel aquifer overlies basement throughout the southern portion of the Lower Hutt Groundwater Zone. This unit is predominantly comprised of poorly sorted, moderately weathered, low permeability gravel, silt and clay which is up to 200 metres thick in places. Only the top 10 to 20 metres of this aquifer has any significant waterbearing potential. The Moera Gravel Aquifer is separated from the overlying Waiwhetu Artesian Aquifer by a thick fine sand and silt layer known as the Wilford Shell Bed. This unit forms an aquitard which limits the upward movement of water from the Moera Gravel Aquifer.

The Waiwhetu Artesian Aquifer is the main water producing unit in the Lower Hutt Groundwater Zone. This aquifer is comprised of high permeability gravel layers separated by discontinuous layers of peat, silt and sand deposited by the Hutt River. Despite the variable geology, the permeability of this aquifer is very high, reducing from 40,000 $m^2$/day in the Waterloo Wellfield to an average of 25,000 $m^2$/day in the Petone Foreshore area. The Waiwhetu Artesian Aquifer in turn is overlain by a low permeability confining layer commonly known as the "main" aquitard. This unit is a lateral equivalent of the fine grained silts and clays which form the present day floor of Wellington Harbour. A diagrammatic cross section of the Lower Hutt Groundwater Zone is presented in Appendix 1.

The main source of water for the Lower Hutt Groundwater Zone is from the Hutt River. Water from the river seeps into the gravels in the unconfined area then flows through the aquifer system following the natural topographic gradient towards Wellington Harbour. Water flowing through the unconfined aquifer either enters the Moera or Waiwhetu aquifers, or flows back into the river in the lower valley. Due to the low permeability of the confining layers (or aquitards) which overlie these aquifers, piezometric levels increase in the lower valley and wells become artesian. This means that under normal conditions a bore screened in the Waiwhetu aquifer near the Petone Foreshore will exhibit a piezometric level of approximately 4 metres above mean sea level, and a bore in the Moera aquifer between 5 and 6 metres above mean sea level.

## 2.3 Groundwater Throughflow

Groundwater flows from the recharge zone in the unconfined area through the confined aquifers and is ultimately discharged beneath Wellington Harbour via numerous submarine springs which are distributed across the harbour floor. It is calculated that under natural conditions the rate of groundwater throughflow in the Waiwhetu Artesian Aquifer is approximately 40 ML/day and in the Moera Gravel Aquifer 4 ML/day.

The rate of groundwater flow through the aquifer system increases in response to abstraction from the confined aquifers. However, during summer low flow periods, the gauged flow loss of approximately 60 ML/day from the Hutt River may be less than the total volume of harbour outflow and abstraction. In this situation piezometric levels begin to fall in the confined aquifer system. Because of the direct connection between the confined aquifer system and the harbour, the volume of water able to be safely abstracted from the resource is limited by the potential for seawater to enter the aquifer if piezometric levels are reduced too far. A safe yield of 90 ML/day has been calculated for the Lower Hutt Groundwater Zone to prevent adverse effects on the quality or availability of the resource.

# 3. Groundwater Quality Protection

Over the past two decades groundwater quality protection has become a well established groundwater management practice. In many countries, especially in North America and Europe, it is now recognised that groundwater quality management is an integral part of the overall management of a groundwater resource. The increased focus on groundwater quality management has come about due to:

- The increasing pressure on groundwater resources to meet demand for public, industrial and irrigation supply.
- The numerous examples of groundwater contamination resulting from land use, industry, or waste disposal.
- Increasing public awareness of water quality issues and higher expectations of water quality.
- The increasing risk of pollution due to the volume and complexity of industrial wastes for which there is shortage of suitable disposal sites.
- Experience of extensive clean-up operations which have been required to mitigate the effects of past land use and waste disposal practices.

The basic tenet of groundwater quality protection is the use of methods such as land use zoning to reduce the potential for groundwater contamination to result from land use or activities on the on or beneath the ground surface. Groundwater quality protection seeks to apply the *ounce of prevention* philosophy to water resource management. Potential sources of groundwater contamination are identified and steps are taken to either eliminate or reduce the risk of contamination resulting from these sources.

The susceptibility of a particular hydrogeological setting to groundwater contamination is usually expressed in terms of groundwater contamination vulnerability. The term groundwater contamination vulnerability is used to represent the intrinsic characteristics which determine the sensitivity of various parts of an aquifer to being adversely affected by an imposed contaminant load and, as a result, vulnerability is a relative rather than absolute concept. For example, unconfined and shallow groundwater is more likely to become contaminated than deeper confined groundwater. However, within a single aquifer system there will be places where the risk of contamination is higher or lower depending on a number of site specific factors.

Groundwater vulnerability assessment is usually undertaken as a zoning tool to assign a range of acceptable and/or unacceptable uses and activities for different areas of an aquifer system. Implementation of a groundwater quality management strategy may involve the use of the results of a groundwater vulnerability assessment to develop planning and regulatory tools to protect groundwater quality. The most common groundwater quality management approach is the use of Groundwater Quality Protection Zones (GPZ). GPZ are mappable identities which identify areas at risk from groundwater contamination. Each groundwater zone has associated a series of controls on controls on land use and activities designed to minimise the potential for groundwater contamination.

Many types of groundwater quality protection zoning have been applied around the world ranging from the simple "blue belt" concept which involves the setting aside of land to be managed for water supply purposes, to the delineation of Wellhead Protection Areas (WHPAs) which are used to develop regulatory measures to prevent the contamination of groundwater at a particular municipal supply abstraction point within an aquifer system.

## Wellhead Protection Areas

Following the lead established in Europe during the 1960s and 70s, the United States Congress recognised the need for conjunctive management of contaminant sources and public water supplies to prevent or minimise groundwater quality degradation by amending the Safe Drinking Water Act in 1986. Changes to this legislation mandated the development of the Wellhead Protection Program (WHPP) by the US Environmental Protection Agency (USEPA). This move led to the development of a legal framework to protect public water supply wells, wellfields, and springs from contamination. This legislation recognised the value of groundwater supplies to individual communities especially where groundwater is the sole source of public water supply. Many countries have developed groundwater quality protection programmes following the lead set by the USEPA.

A large number of communities in the U.S. have developed *Wellhead Protection Plans* with the assistance of either federal and state agencies. While individual plans are specific to each community there are common components to most:

- Vulnerability assessment
- Improved definition of aquifer hydrogeology
- Identification of potential contaminant sources
- Identification of groundwater protection zones
- Regulation of land use activities in hydrogeologically vulnerable areas
- The implementation of a comprehensive groundwater quality monitoring programme
- Community education and involvement in implementation of contamination prevention programmes
- Development of contingency plans in case of an incident likely to result in groundwater contamination.

The key aspect to the development of wellhead protection plans is the adoption of a proactive approach to groundwater resource management. Potential contaminant sources are identified and steps are taken to minimise the risk of contamination by controlling land uses and activities which may have an adverse effect on groundwater quality. These measures are followed by the development of a comprehensive groundwater quality monitoring programme to enable early detection of contamination events or changes in quality.

Further detail of various groundwater quality protection approaches is given in Appendix 2.

# 4. Groundwater Quality Management in the Lower Hutt Valley

## 4.1 Groundwater Vulnerability

Two groundwater vulnerability mapping exercises have been undertaken in the Lower Hutt Groundwater Zone utilising the DRASTIC method. Brown *et al.* (1994) undertook a groundwater vulnerability mapping exercise for the Wellington Regional Council as part of the preparation of the Regional Plan for Discharges to Land. For the purposes of regional groundwater vulnerability assessment the study area was divided into 10 basic hydrogeologic settings and a DRASTIC rating was developed for each, based on characteristic properties. This study rated recent braided river gravel, sand and silt as the most vulnerable hydrogeological setting to groundwater contamination. Such deposits occur adjacent to the Hutt River across the recharge area of the Lower Hutt Groundwater Zone. The remainder of the unconfined aquifer throughout the Lower Hutt Valley was rated as moderately to highly vulnerable to groundwater contamination.

Liddell (1995) completed a more local scale investigation of groundwater vulnerability in the Lower Hutt Groundwater Zone as part of an investigation of the pollution risk of the Hutt Aquifer system. This investigation utilised a GIS overlay-type approach to determining groundwater vulnerability in both the unconfined and confined aquifers. Figure 2 shows the vulnerability map compiled for the confined aquifer. As would be expected this map shows a significant reduction in the vulnerability of the Waiwhetu Artesian Aquifer to groundwater contamination south of the inland margin of the main aquitard.

In the unconfined area, the vulnerability to groundwater contamination reduces towards the eastern side of the valley reflecting the change in aquifer geology from high permeability alluvial gravels, through lower permeability alluvial gravel and overbank sand and silt, to poorly sorted alluvial fan and slope debris at the base of the Eastern Hutt Hills.

## 4.2 Groundwater Quality Protection Zones

The basis of a preventative, rather than reactive, approach to groundwater quality management is the identification of groundwater quality protection zones (GPZ) based on the vulnerability of the groundwater to contamination and the possible future uses and values of the groundwater (Freeman and Ayrey, 1988). Potential threats to groundwater quality in the Lower Hutt Groundwater Zone can be divided into three broad categories:

- Chemical contamination
- Microbial contamination
- Saline intrusion.

The primary objective of groundwater quality management in the Lower Hutt Groundwater Zone is to maintain the quality of groundwater in the Waiwhetu Artesian Aquifer. While this aquifer is protected from direct contamination by the low permeability main aquitard, it remains vulnerable to both contamination originating within the unconfined area and saline intrusion due to the overexploitation of this resource. The groundwater quality protection zones proposed in this report are intended to give an indication of the potential for contamination in different parts of the aquifer system to affect the quality of water in the Waiwhetu Artesian Aquifer, particularly at municipal supply wells in the Waterloo Wellfield.

