PROTECTING CHRISTCHURCH'S WATER QUALITY THROUGH GROUNDWATER MODELLING,TREATMENT AND HOLISTIC DECISION MAKING

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ABSTRACT

Christchurch City is blessed with a groundwater supply of pristine quality, and this is enjoyed by all.

The onset of the Drinking Water Standards for New Zealand 2005, DWSNZ 2005 (Revised 2008), has required Christchurch City Council to assess a small number of water supply wells with regard to complying with the criteria for secure groundwater. This largely relates to some wells being too shallow.

In 2008, CCC asked Pattle Delamore Partners Ltd (PDP) and GHD Ltd to work in parallel on whether the most suitable option for CCC to address this was to drill deeper (to access aquifers with secure groundwater) or to treat the existing water using ultraviolet (UV) irradiation.

This joint paper outlines PDP's involvement in advising CCC with regard to hydrogeological matters relating to compliance with DWSNZ, including development of an advanced hydrogeologic model and the methodologies involved. Peter Callander outlines how a specific methodology was derived for the CCC case.

Chris Taylor presents work relating to water treatment on this subject, building on work Chris delivered in 2005. Chris presents pre designs of UV systems from selected sites. Challenges were overcome as a number of sites have limited room for the UV installations and required pipework configuration.

Bryan Hickling presents CCC's view and how decisions were made against the two options provided, balancing commercial, environmental and cultural sensitivities.

KEYWORDS

Ultraviolet (UV) irradiation, hydrogeoloic, aquifer, secure groundwater

1 INTRODUCTION

1.1 THE PROJECT

Christchurch's water source has long been the envy of New Zealand. The South Island's largest urban centre (circa 340,000 people) having a water supply based wholly upon groundwater, requiring no treatment to provide safe and wholesome drinking water.

With the onset of more stringent water quality standards, in particular the Drinking Water Standards for New Zealand 2005 (Revised 2008)[1] Christchurch City Council (CCC) were faced with investigating a small number of their wells and pump station sites to verify if they complied with the requirements for secure groundwater

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[1] Hereafter DWSNZ

Figure 1 Christchurch City

under DWSNZ. This typically applies to bores that are less than 30 m deep or that have had *E. coli*[2] detected on occasions during monitoring.

The options available were:

- 1. Do nothing
- 2. Abandon the non secure wells, and source from elsewhere in the network
- 3. Drill deeper to access secure groundwater.
- 4. Install ultraviolet (UV) irradiation to enable these wells to comply with the protozoa section of DWSNZ.

Options 3. and 4. were chosen to carry forward, and these are discussed in this paper.

1.2 THE TEAMS

GHD Ltd and Pattle Delamore Partners Ltd (PDP) were chosen by CCC to look closer at Options 3 and 4 respectively. Chris Taylor headed up GHD's team for the UV design option. Chris originally advised CCC on the project in 2005, in addition to reviewing wider supply options for CCC should the groundwater system become contaminated.

Peter Callander led the investigation in to drilling deeper at the non compliant sites. Peter led the delivery of the verified hydrogeological model of the groundwater system, used to verify the compliance status to DWSNZ, and has been advising CCC in groundwater science for many years.

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[2] Escherichia coli- a Gram negative bacterium that is commonly found in the lower intestine of warm-blooded organisms (endotherms).

Bryan Hickling, CCC's Project Manager, managed the project on behalf of CCC. Bryan drafted the CAPEX application paper to CCC Management, with regard allocating budget as part of the 2009-19 Long Term Council Community Plan (LTCCP) for the project.