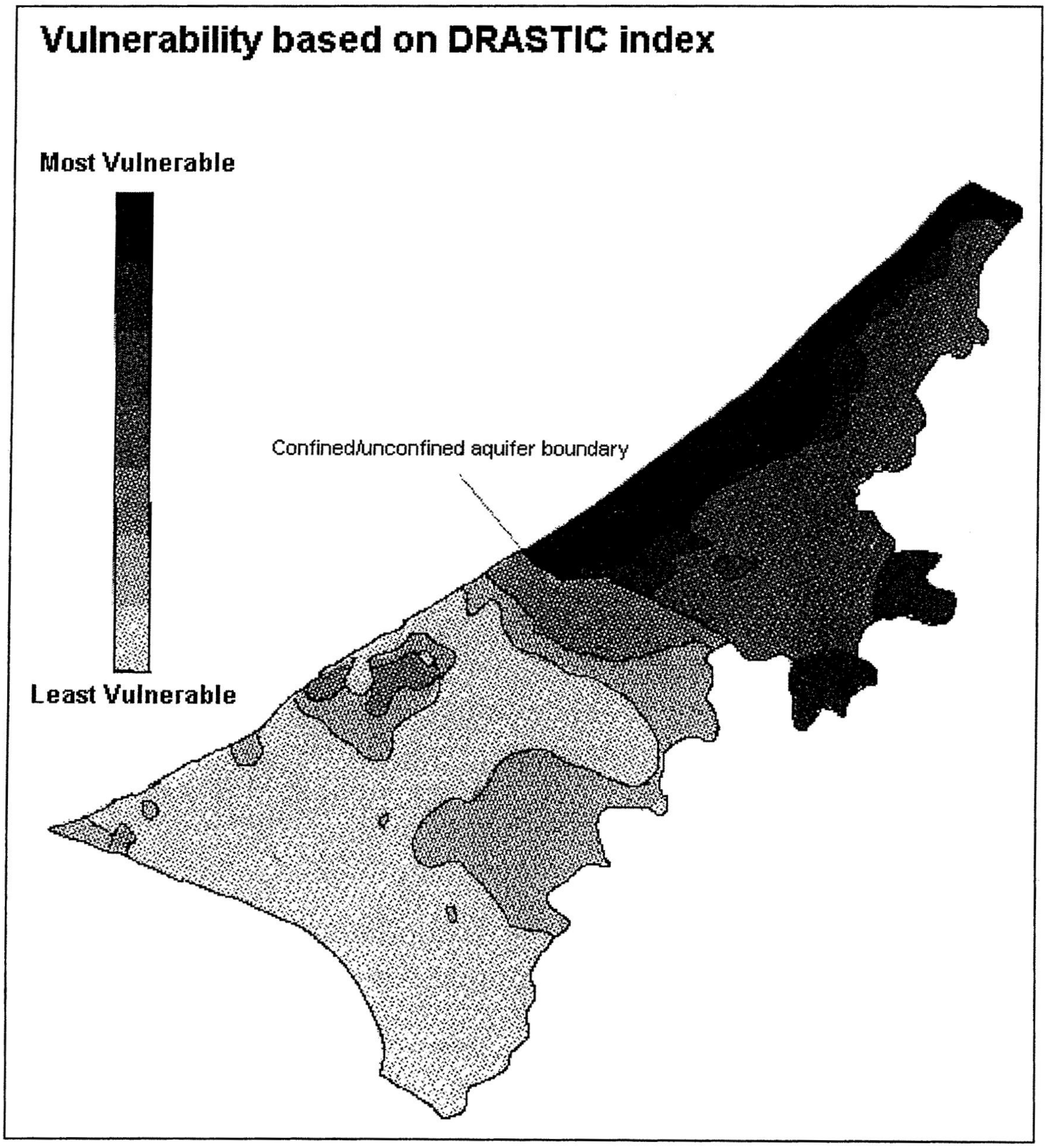


**Figure 2: Groundwater Contamination Vulnerability of the Waiwhetu Artesian Aquifer (Liddell, 1995)**

Due to the geology and geometry of the Lower Hutt Groundwater Zone, the proposed groundwater quality protection zones encompass the entire aquifer system. Delineation of the boundaries of the aquifer system within the Hutt Valley is relatively straightforward. The aquifer system is bounded to the east and west by greywacke ridges which effectively act as groundwater flow boundaries. The northern boundary is within the narrow confines of Taita Gorge which also defines the northern margin of the recharge zone. The zone of contribution (ZOC) for the confined aquifer system is equivalent to the recharge zone for the Lower Hutt Groundwater Zone. This area is roughly triangular in shape and lies between the flow boundaries to the east and west of the Hutt Valley, and extends south from Taita Gorge to the northern margin of the main aquitard.

The following section outlines preliminary groundwater quality protection zones for the Lower Hutt Groundwater Zone which provide a starting point for the development of a groundwater quality protection strategy. As these proposed protection zones are based on very simple criteria (ZOC, ZOI and simple hydraulics) further work is required to improve delineation based on more definitive criteria such as time of travel (TOT) or contaminant transport modelling. Once accurately delineated, the groundwater protection zones can be used as planning tools to implement a groundwater quality protection programme. The proposed groundwater quality management zones for the Lower Hutt Groundwater Zone are shown on Figure 3.

***Zone 1: Confined Aquifer***. The Waiwhetu Artesian Aquifer is protected from direct contamination by the overlying silt aquitard. However, due to the direct connection between this aquifer and the harbour the potential exists for the intrusion of seawater into the aquifer as a result of a reduction in piezometric head levels. Piezometric levels may be reduced sufficiently to result in saline intrusion as a result of excessive abstraction or damage to the integrity of the confining layer. Therefore the management objective in this zone is the prevention of saline intrusion into the Waiwhetu Artesian Aquifer.

The potential for saline intrusion into the Waiwhetu Artesian Aquifer was recognised by Donaldson and Campbell (1977) who proposed a level of 1.4 metres above mean sea level at the McEwan Park monitoring site near the Hutt River Mouth as a minimum operating piezometric level for the Waiwhetu Artesian Aquifer. Derivation of the minimum operating level was based on an observed relationship between aquifer levels at McEwan Park and Somes Island. Recent monitoring data does not support this relationship. However, until a review of the minimum level is undertaken, it is assumed that this level is sufficiently conservative to stand as an arbitrary figure. Provision for the minimum foreshore water level has been included under rule 18 of the Proposed Regional Freshwater Plan which specifies that:

> *The abstraction of groundwater from the Lower Hutt Groundwater Zone shall cease when the groundwater level of the aquifer at McEwan Park falls below 1.4 metres.*

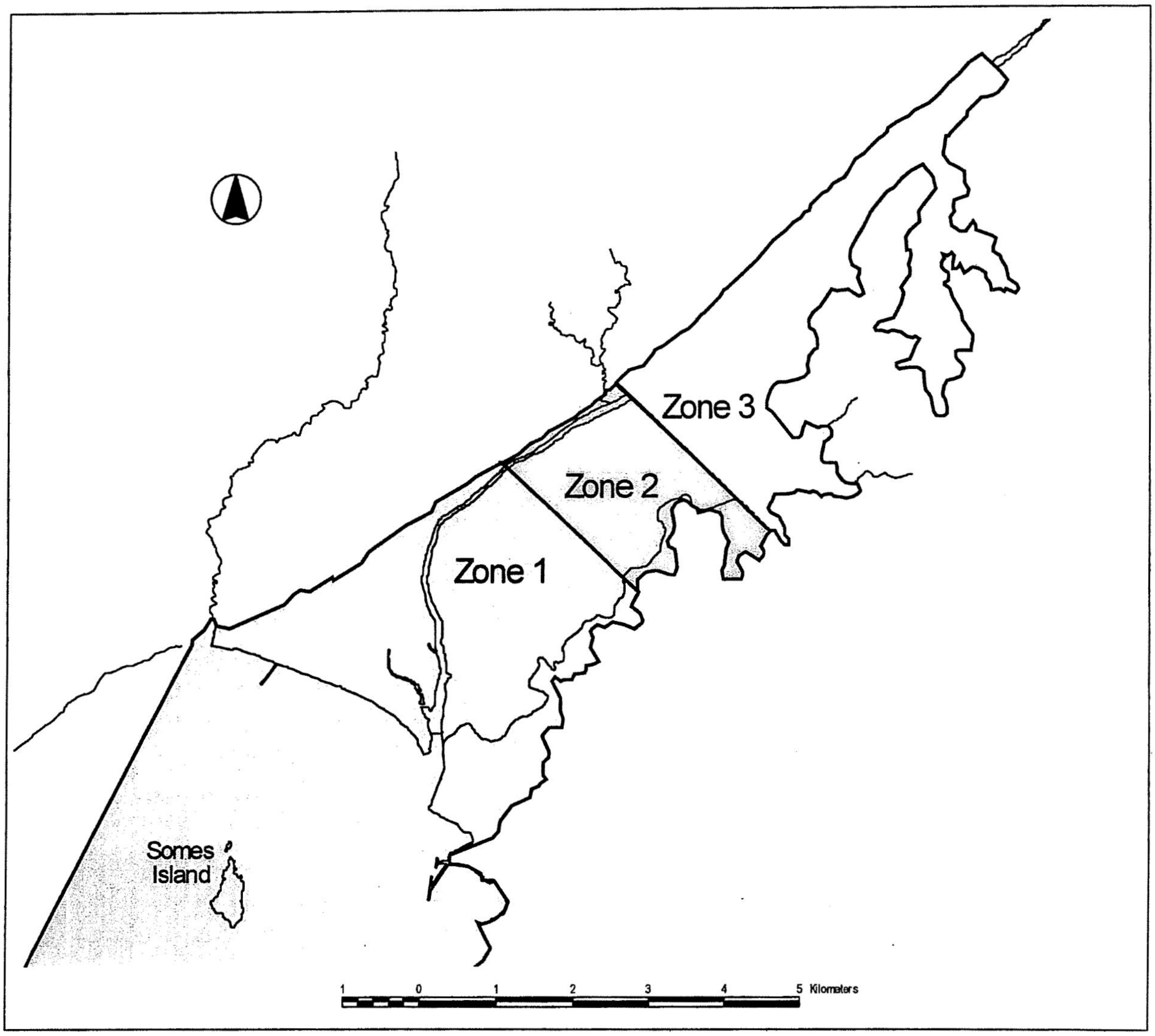


**Figure 3: Proposed groundwater quality protection zones for the Lower Hutt Groundwater Zone**

Although not specifically developed for groundwater quality protection purposes, Rules contained in the Proposed Regional Freshwater Plan also place controls on construction activities and the volume of groundwater abstraction both of which may impact on piezometric levels in the Waiwhetu Artesian Aquifer. Rule 10 specifies that:

*The construction of any bore/well or hole, or the driving of any pile which is:*

- *deeper than 5 metres*
- *in the Lower Hutt Groundwater Zone*

*is a discretionary activity.*

As a result the Regional Council has the ability to control construction activities in the Lower Hutt Groundwater Zone which may pose a threat to the integrity of the confining layer. The Regional Council may also impose resource consent conditions which require bores in the Lower Hutt Groundwater Zone to be fitted with secure wellheads and backflow prevention devices.

Groundwater abstraction is controlled by Rule 17 which sets the maximum rate of use of groundwater in the Lower Hutt Groundwater Zone at 32.85 million cubic metres per year.

While the Proposed Regional Freshwater Plan allows the Council to control the construction of new bores in the confined aquifer, it does not include provision for dealing with abandoned/unused or poorly constructed existing wells which may present a threat to groundwater quality. At present, the Wellington Regional Council has control of appropriate remedial action under the *Wellington Regional Water Board Bylaws 1976*. Although much of the content of the bylaws is duplicated in the Proposed Regional Freshwater Plan, any repeal of this legislation should retain retrospective control over existing bores and construction activities.

The regulatory controls outlined above indicate that at present there are sufficient protection measures in place to effectively control groundwater quality in the area of Zone 1 proposed in this report.

***Zone 2: Zone of Influence of Waterloo Wellfield***: Although the zone of contribution to the confined aquifer system includes the entire unconfined area, only part of this zone is under the direct influence of municipal supply abstractions in the Waiwhetu Artesian Aquifer.

Figure 4 shows the response of water levels recorded at the Mitchell Park water level recording site. This bore is screened in the Waiwhetu Artesian Aquifer very close to the unconfined/confined aquifer margin. Clearly aquifer levels at this site are affected by abstraction from the Waterloo Wellfield. The exact extent of the ZOI is difficult to determine as the area affected by drawdown from the Waterloo Wellfield is dependant on the rate of groundwater abstraction. Also, in the unconfined area it is difficult to separate the effects of groundwater abstraction from changes in aquifer levels due to recharge events. For example, periods of recession in piezometric levels in the unconfined aquifer correspond to periods of recession in Hutt River flow and conversely recharge events commonly correspond to a reduction in demand and consequently a lower rate of abstraction.

For the purposes of this report the ZOI of the Waterloo wellfield is assumed to extend a distance of at least 1 kilometre north of the unconfined/confined zone boundary. This assumes a fixed radius of approximately 3000 metres from the Waterloo Wellfield. Application of Darcy's equation to calculate groundwater flow velocity indicates a flow velocity of approximately 12 m/day in Zone 2. This calculation assumes an aquifer permeability of 1000 $m^2$/day, a hydraulic gradient of 0.003 m/m and an aquifer porosity of 25 percent. From this velocity calculation the minimum time of travel between the northern extent of the ZOI and the Waterloo Wellfield is estimated to be approximately 250 days, and from the nominal confined/unconfined aquifer boundary, 165 days.

Estimation of groundwater flow velocity using such a simplistic method does not account for the heterogeneity observed in alluvial aquifer systems. Due to the nature of deposition, features which represent buried river channels are commonly observed. These features commonly contain high permeability gravels and form preferential flow paths through which groundwater may flow at a much higher rate than that calculated from average aquifer parameters. Therefore, while it is generally accepted that substantial attenuation of microbial contamination occurs over a few hundred metres, it is possible that microbial contaminants may be transported over substantial distances through these preferential flow paths. For example, tracer tests undertaken by Liddell (1995) near Fraser Park in the recharge zone showed a groundwater flow velocity of approximately 111 m/day compared to the average velocity of 12 m/day calculated above.

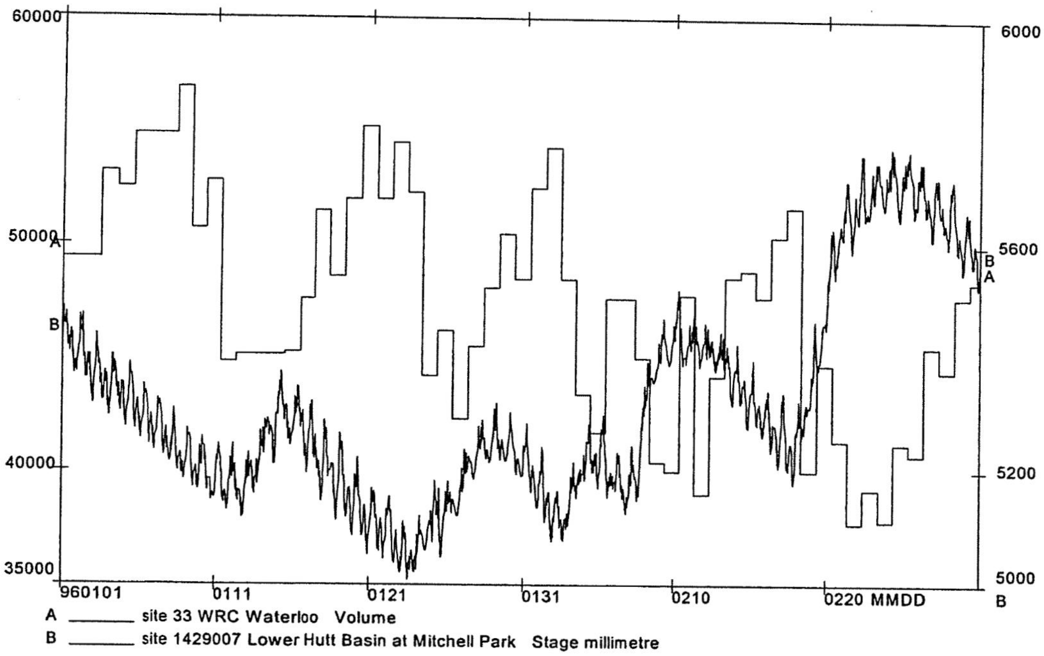


**Figure 4: Groundwater level fluctuations at Mitchell Park (1429007) in response to abstraction from the Waterloo Wellfield**

Due to the irregular nature of the Melling Peat aquitard, it is proposed that Zone 2 is extended 1 kilometre either side of the nominal unconfined/unconfined aquifer boundary shown in Figure 1. The separation between the southern boundary of Zone 2 and the Waterloo Wellfield provides a minimum distance for the natural attenuation of contamination. Activities and land uses should be managed in this area to reduce the potential for both chemical and microbial groundwater contamination.

***Zone 3: Zone of Contribution***: This groundwater quality protection zone includes the remainder of the unconfined area not included in Zone 2. This area forms the majority of the recharge zone for the confined aquifer system. Contamination of groundwater in this area by inorganic or organic chemicals such as heavy metals, metalloids, pesticides, hydrocarbons, and volatile organics has the potential to impact on downgradient groundwater quality.

Due to the separation between Zone 3 and the Waterloo Wellfield the threat posed by microbial contamination is significantly reduced. As a result the level of protection required in this zone is primarily related to the possibility of non-degradable chemicals contaminating groundwater.

The DRASTIC map produced by Liddell (1995) shows the vulnerability of the Waiwhetu Artesian Aquifer to contamination originating from elsewhere in the unconfined area is highest close to the Hutt River. This is due to the higher permeability aquifer materials in this area along with thin alluvial soils and a higher water table. In the future it may be possible to further delineate groundwater quality protection zones in the ZOC based on analyses of aquifer vulnerability.

Table 2 presents a brief outline of the proposed groundwater quality protection zones for the Lower Hutt Groundwater Zone. Further work is required to improve delineation of groundwater protection zones for this area. This includes providing better definition of aquifer parameters and heterogeneity and improving the understanding of contaminant transport mechanisms. Isotope investigations would be extremely useful in the development of time of travel criteria for groundwater quality protection zoning.

**Table 2: Proposed groundwater quality protection zones for the Lower Hutt Valley**

| Zone | Description | Management Issue | Method |
|---|---|---|---|
| 1 | Waiwhetu Artesian Aquifer not including Zone 2 | Saline Intrusion | Freshwater Plan methods/rules |
| 2 | Unconfined and Waiwhetu Aquifers, 1 km either side of unconfined/confined boundary | Chemical/Microbial Contamination | Land Use, Regulatory Control, Monitoring |
| 3 | Unconfined area north of Zone 2 | Chemical Contamination | Land Use, Regulatory Control, Monitoring |

## 4.3 Development of a Groundwater Quality Management Strategy

Following the delineation of preliminary groundwater quality protection zones for the Lower Hutt Groundwater Zone, the next step in the development of a groundwater quality management plan is the identification of current or potential land uses or activities within each zone which are incompatible with management objectives. This process requires a comprehensive assessment of potential threats to groundwater quality in each protection zone. Once this is completed a groundwater quality management plan can be developed which includes groundwater quality management tools such as:

*Zoning*: Zoning consists of developing land use planning regulations to avoid conflict between the established groundwater quality management objectives and future land uses or developments within the proposed groundwater quality protection zones. The production of a groundwater quality management strategy requires identification of potential future activities which are not compatible with groundwater quality management objectives. Zoning is generally applied to future development and does not directly affect existing activities. The downside is that zoning is often viewed as overly restrictive and can be politically contentious.

It is anticipated that land use zoning for groundwater quality protection would have a minor impact on development in the Hutt Valley. Due to the residential development in this area it is unlikely that activities which pose significant threats to groundwater quality such as landfills or sewage treatment operations would ever be established in this area. However, zoning would be a useful tool to locate future activities which pose a limited threat to groundwater quality in areas least vulnerable to contamination. For example, future industrial development in the recharge zone should be concentrated along the eastern side of the valley where groundwater vulnerability is lowest.

*Design and operating standards*: The implementation of design or operating standards is a practical way of controlling existing activities which pose a risk of groundwater contamination. Design standards are usually applied to new engineering projects while operating standards such as codes of practice or best management practices (BMP) can be developed or implemented for existing activities.

An example of a design and operating standard which has been successfully implemented is the oil industry code of practice which has been developed for underground storage tanks. Similar codes of practice have been developed by the Chemical Industry Council. Method 26 of the Proposed Regional Freshwater Plan requires the WRC where necessary to develop standards, guidelines and codes of practice for a range of activities which may impact on groundwater quality.

*Public Education*: One of the most important components of a groundwater quality management plan is public education. This is an effective tool for gaining support for regulatory measures and other groundwater quality protection programmes. Steps are required to raise awareness of the need for groundwater quality protection and to have public participation in the implementation of groundwater quality initiatives.

*Source Prohibitions*: require the removal of activities or hazardous materials from particular groundwater quality protection zones. This is a backup for design and operating standards in cases where no workable solution can be found to reduce the risk of contamination posed by certain activities.

## 4.4 Case Study: Shell Avalon UST Leak

The need for the development of a comprehensive groundwater quality management programme is illustrated by past experience of groundwater contamination in the Lower Hutt Groundwater Zone. In November 1988 the Wellington Regional Council was notified of a major groundwater contamination incident in the recharge zone. The incident involved the loss of approximately 70,000 litres of petrol from an underground storage tank at Shell Avalon Motors in Avalon.

Preliminary investigations were undertaken to ascertain the extent of soil and groundwater contamination at the site in early 1989, but it was not until late April 1989 that a remediation programme commenced to recover the lost product. Over a period of several months a total of approximately 2500 litres of petrol was recovered. Seven monitoring bores were installed downgradient of the site aligned in the presumed groundwater flow direction. A number of existing bores were also used for sampling. High levels of BTEX contamination were detected in the three monitoring bores located closest to the spill site. Benzene and xylene at levels above drinking water standards were detected intermittently in the remaining bores until at least mid-1991. This pattern was maintained with observed BTEX concentrations reducing in all bores until regular monitoring ceased in late 1993.

Due to the limited areal distribution of the contamination, and the low levels of contaminants detected away from the immediate spill site it was assumed that the majority of the contamination had been naturally attenuated close to the point of discharge. During the investigation, elevated lead and benzene concentrations were detected in bores at Hutt Hospital, Mitchell Park and Copeland Street. This contamination was considered to have originated from sources other than the Avalon spill. No traces of BTEX or lead contamination were detected in monitoring carried out on production bores in the Waterloo Wellfield up to mid-1993.

In hindsight there are a number of lessons which can be drawn from this incident including:

- The vulnerability of groundwater in the unconfined area to contamination.
- The lack of contingency planning to deal with a major groundwater contamination incident.
- The limited knowledge of contaminant fate and transport mechanisms in heterogeneous aquifer systems
- Evidence of hydrocarbon contamination of groundwater was found near the unconfined / confined aquifer boundary which could not be attributed to the Avalon spill.

# 5. Contaminant Source Assessment

The international literature is full of examples of groundwater contamination due to a vast array of sources. In many locations, especially major population centres, conflict has developed between groundwater quality protection and economic development. To overcome this conflict, many areas have developed groundwater management plans which place controls on land use and activities in areas vulnerable to contamination.

The first step in developing a groundwater quality management plan is the compilation of a contaminant source inventory which identifies activities and land uses (past or present) in the protection area which have the potential to have an adverse impact on groundwater quality. This enables sites contaminated by past activities to be identified and, if required, remediated. Controls can also be placed on existing activities and land use zoning can be implemented to control future development to minimise the risk of groundwater contamination.

## Lower Hutt Groundwater Zone

Lower Hutt is fortunate that the majority of activities which may pose a major threat to groundwater quality such as chemical manufacturing, petroleum bulk storage and heavy engineering industries are concentrated in the Seaview and Gracefield areas. The Waiwhetu Artesian Aquifer has a high degree of protection from groundwater contamination in these areas due to the thick, low permeability silt confining layer and positive heads in the aquifer. Although development in the unconfined area has largely been urban, this type of development may also pose a threat to groundwater quality.

The USEPA (1993) outlined an extensive list of potential sources of groundwater contamination found in WHPAs (Table 6). While this list is by no means exhaustive, there are a number of activities included in the list which are currently undertaken in the Lower Hutt Groundwater Zone. Activities which pose a threat to groundwater quality in the Lower Hutt Groundwater Zone can be grouped into five categories. These include:

- Microbial contamination
- Petroleum hydrocarbons
- Pesticides
- Industrial chemicals
- Other.

*Microbial Contamination*: Due to the natural die-off of micro-organisms in the subsurface environment, the threat to municipal water supply wells posed by microbial contamination increases with the proximity of the source to the production bore. Potential sources of microbial contamination in the Lower Hutt Groundwater Zone include municipal sewer lines and connections, stormwater discharge and recharge from the Hutt River.

**Table 3: Common Sources of Groundwater Contamination in Wellhead Protection Areas USEPA (1993)**

**Agricultural**

- Animal burial areas
- Animal feedlots
- Chemical application (pesticides, fungicides, fertilizers, etc.)
- Chemical storage areas
- Irrigation
- Manure spreading and pits

**Commercial**

- Airports
- Auto repair shops
- Boat yards
- Car washes
- Cemetaries
- Construction areas
- Dry cleaning establishments
- Educational institutions (labs, lawns, and chemical storage areas)
- Gasoline stations
- Golf courses (chemical application)
- Jewelry and metal plating
- Laundromats
- Medical institutions
- Paint shops
- Photography establishments and printers
- Railroad tracks and yard maintenance
- Research laboratories
- Road de-icing activities (road salt)
- Road maintenance depots
- Scrap and junkyards
- Storage tanks (above and below ground)

**Industrial**

- Asphalt plants
- Chemical manufacture, warehousing, and distribution activities
- Electrical and electronic products and manufacturing
- Electroplaters and metal fabricators
- Foundries
- Machine and metalworking shops
- Manufacturing and distribution sites for cleaning supplies
- Mining and mine drainage
- Petroleum products production, storage, and distribution center
- Pipelines (oil, gas, and coal slurry)
- Septic lagoons and sludge
- Storage tanks
- Toxic and hazardous spills
- Wells (operating and abandoned)
- Wood preserving facilities

**Residential**

- Fuel storage systems
- Furniture and wood strippers and refinishers
- Household hazardous products
- Household lawns (chemical application)
- Septic systems, cesspools, and water softeners
- Sewer lines
- Swimming pools (chlorine)

**Waste Management**

- Fire training facilities
- Hazardous waste management units
- Municipal incinerators
- Municipal landfills
- Municipal wastewater and sewer lines
- Open burning sites
- Recycling reduction facilities
- Stormwater drains and retention facilities
- Transfer stations

**Naturally Occuring**

- Ground-water and surface-water interactions (iron and manganese)
- Natural leaching (uranium and radon gas)
- Salt-water intrusion and brackish water upconing

*Petroleum hydrocarbons*: Petroleum hydrocarbons include a wide range of organic chemicals which are used for many applications. Hydrocarbon contamination is of concern as many of these compounds are relatively persistent in the subsurface environment and may be highly toxic or carcinogenic. Potential sources of hydrocarbon contamination in the unconfined area include stormwater discharge, underground storage tanks (UST) and transportation corridors.

*Pesticides*: The usage of pesticide in the Lower Hutt Groundwater Zone is assumed to be relatively low, however, there is potential for contamination to occur due to use of these compounds in applications such as household use, golf courses, weed control in parks and reserves, as well as in the manufacture or storage of these products.

*Industrial chemicals*: Industrial chemicals include a vast range of different chemicals which are used in industrial or domestic applications. Potential groundwater contaminants from these compounds range from organic solvents to inorganic toxins such as heavy metals used in applications such as dry cleaning, metal plating, paint storage and manufacture, and laboratories.

*Other*: Other potential sources of groundwater contamination in the Lower Hutt Groundwater Zone include changes in the quality of aquifer recharge due to quality changes in the Hutt River, contamination resulting from improperly constructed or abandoned wells, and contamination resulting from the re-injection of cooling water. A further potential source of contamination is accidental spillage. Such situations may occur due to fire or an accident along a transportation corridor, e.g., the ICI chemical fire in Auckland.

A first step toward the development of a contaminant source inventory for the Lower Hutt Groundwater Zone has been undertaken by the compilation of a potentially contaminated sites register by the Resource Quality Section of the Wellington Regional Council. This list is a preliminary assessment of potentially contaminated sites in the Wellington Region and is by no means exhaustive. The register includes 27 sites located in the unconfined area of the Lower Hutt Groundwater Zone. Activities which are currently, or have in the past been, carried out at these sites include land filling, timber treatment, chemical use and/or storage, engineering, and underground storage tanks. Applying a simple comparative risk assessment, eight of the sites are ranked high priority for remedial action, 17 medium priority and 3 low priority.

While the potentially contaminated site register identifies sites which may pose an environmental risk due to past or present land use, the development of a groundwater quality protection plan requires a comprehensive contaminant source inventory to be complied which includes all potential sources of groundwater contamination. Examples include municipal sewer lines, stormwater discharges and non-point sources such as transportation corridors and pesticide use.

# 6. Groundwater Quality Monitoring

A comprehensive groundwater quality monitoring programme is an integral part of achieving the objectives of a groundwater quality management strategy. Since the aim of groundwater quality management is to safeguard the quality of a groundwater resource, success in achieving management objectives can only be attained by understanding the current state of water quality and the way in which water quality is changing. A successful groundwater quality monitoring programme will aid the understanding of groundwater geochemistry as well as detect any contamination of the resource.

Meyer (1990) suggested five types of groundwater quality monitoring which are applicable to groundwater quality management:

- Monitoring at supply wells;
- Monitoring at the boundaries of the groundwater protection zone;
- Monitoring of point source contamination;
- Monitoring of non-point source contamination; and
- Non source specific monitoring.

*Monitoring of supply wells*: This is a direct measure of water quality at the most critical point in the aquifer. This type of monitoring, while useful, does not fully support the goals of groundwater quality management to provide proactive protection from, rather than reactive detection of, contamination events. As a result groundwater contamination may only be detected after a large portion of the source area is affected requiring costly treatment or the development of alternative sources.

*Background monitoring at protection zone boundaries*: This type of monitoring provides a measure of background water quality and provides a benchmark against which changes in groundwater quality within the protection zone can be measured.

*Point source monitoring*: This type of groundwater quality monitoring is used to measure the impacts of known or potential point sources of groundwater contamination.

*Non-point source monitoring*: In many cases non-point source contamination presents a major threat to groundwater quality. Non-point source monitoring may be used to asses the effect of groundwater contamination resulting from non-point sources such as fertiliser or pesticide application.

*Non-source specific monitoring*: Non-source specific monitoring may be used to provide information on the general water quality over the entire groundwater quality protection area or provide data on the attenuation rate of a contaminant as it moves through the aquifer system.

## 6.1 Current Groundwater Quality Monitoring Network

At present there are three groundwater quality monitoring programmes in place in the Lower Hutt Groundwater Zone:

(1) Baseline groundwater quality monitoring programme
(2) Saline intrusion monitoring
(3) Monitoring of municipal supply bores

*Baseline groundwater quality monitoring programme*: This monitoring is undertaken by the Resource Investigations Department of the Wellington Regional Council as part of the overall state of the environment (SOE) monitoring programme. The objective of this monitoring programme is to provide information on ambient conditions and trends in groundwater quality. At present the monitoring network consists of six monitoring sites which are monitored on a quarterly basis. One monitoring site is located at Avalon Studios in the unconfined area, four monitoring bores are screened in the Waiwhetu Artesian Aquifer while the remaining bore is screened Moera Gravel Aquifer.

*Saline Intrusion Monitoring*: A saline intrusion monitoring programme was commenced by the Resource Investigations Department of the Wellington Regional Council in November 1996. This monitoring is currently undertaken as a targeted groundwater quality investigation. At present samples are collected from four bores along the Petone foreshore as well as from the Somes Island bore and analysed for specific indicators of saline intrusion. Four sampling rounds are undertaken per year, the frequency of which is dependant on the seasonal pattern of abstraction from the Waiwhetu Artesian aquifer.

*Monitoring of municipal supply bores*: Monitoring of municipal supply bores at Gear Island and the Waterloo Wellfield undertaken by Metro Water to assess compliance with requirements of the Drinking Water Standards for New Zealand (Ministry of Health, 1995).

While current groundwater quality monitoring provides data to meet specific project objectives, only the saline intrusion monitoring programme provides proactive monitoring of water quality in the Waiwhetu Artesian Aquifer. At present there is no monitoring of water quality in the critical zone around the unconfined/confined aquifer boundary. Monitoring in this zone would provide early warning of changes in water quality or contamination events while allowing sufficient time for contingency measures to be put into place before water quality at the Waterloo Wellfield was affected.

## 6.2 Present Groundwater Quality

Detailed discussion of the pattern of groundwater quality and the geochemical processes occurring in the Lower Hutt Groundwater Zone is given in WRC (1995), while the results of the first three years of the baseline groundwater quality monitoring programme are outlined in WRC (1996).

In general, groundwater quality in the Lower Hutt Groundwater Zone is very high. Groundwater is soft and contains low concentrations of dissolved ions well within drinking water standards (Ministry of Health, 1995). Gradual changes in aquifer geochemistry are observed with increasing distance from the recharge area. Dissolved ion concentrations increase and the water becomes increasingly reduced along the groundwater flow path. The mechanisms responsible for the observed changes in chemistry include the gradual weathering of aquifer materials releasing soluble ions into solution and redox processes involved in the oxidation, mineralisation and subsequent reduction of organic nitrogen contained in aquifer recharge. Figure 5 shows a trilinear diagram of representative groundwater quality analyses from the Lower Hutt Groundwater Zone. This diagram illustrates the gradual change in chemical composition from the recharge area (location C) through to Somes Island (location 2).

Total dissolved solids concentrations are less than 160 mg/L throughout the aquifer system reflecting the relatively short groundwater residence time. The major changes in chemistry observed within the aquifer system include the reduction in groundwater pH in the northern portion of the Waiwhetu Artesian Aquifer as a result of the oxidation of organic nitrogen contained in aquifer recharge, and the increase in iron and manganese concentrations in the harbour area which follow the completion of nitrate reduction. The acidic nature of groundwater in the vicinity of the Waterloo Wellfield requires pH correction before utilisation for municipal supply.

Results of baseline groundwater quality monitoring indicate that major ion chemistry is relatively stable in the Lower Hutt Groundwater Zone. Figure 6 shows a time series plot of analyses from Avalon Studios which is located in the recharge zone. A slight seasonal fluctuation in parameter concentration is observed at this site possibly reflecting seasonal changes in the pattern of aquifer recharge.

The effect of abstraction on groundwater quality in the Waiwhetu Artesian Aquifer is not well understood. For example, Figure 7 shows a time series plot of nitrate-nitrogen concentrations at the Penrose Street and Bloomfield Terrace wells in the Waterloo wellfield. The observed trend of decreasing nitrate levels may be due to the increasing rate of groundwater abstraction from Waterloo which has decreased the groundwater residence time consequently reducing the time available for oxidation of nitrogen contained in recharge from the Hutt River. However, similar trends have not been observed in other bores in the Waterloo Wellfield with the remaining bores either showing no clearly discernible trends in nitrate-nitrogen concentration or a slight rise over a similar time period. The reasons for the disparate trends in water quality in production bores located less than 500 metres apart is unknown.

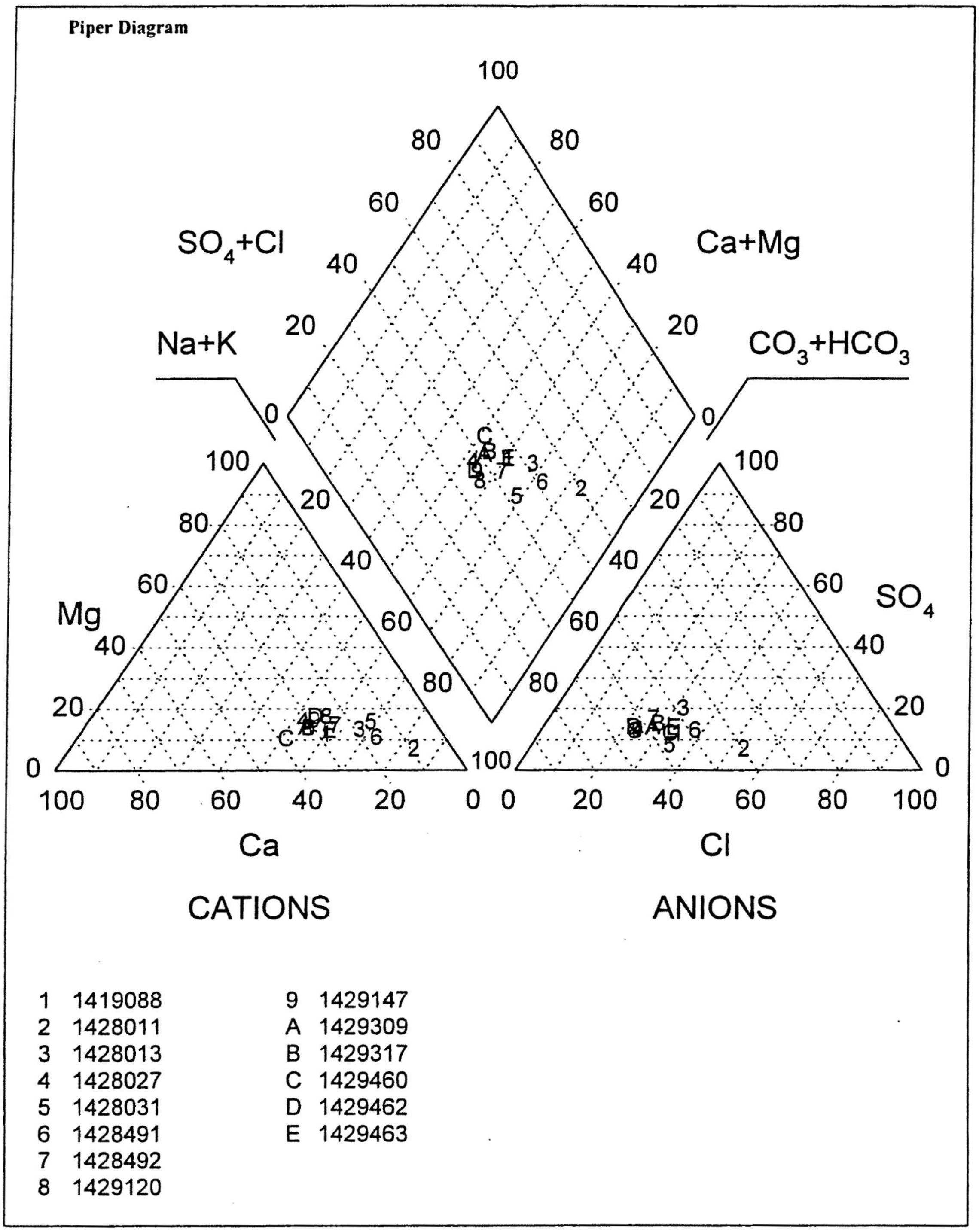


**Figure 5: Piper trilinear plot of analyses from the Lower Hutt Groundwater Zone**

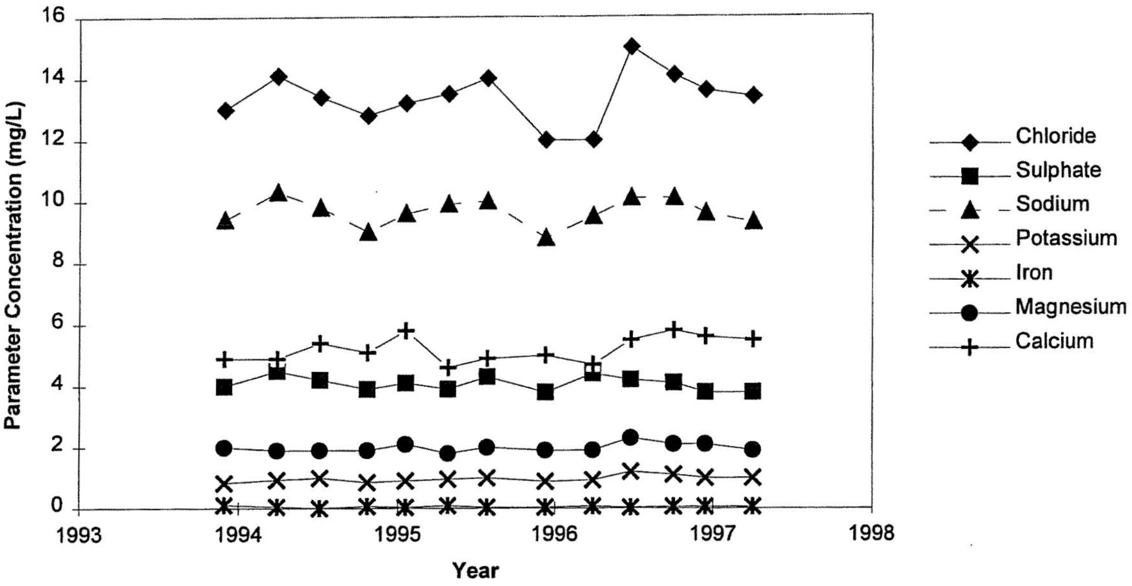


**Figure 6: Time series plot of groundwater quality analyses from Avalon Studios (1419088)**

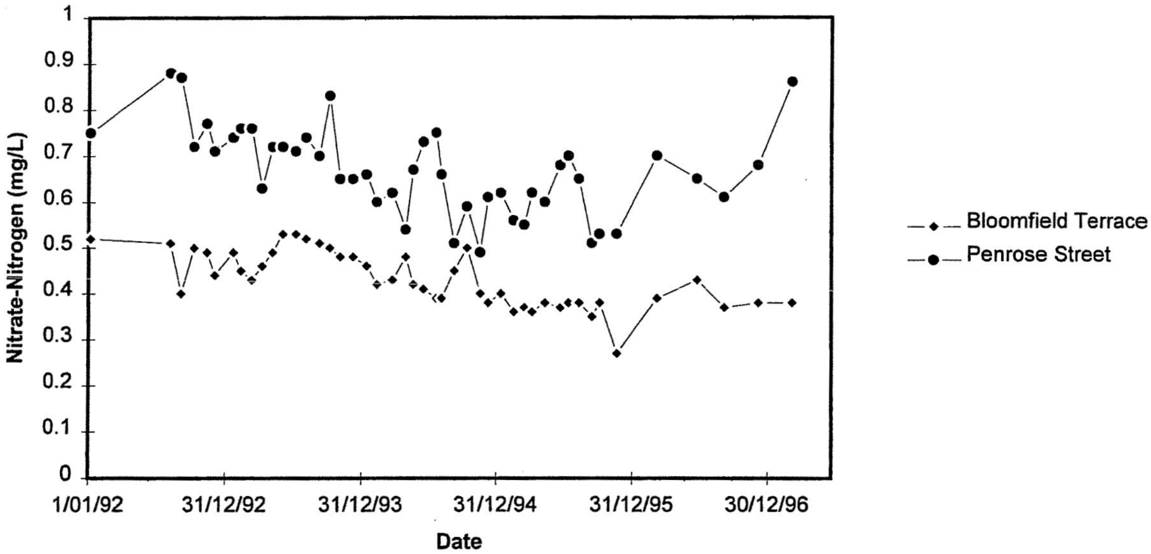


**Figure 7: Time series plot of nitrate-nitrogen concentrations recorded at Penrose Street and Bloomfield Terrace**

## 6.3 Future Groundwater Quality Monitoring

The development of a groundwater quality management plan for the Lower Hutt Groundwater Zone requires the implementation of a groundwater quality monitoring programme which provides proactive monitoring of water quality. A monitoring network should be established along the confined/unconfined aquifer margin to provide early warning of changes in groundwater quality which may impact on downgradient abstractions for municipal supply. Proposed increases in the rate of groundwater abstraction from Waterloo may further increase the need for proactive groundwater quality monitoring by decreasing the residence time of groundwater flowing through the aquifer system. As a result, less time will be available for the natural attenuation of contaminants entering the aquifer system in the unconfined area.

Possible monitoring sites include bores located on Fairway Drive and Thornycroft Avenue installed during monitoring of the Avalon spill, and a bore located at Naenae College installed as part of investigations undertaken by Liddell (1995). The development of a comprehensive monitoring network may also involve the installation of additional bores to complete coverage across the Hutt Valley near the unconfined/confined aquifer boundary. The sampling programme would initially involve analyses of samples for major ions and microbial contamination on a regular basis (1-2 monthly) with less frequent sampling (3-6) monthly undertaken for a wide range of organic and inorganic water quality determinands.

# 7. Summary

The Lower Hutt Groundwater Zone, or more specifically the Waiwhetu Artesian Aquifer, is an extremely valuable water resource to the Wellington Region. Current abstraction from this resource provides up to 35 percent of the municipal supply requirements of the greater Wellington area. While protected from direct contamination, this aquifer system is vulnerable to contamination originating in the recharge zone or to the effects of saline intrusion resulting from a loss of head due to abstraction or damage to confining layers. In contrast to the major surface water catchments in the Wellington Region, only limited attention has been paid to the control of activities and land uses which may impact on the quality of this resource.

This report proposes the development of groundwater protection zones in the Lower Hutt Valley as part of an overall groundwater resource management strategy. The objective of this proposal is to reduce the risk of adverse effects on the quality of the resource. Policies contained in the Proposed Regional Freshwater Plan effectively control activities which may result in saline intrusion into the Waiwhetu Artesian Aquifer, however no controls are currently in place to reduce the potential for contamination of this resource from land use and activities in the recharge area.

Past experience has shown that groundwater in the unconfined area is vulnerable to contamination and, that based on present knowledge, potential downgradient effects cannot be predicted accurately enough to assume the separation between the confined aquifer margin and the Waterloo Wellfield provides sufficient time for the attenuation of all potential contaminants.

Three preliminary groundwater protection zones are proposed in this report based on the zone of influence (ZOI), and zone of contribution (ZOC) to the Waiwhetu Artesian Aquifer, or more specifically the Waterloo Wellfield. The report proposes the following zones:

| | |
|---|---|
| Zone 1: | Confined Aquifer; Abstraction and construction activities controlled to prevent saline intrusion or damage to the structural integrity of confining layers. |
| Zone 2: | Confined Aquifer Margin; Land use managed to prevent chemical or microbial contamination of groundwater |
| Zone 3: | Unconfined Aquifer/Recharge Zone; Land use managed to prevent chemical contamination of groundwater |

Further work is required to improve delineation of the groundwater quality protection zones proposed in this report including providing better definition of aquifer hydrogeology and heterogeneity as well as improved understanding of contaminant transport mechanisms.

The current high quality of the groundwater resources in the Lower Hutt Groundwater Zone should not be taken for granted especially as the demands on the resource are likely to increase in the near future. Application of a proactive groundwater quality

protection strategy may preclude the occurrence of groundwater contamination which has to potential to have a significant adverse monetary and social impact on the Region.

# 8. Recommendations

The development of a groundwater quality protection strategy for the Lower Hutt Groundwater Zone requires commitment from both the Wellington Regional Council and The Hutt City Council to the sustainable management of this resource. Development of a groundwater quality protection programme also requires:

- Improved delineation of aquifer hydrogeology and contaminant transport mechanisms.
- Compilation of a comprehensive contaminant source inventory for the unconfined area.
- Implementation of a proactive groundwater quality monitoring programme designed to provide advance warning of contamination events or changes in groundwater quality.
- Development of planning tools such as land use zoning and design and operating standards to limit the threat to groundwater quality posed by existing activities and ensure future development is compatible with groundwater quality protection goals.
- Contingency planning to prevent significant adverse impacts on groundwater quality resulting from accidents or natural disasters.
- Public education to increase awareness of groundwater quality issues and allow public participation in the development and implementation of groundwater quality protection initiatives.

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# Appendix 1:

# Hydrogeology of the Lower Hutt Groundwater Zone

# Hydrogeology of the Lower Hutt Groundwater Zone

## 1. Geology

The Lower Hutt Basin is one of a series of basins formed by longitudinal warping about an axis normal to the Wellington Fault. The deformation occurred during the mid to late Pleistocene (Donaldson and Campbell, 1977). Four basins have been recognised; the Lower Hutt/Port Nicholson Basin, the Upper Hutt Basin, the Te Marua Basin and the Pakuratahi Dasin (Stevens, 1990). Deposited within these basins are thick sequences of alluvial and, in the case of the Lower Hutt Basin, marine sediments.

During the Quaternary period, the relative ground and sea levels fluctuated considerably in response to tectonic activity and climatic oscillations. During periods of marine regression (Glacial Periods), the Hutt River Delta extended toward the present harbour entrance and extensive deposits of alluvial gravel were formed. During periods of marine transgression (Interglacial Periods) the sea inundated the Lower Hutt Basin and fine sediment (silts and clays) were deposited over the gravel sheets, forming impermeable layers of sediment. Extensive, permeable gravel sheets now form the aquifers of the Lower Hutt Groundwater Zone, while the fine sediments composed of low permeability clays and silts, form aquitards and aquicludes.

The Lower Hutt/Port Nicholson Basin extends from Taita Gorge south towards the entrance of Wellington Harbour. At its deepest point the basin contains over 300 metres of sediment deposited over greywacke basement.

Stevens (1956) divided the sub-surface geology of the Lower Hutt basin into seven distinct units. Based on these units, along with bore log and geophysical survey data, Donaldson and Campbell (1977) determined the following hydrogeologic units within the Lower Hutt Groundwater Zone (in ascending order):

- Greywacke basement
- Moera Gravels (Aquifer)
- Wilford Shell Beds (Aquitard)
- Waiwhetu Artesian Aquifer (Aquifer)
- Petone Marine Beds/Melling Peat (Main Aquitard)
- Taita Alluvium (Aquifer)

In the north of the Hutt Valley a single stratified alluvial gravel aquifer overlies the greywacke basement. South of an approximate line extending across the valley in the region of Hutt Golf Course, two layers of low permeability marine sediments divide the sequence of alluvial sediments into two confined aquifers overlain by a thin unconfined aquifer.

## 2. Hydrogeologic Units

### Moera Gravel Aquifer

A sequence of alluvial silts, sands, gravels and clays overlies the greywacke basement in the lower valley. This unit known as the Moera Basal Gravels (Stevens 1956) is up to 200 metres thick near the Petone foreshore. A limited number of bore holes penetrate this unit and as a result the exact stratigraphy and hydraulic characteristics of this aquifer remain poorly defined. From the available information four distinct lithological units have been identified within the Moera Gravel aquifer:

- An upper succession of weathered gravels
- A section of marine sands and silts
- A thin layer of silt and peat beds
- A thick succession of highly weathered tightly packed gravel, sand and silts overlying basement.

Hutton (1965) distinguished two hydrogeological units within the Moera Gravel Aquifer. These were a lower unit of highly variable salinity, and an upper "fresh water" unit between 16 and 60 metres thick. The origin of the saline water contained in the lower portion of this unit has been attributed to either connate water incorporated into the sediments at the time of deposition or the seepage of geothermal water from along the Wellington Fault.

Both units exhibited comparable artesian pressures indicating complete hydraulic connection. Piezometric levels in the Moera Gravel Aquifer are generally between 1 and 2 metres above those in the overlying Waiwhetu Artesian Aquifer. Analysis of water level data indicates that the Moera Gravel aquifer is moderately well confined and some response to abstraction from the Waiwhetu Artesian Aquifer is observed indicating a degree of leakage across the Wilford Shell bed confining layer.

### Wilford Shell Bed

The Wilford Shell bed forms an aquitard which confines the underlying Moera Gravel Aquifer. The limited geological data available indicates this unit is between 17 and 22 metres thick and occurs at depths ranging from 70 to 83 metres at the Petone Foreshore. The depth and thickness of this unit decrease with distance inland. This unit is comprised of a thick layer of silt underlain by alternating beds of gravel and silt which contain shell fragments. Stevens (1990) suggested that this unit was deposited during the late Flandarian sea level rise when the position of the coastline was close to Taita Gorge.

### Waiwhetu Artesian Aquifer

The Waiwhetu Artesian Aquifer forms the major water producing unit in the Lower Hutt Groundwater Zone. The materials comprising this unit are highly variable, ranging in size from coarse gravel to clay. The internal stratigraphy of this unit is typical of many coarse grained aquifer systems deposited in a high energy alluvial settings throughout New Zealand. The highly permeable gravels which form the main waterbearing units are separated by discontinuous lenses of peat, silt and sand.

Despite the variable geology, aquifer permeability is remarkably consistent throughout the valley. Transmissivity values reduce from approximately 40,000 $m^2$/day in the Waterloo wellfield to an average of approximately 25,000 $m^2$/day in the Petone Foreshore and Somes Island area.

The thickness of the Waiwhetu Artesian Aquifer varies between 45 and 60 metres and in, general, water bearing capacity decreases with depth. Water levels in this aquifer increase from the inland margin of the confining layer to the coastline. In the region of the Waterloo wellfield water levels are close to, or slightly above ground level, while at the Petone Foreshore the Waiwhetu Artesian Aquifer exhibits a positive head of between 3.5 and 4.5 metres above mean sea level under normal operating conditions. Barometric and tidal response data indicate that the Waiwhetu Artesian Aquifer is well confined.

**Petone Marine Beds/Melling Peat**

The Petone Marine Beds and the Melling Peat form the confining layer for the Waiwhetu Artesian Aquifer. This layer is commonly referred to as the "main aquitard". The Petone Marine Beds are a lateral equivalent of the sediments deposited on the present day harbour floor and can be identified from bore logs up to 2.5 kilometres inland of the present day coastline. These marine silts and clays range from 1 to 31 metres thick, with the upper surface of the unit no more than 10 metres below the ground surface. The Petone Marine Beds decrease in thickness inland and interdigitate with the silty-sand, silt packed gravels, clay and peat of the Melling Peats.

The Melling peat is the marginal marine equivalent of the Petone Marine Beds, deposited in the extensive low energy coastal swamp environment which existed until recent development. The Melling Peats extend the main confining layer a further 1500 metres inland to an irregular margin which extends across the Hutt Valley in the vicinity of the Hutt Golf Course. The extent of the Melling Peat was used by Hutton (1965) to define the limits of the unconfined and confined aquifer systems in the Lower Hutt Groundwater Zone.

Carbon dating of wood fragments from the Melling Peat indicates an age of approximately 4,400 years for these sediments. Stevens (1990) suggests that from carbon dates, sea level rise and climatic indicators, the Melling Peat and the lower members of the Petone Marine Beds were deposited during the Post-Glacial Climatic Optimum.

**Taita Alluvium**

The Taita Alluvium represents a thin veneer of alluvial gravels deposited in recent times on the active floodplain of the Hutt River. South of the unconfined/confined aquifer boundary a thin layer of Taita Alluvium overlies the main aquitard forming a thin unconfined aquifer which extends to the present coastline.

Figure 1 shows a diagrammatic cross section of the Lower Hutt Groundwater Zone.

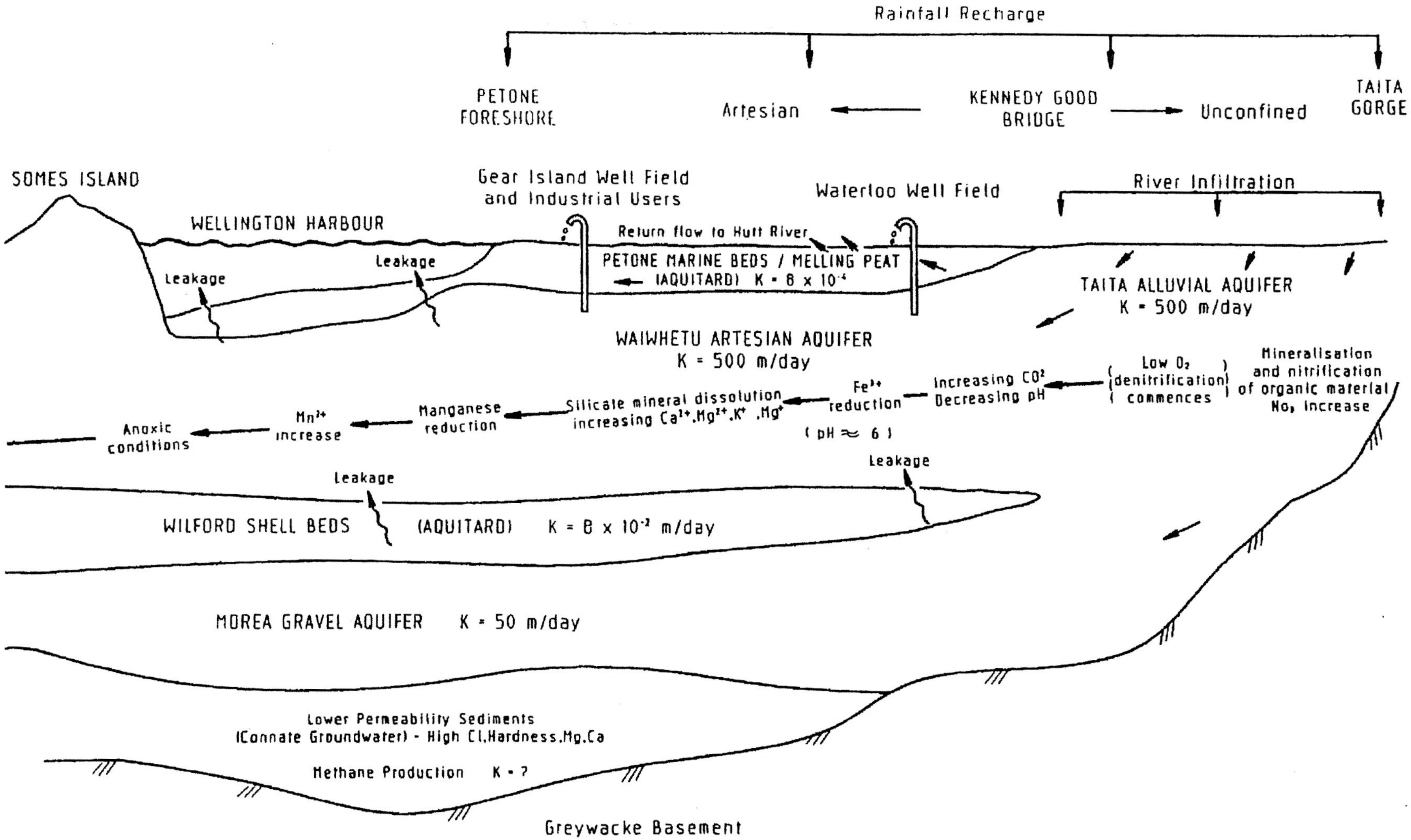


**Figure 1: Diagrammatic cross section of the Lower Hutt Groundwater Zone WRC (1995)**

## 3. Recharge

North of the unconfined /confined aquifer margin the Taita Alluvium overlies a thick undifferentiated sequence of Quaternary gravels which represent lateral equivalents of the Moera and Waiwhetu gravels. These alluvial materials form a single unconfined aquifer which is the recharge zone for the confined aquifers to the south. The unconfined aquifer receives the majority of recharge from the Hutt River in the reach between Taita Gorge and Avalon. Concurrent gaugings undertaken in the Hutt River indicate that under mean annual low flow conditions, recharge to the unconfined aquifer is approximately 80 ML/day (WRC 1995). The rate of river recharge increases significantly in response to high stage events in the Hutt River. Figure 2 shows the relation between groundwater levels recorded at Taita Intermediate and flow in the Hutt River at Taita Gorge. Periods of highest groundwater levels clearly follow periods of high flow in the Hutt River. Additional recharge is derived from rainfall infiltration into the unconfined aquifer. WRC (1995) calculated that the contribution of rainfall recharge was less than 5 percent of overall recharge to the aquifer system.

Groundwater levels are generally less than 5 metres below ground level throughout the unconfined area and the aquifer is overlain by permeable alluvial soils.

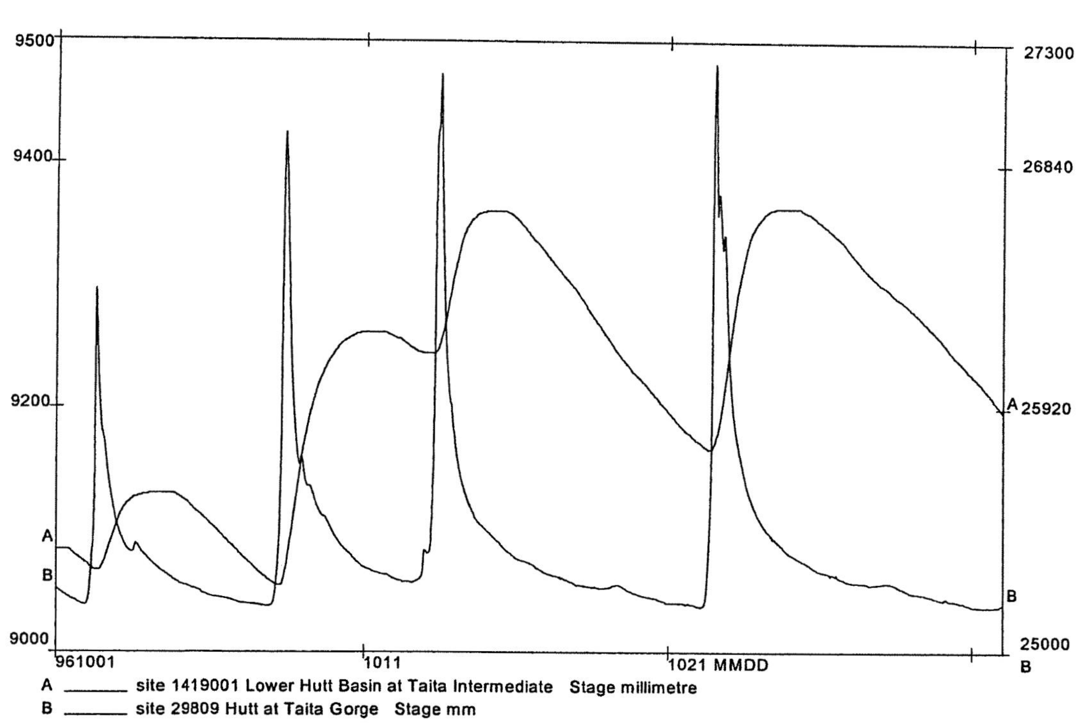


**Figure 2: Response of unconfined aquifer levels at Taita Intermediate (1419001) to flow in the Hutt River**

## 4. Groundwater Throughflow

Groundwater flows south through the aquifer system following the natural topographic gradient towards the harbour. Groundwater flows from the recharge area either into the confined aquifer system or remains in the thin Taita Alluvium gravels which overlie the main aquitard. Stevens (1990) estimated that approximately 80 percent of recharge to the unconfined area flows into the confined aquifer system. The stage height of the Hutt River, groundwater levels in the unconfined aquifer and the volume of abstraction from the Waiwhetu Artesian Aquifer in the lower valley all influence the volume of water flowing into the confined aquifer system. The majority of groundwater which remains in the Taita Alluvium gravels return to the Hutt River in the lower reaches.

Groundwater is also discharged from the unconfined aquifer via springs which feed the Waiwhetu Stream. This stream has a one day two year return period low flow of approximately 25 L/sec (2,160 $m^3$/day), the majority of which is derived from spring flow.

Groundwater flowing through the Waiwhetu Artesian Aquifer under natural conditions is discharged beneath Wellington Harbour via numerous submarine springs which are distributed across the harbour floor. Major areas of leakage are concentrated in areas where the capping sediments are thin, such as off the Hutt River mouth, or around structural highs such as Somes Island where the confining layers have been disrupted by localised sedimentation or fault movement. The volume of discharge from these submarine springs is uncertain but under non-pumping conditions it is likely to be significant. It is uncertain if there is any direct connection between the Moera Gravel Aquifer and the harbour.

# Appendix 2:

# Groundwater Quality Protection Zones

# Groundwater Quality Protection Zones

## 1. Groundwater Vulnerability

The National Research Council (1993) distinguish two types of groundwater vulnerability, intrinsic and specific. Intrinsic vulnerability reflects properties that are a function of the natural setting such aquifer materials and depth to groundwater. On the other hand, specific vulnerability considers the attributes or properties of a specific contaminant and includes factors such as circumstances of land and chemical use and the behaviour of the contaminant in the subsurface environment.

All determinations of groundwater vulnerability involve uncertainty due to the natural variability which occurs within heterogeneous aquifer systems, and the resolution of available data to an appropriate scale. Mapping of aquifer vulnerability and the resource management tools based on the maps, need to recognise this uncertainty (Smith, 1996). Some of the principal features which influence aquifer vulnerability are outlined in Table 1.

The National Research Council (1993) outlined three basic laws for groundwater vulnerability assessment:

(1) *All groundwater is vulnerable*

(2) *Uncertainty is inherent in all vulnerability assessments*

(3) *The obvious may be obscure and the subtle indistinguishable*

**Table 1: The principal geologic and hydrologic features which influence an aquifer's vulnerability to contamination (adapted from NRC 1993)**

| Hydrogeologic Property | Low Vulnerability | High Vulnerability |
|---|---|---|
| 1. ***Hydrogeological Framework*** | | |
| Unsaturated Zone | Thick unsaturated Zone, with high levels of clay and organic material | Thin unsaturated zone, composed of high permeability sand gravel etc. |
| Confining Unit | Thick low permeability confining unit, e.g., sand, silt or clay | No confining unit |
| Aquifer Properties | Low permeability materials, e.g., silt, sand, claybound gravel | High Permeability materials, e.g., sand, gravel, cavernous limestone |
| 2. ***Groundwater Flow System*** | | |
| Recharge Rate | Negligible recharge rate | High recharge rate |
| Location in Regional Flow System | Located in deep, sluggish part of regional flow system | Located within recharge area or cone of depression of pumped well |

There are three main methods of groundwater vulnerability mapping:

- Overlays and indexing of vulnerability ratings, e.g., DRASTIC
- Methods employing process-based simulation models, i.e., analytical or numerical solutions to mathematical equations.
- Statistical methods.

The most commonly used method for groundwater vulnerability mapping involves the application of the DRASTIC system. Drastic is a simple ranking method developed by Aller *et al.* (1987) which is used to assess the vulnerability of an aquifer to localised or regional groundwater contamination. The seven hydrogeological factors which are used to calculate a DRASTIC score include:

**D**epth to water table
**R**echarge
**A**quifer Media
**S**oil Media
**T**opography
**I**mpact of the vadose (unsaturated) zone
Hydraulic **C**onductivity

Each of the factors is ranked between 1 and 10 and the rank is multiplied by an assigned weight between 2 and 5. The weighted ranks are then summed to give a score for a particular hydrogeologic setting, with higher score indicating greater vulnerability to groundwater pollution. The DRASTIC system enables a relative comparison which can identify the most vulnerable areas within a particular hydrogeological setting. The outputs from a DRASTIC mapping exercise are dependent on the mapping scale used. For example results of a regional scale DRASTIC evaluation may vary greatly from those on a more localised scale. However, in all mapping exercises the resolution of vulnerability cannot exceed the resolution of uncertainty in the information available.

The mapping of aquifer vulnerability is a useful exercise to identify specific areas in an aquifer system which are most susceptible to contamination. However, determination of aquifer vulnerability does not account for the effects of contamination over a long time period. For example, a single contamination event may only have a limited localised impact but over an extended period the contamination may have a significant effect on downgradient users of the resource. As a result there has been a move to the definition of wellhead protection areas which take account of the effects of contamination over a wide area, on a specified downgradient location, such as a municipal supply well.

## 2. Wellhead Protection Areas

The first groundwater protection policies were enacted in Europe, notably in the Netherlands and Germany, during the 1960s and 70s. In 1979 the European Community (EC) approved a directive which required all member states to protect (by law, regulation and administrative provision) all usable groundwater against direct or indirect discharges or certain listed substances. These policies recognised that groundwater was an extremely valuable water resource and the safeguarding of the quality of the water was a high priority to ensure the resource was able to be utilised for water supply into the future

In June 1986 the United States Congress established the concept of WHPAs in an amendment to the Safe Drinking Water Act (1986). This legislation required all states to submit a Wellhead Protection Program (WHPP) to the USEPA by June 1989, with two further years to implement the WHPP. The overall goals of the WHPP was to:

- provide a remedial action zone to protect wells from unexpected contaminant releases
- provide an attenuation zone to bring concentrations of specific contaminants to desired levels before they reach the wellhead
- provide a wellhead management zone in all or part of a well's present or future recharge area.

This legislation focused much attention, and the not inconsiderable resources of the USEPA, on the development of groundwater quality management programmes. The impetus given to groundwater quality protection by the WHPP is reflected by the development of groundwater quality protection plans for a large number of groundwater resources around the world.

The most common form of groundwater quality protection zoning is the delineation of wellhead protection areas (WHPA). A wellhead protection area is defined as:

> *the surface and subsurface area surrounding a well, wellfield, or spring through which contaminants may pass and reach the ground water contributing to the supply source* (USEPA, 1993).

The delineation of WHPAs assumes three general categories of threats to groundwater quality (USEPA 1987):

- direct introduction of contaminants in the immediate well area
- microbial contaminants
- chemical contaminants (particularly toxic and/or persistent chemicals which are mobile non-adsorbent on subsurface media, recalcitrant and do not dilute or otherwise attenuate to non-harmful concentrations).

The third target directly influences the groundwater quality protection programme. In most hydrogeological settings public supply bores can be protected from microbial contamination be a relatively small buffer zone (of the order of hundreds of metres), however chemical contamination may persist for a long period and may be transported considerable distances in the subsurface environment, thus becoming a major technical and administrative challenge (USEPA 1987).

The concept of a WHPA is shown in Figure 1. This includes:

- a mapped WHPA
- an understanding of the contaminant sources which could be present in the WHPA
- an understanding of aquifer hydrogeology and contaminant transport mechanisms
- a monitoring programme to determine the occurrence of contamination

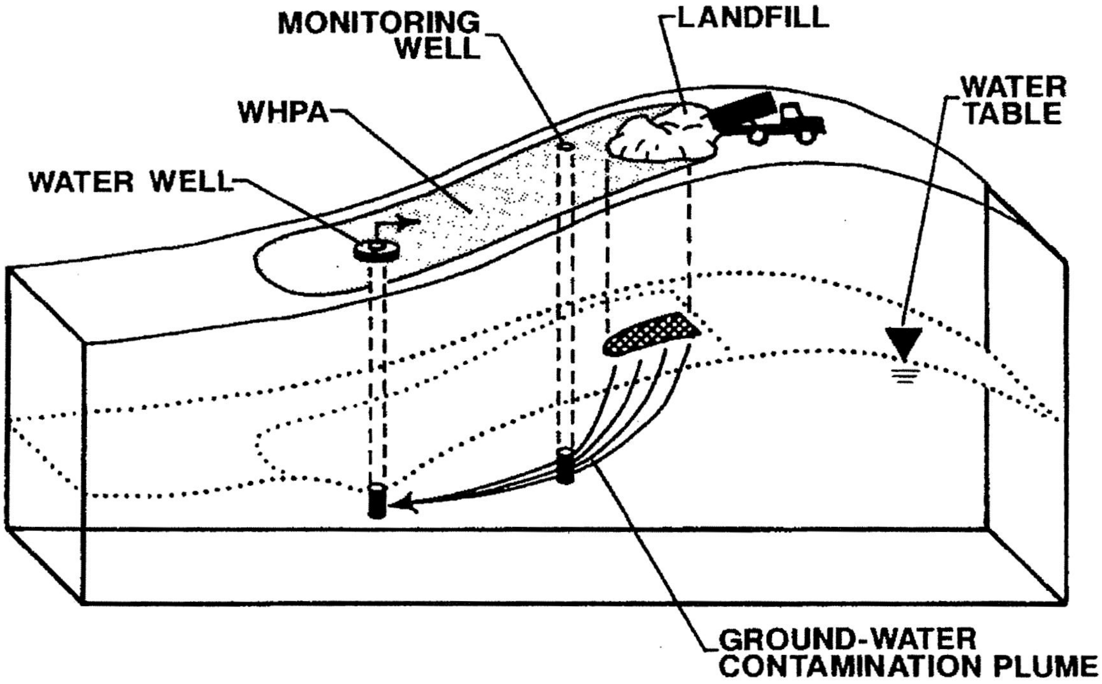


**Figure 1: Conceptual wellhead protection area and monitoring scenario (USEPA, 1993)**

## 3. Wellhead Protection Area Delineation

Many different approaches to the delineation of WHPAs have been adopted in Europe and North America depending on specific technical, political considerations. The simplest concepts applied for the delineation of groundwater quality protection zones are (USEPA 1992):

**Zone of Influence (ZOI)**: *the area surrounding a pumping well within which the water table or potentiometric surfaces have been changed due to groundwater withdrawal*, i.e., the projection of the cone of depression at the land surface

**Zone of Contribution (ZOC)**: = *capture zone: the area surrounding a pumping well that encompasses all areas or features that supply groundwater recharge to the well,* i.e., the entire area recharging the ZOI for some criteria (e.g., time, distance, boundary) upgradient of the downgradient inflection point.

The USEPA (1993) outline a number of criteria which can be applied to the delineation of WHPAs either singly, or in conjunction. These criteria include:

**Distance criterion**: establishes a simple radius from the groundwater source to the well; it is used to establish setback rules for general microbial protection. A first step delineation, it is normally selected on non-technical grounds

**Drawdown**: establishes the extent to which pumping lowers the water table of an a unconfined aquifer or the potentiometric surface of a confined aquifer. It establishes the zone of influence or cone of depression which may accelerate the migration of contaminants towards the well and may vary from a few metres to kilometre scale.

**Time of travel**: establishes the minimum time it takes for a contaminant to reach the well. It incorporates a comprehensive evaluation of the physical processes of contamination and may be used to predict both the contaminant concentration as well as arrival time as a basis for zoning.

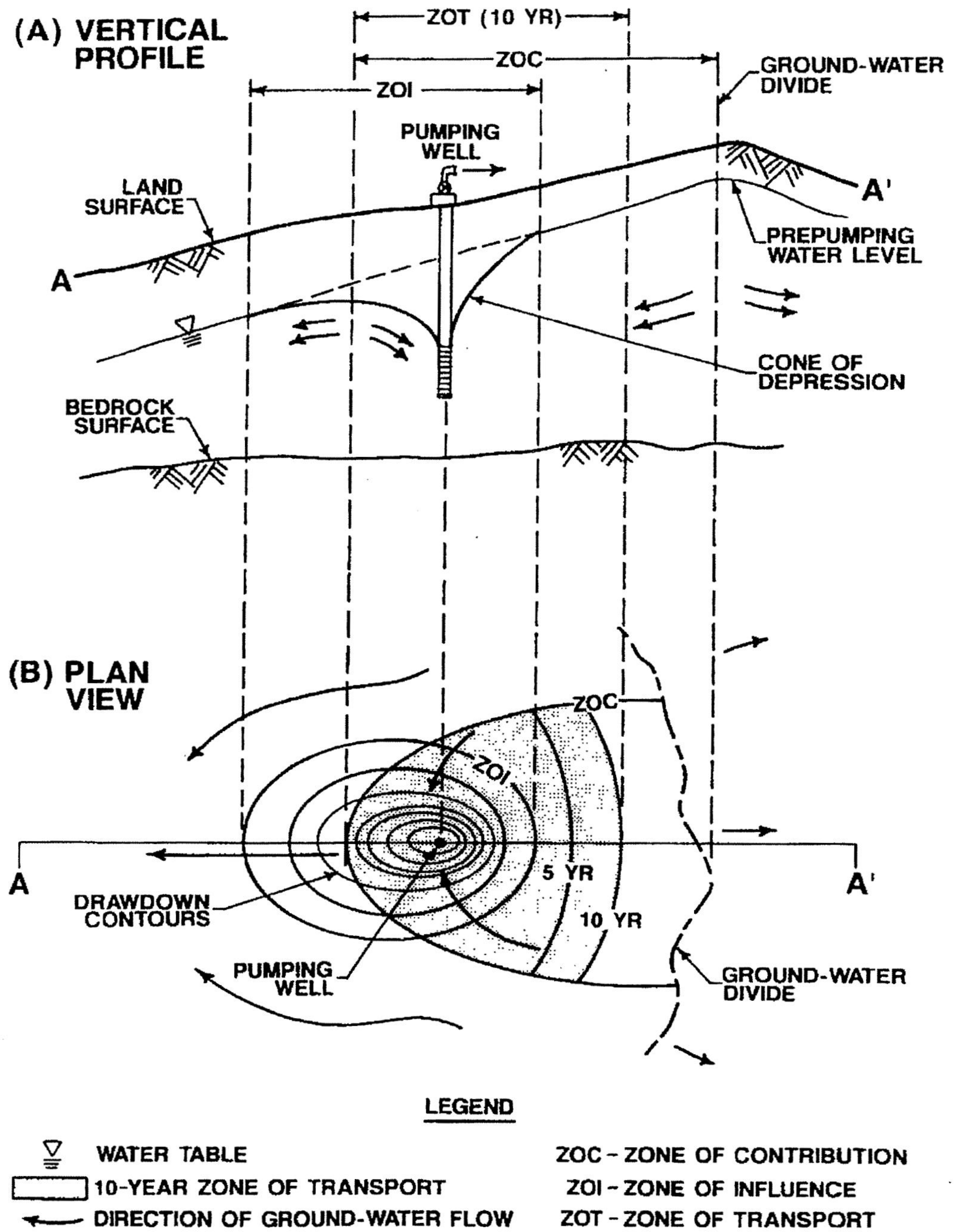


**Figure 2: WHPA concepts and terminology (USEPA, 1993)**

**Flow Boundaries**: these are important especially where the time of travel to boundaries is brief. This criterion uses groundwater divides and/or other physical features which control groundwater flow.

**Assimilative capacity**: applies knowledge of how the saturate and unsaturated zones function to help attenuate the concentration of contaminants. It can be a measure of safety, but is too complex for most applications.

Once the criteria for delineation of the groundwater quality protection zones have been determined, specific methods for mapping the selected criteria need to be chosen. Specific delineation methods include:

**Arbitrary fixed radius**: involves drawing a circle of a specified radius around a well being protected. The radius is either an arbitrary or estimated radial distance based on physical or microbial threats.

A **calculated fixed radius**: draws a circle of a fixed radius for a specified time-of-travel criterion. It uses a simple equation based on the volume of water removed from the aquifer using time of travel multiplied by the pumping rate to outline distances. The time chosen should allow cleanup of groundwater quality or adequate dilution and dispersion of the contaminant.

**Simplified variable shapes**: standardised shapes based on time of travel and flow boundaries from drawdown. The "form" of the protection zone is derived from hydrogeologic and pumping figures modelled on conditions similar to those at the wellhead. Once chosen, this shape is orientated around the well according to groundwater flow patterns. This method works best in areas containing few flow boundaries and geologic heterogeneities.

**Analytical methods**: simplified flow / transport partial differential equations solved by computer simulation of idealised initial boundary conditions. These require input of hydrogeologic parameters including transmissivity, porosity, hydraulic gradient, hydraulic conductivity, and the saturated thickness of the aquifer.

**Hydrogeologic mapping**: maps of time of travel and flow boundaries using geological and geophysical data including tracer techniques and age assessment.

**Numerical flow and transport models**: computer models able to handle complex boundary and hydrogeologic conditions, e.g., heterogeneous aquifer properties.

Establishing WHPA on distance from well criteria is often an initial effort. This method is somewhat arbitrary as it does not take into account groundwater flow or contaminant transport characteristics. A slightly more sophisticated criterion is to base the WHPA on an estimate of the zone of influence (ZOI), therefore at least incorporating an element of groundwater hydraulics.

In an aquifer which has significant regional groundwater flow, there will be areas that contribute to the well but are outside the ZOI (Meyer, 1990). In this case the WHPA must extend beyond the ZOI and encompass much if not all the zone of contribution (ZOC). In an aquifer which is areally extensive it may be impractical to delineate the WHPA as the entire ZOC . In this case the WHPA can be limited to the portion of the ZOC which contributes to the well over a specified time period. Once the criteria for delineation of the WHPA are determined, they can then be applied utilising one of the delineation methods outlined above.

# 4. WHPA Examples

The use of wellhead protection areas is a well established groundwater quality management practice throughout Europe. Table 2 outlines the criteria used by a number of European countries for delineation of groundwater quality protection zones and the restrictions placed on land use within each of the zones defined. From this data it can be seen that there are three broad categories of groundwater quality zones delineated either on the basis of an arbitrary distance or time-of travel criteria:

- Zone 1: The immediate area of the well head. Land use in this area is limited to water supply activities.
- Zone 2: Up to 1000 metres or 60 days. Land use in this area is controlled to limit potential for chemical or microbial contamination.
- Zone 3: Extensive area where a wide range of land use activities are limited or controlled to prevent chemical contamination

Table 3 illustrates the range of activities which were controlled in groundwater quality protection zones in the former Federal Republic of Germany.

Many detailed descriptions of the development of wellhead protection zones are available in the literature (e.g. USEPA 1993, Schleyer *et al.*, 1993). Delineation methods used range application of from the identification of watershed boundaries to detailed investigation programmes which provide data for complex numerical modelling exercises.

**Table 2: Dimensions of groundwater quality protection zones in Europe (after Van Waeganingh, 1985)**

| Prohibitions | Austria | Belgium | Finland | Netherlands | France | German Dem. Rep | German Fed. Rep. | Hungary | Sweden | Switzerland | UK |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Only water supply activities allowed | Protection area | 100m 24 hrs | Intake area | Catchment area <30m | 10 - 20 m | Zone I 5 - 10m | Zone I 10 - 100m | Protection Zone | Well area | Zone I 10 - 20m | 1 -50 days |
| Prohibition of building, agricultural restrictions | 50 days | 300 - 1000m 50 days | Inner Protection Zone 50 days | 50 - 60 days (microbial contaminants) | Inner Protection Area | Protection Zone II 60 days | Zone II 50 days | 50 days | Inner Protection area >60 days >100m | Zone II 10 days >100m | 50-400 day capture zone |
| Restrictions on certain industries, storage and transport of certain chemicals | Partial Protection area | Remote protection area | External sanitary protection zone | Protection area 10 years delay *(approx. 800m from well)* | Remote protection area | Zone IIIA 10 years | Zone IIIA 2 km | Outer protection area *(25 - 100 years delay)* | Outer protection area | Zone IIIA 200 m | 400 days + long-term support |
| | | | | Protection area 25 years delay *(approx. 1200 metres from well)* | | Zone IIIB 25 years | Zone IIIB | | | Zone IIIB | |

**Table 3: Activities, processes and installations not acceptable in wellhead protection areas in the Federal Republic of Germany (Schleyer *et al.*, 1993)**

| Zone I (10 m) | Zone II (50 days) | Zone IIIA | Zone IIIB |
|---|---|---|---|
| • Vehicle and pedestrian traffic | • Construction, plants and workshops | • Commercial use of hazardous chemicals | • Oil refineries and smelting works |
| • Agriculture | • Farms, stables and sheds | • Mass livestock | • Chemical plants and nuclear reactors |
| • Manure and Pesticides | • Building sites and material stockpiles | • Open storage of pesticides | • Wastewater injections |
| | • Roads and railways | • Wastewater treatment | • Deposition and underground storage of water-endangering substances |
| | • Transfer points and parking lots | • Hospitals, sanatoriums and urbanisation | • Pipelines for water-endangering substances |
| | • Sports facilities and camping sites | • Storage of water-endangering substances | |
| | • Car washing and oil change | • Airports and associated facilities | |
| | • Cemeteries | • Military facilities and manoeuvres | |
| | • Removal of surface layers | • Waste sites | |
| | • Mining and explosives | • Sewage treatment plants | |
| | • Intensive grazing | • Injection of cooling waters | |
| | • Allotments | • Essential removal of surface layers | |
| | • Fuel Storage and transport of | • New Cemeteries | |
| | • hazardous substances | • Shunting stations | |
| | • Wastewater pipes | • Road construction with water-endangering substances | |
| | • Fishponds | | |
| | | • Drilling | |
| * includes Zone IIIA, IIIB and Zone II restrictions | * includes Zone IIIA, IIIB restrictions | * includes Zone IIIB restrictions | |

The concept of groundwater quality protection zones around public supply wells was first mooted in New Zealand by Freeman and Ayrey (1988). They proposed a groundwater quality management plan which involved a series of groundwater quality protection zones and WHPAs around public supply and private wells to prevent contamination of groundwater used for drinking water supply. The proposed zones (Table 4) also included restrictions on activities to prevent impacts from these sources. A proximate wellhead protection zone was proposed to prevent contamination in the immediate area of the wellhead, along with two further WHPAs (Zones 1 and 1a) and two groundwater quality protection zones (Zones 2 and 3). While the concept in its entirety was not adopted by the Canterbury Regional Council, parts of it which relate to the siting of septic tanks have been included in the Transitional Regional Plan. Further groundwater quality protection measures are being considered for inclusion in draft Regional Plans currently being prepared.

**Table 4: Proposed groundwater quality protection zones for Canterbury (Freeman and Ayrey, 1988)**

| Zone | Area | Basis |
|---|---|---|
| 1 | • 1000m upgradient of the unconfined/confined aquifer boundary<br>• 1000m upgradient and 200m downgradient from a public supply bore<br>• 150m upgradient and 30m downgradient of an individual domestic bore | Protection against worst effects of bacterial contamination |
| 1a | • 2000m upgradient of from the unconfined/confined aquifer boundary<br>• 2000m upgradient and 200m downgradient from a public supply bore<br>• 300m upgradient and 300m downgradient from an individual domestic bore | Protection against worst effects of non-degradable chemicals |
| 2 | All unconfined groundwater not included in 1 or 1a | Protect quality of water to scattered individual shallow domestic supply bores and allow future location of public and individual drinking water supply wells. |
| 3 | Overlying the majority of the confined coastal aquifers. (Confined = presence of >3m fine surface sediments, principally silts) | Maintain the upwards hydraulic pressure to protect against saltwater intrusion. |

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