2 THE GROUNDWATER SYSTEM

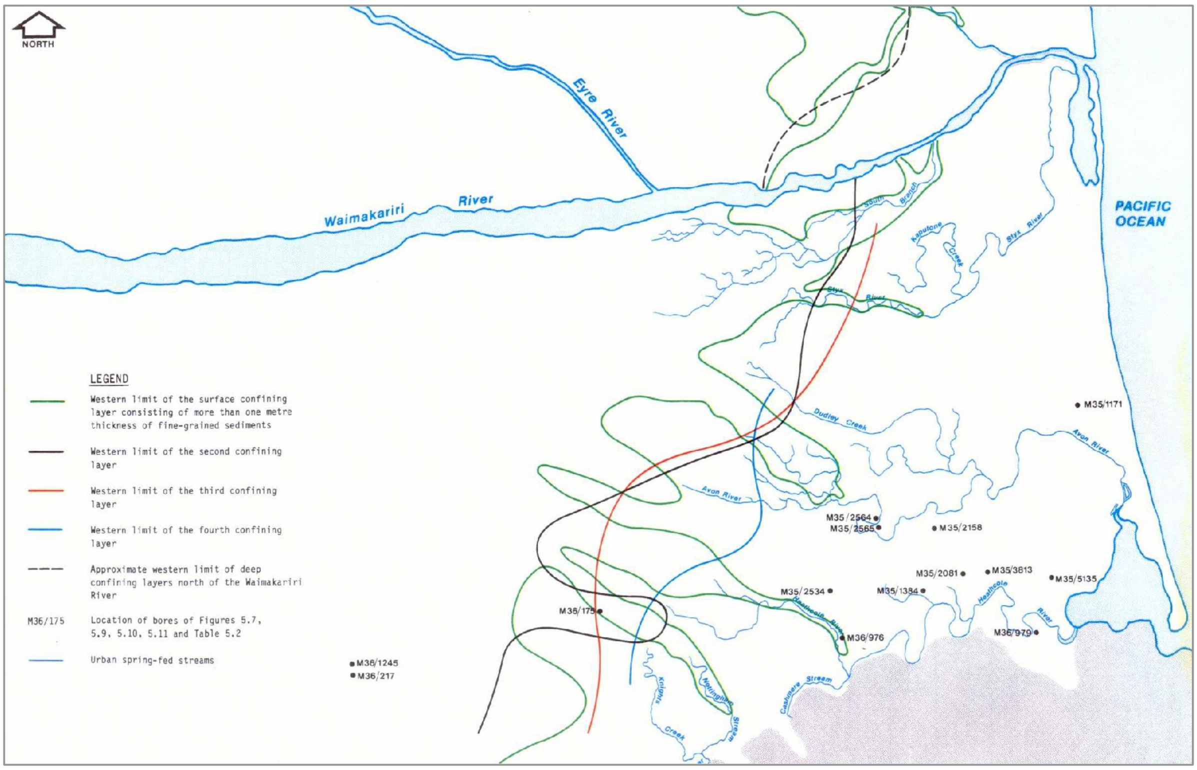
The alluvial gravel plains of Christchurch City and their costal margin between the Banks Peninsula Volcanics and Waimakariri River forms a very productive aquifer system. Alluvial processes have deposited widespread gravel dominated sediments derived from the Southern Alps extending beyond the present day coastline. Over the last 500,000 years the coastline has alternated between a more westerly position (during interglacial periods) and a more easterly position (during glacial periods). The alternating climatic sequence of glacial and interglacial periods has led to an alternating sequence of alluvial gravel aquifers separated by lower permeability sands and silts formed by estuarine and marine deposits that are thickest at the coast and become thinner inland, eventually pinching out around the central and western areas of urban Christchurch. These low permeability sediments "confine" the gravel aquifers and, in combination with an upward hydraulic gradient, protect them from shallow infiltration of surface water.

Figure 2 Christchurch's water is just as good as bottled mineral water

Further west, beyond these low permeability estuarine and marine sediments, the strata is dominated by the more permeable alluvial sediments comprising various mixtures of gravels, sands and silts.

The inland extent of confining layers above aquifers in the City's aquifers is shown in Figure 3. The aquifers are primarily recharged by seepage losses from the Waimakariri River and infiltrating rainfall through the more permeable soils of the western city.

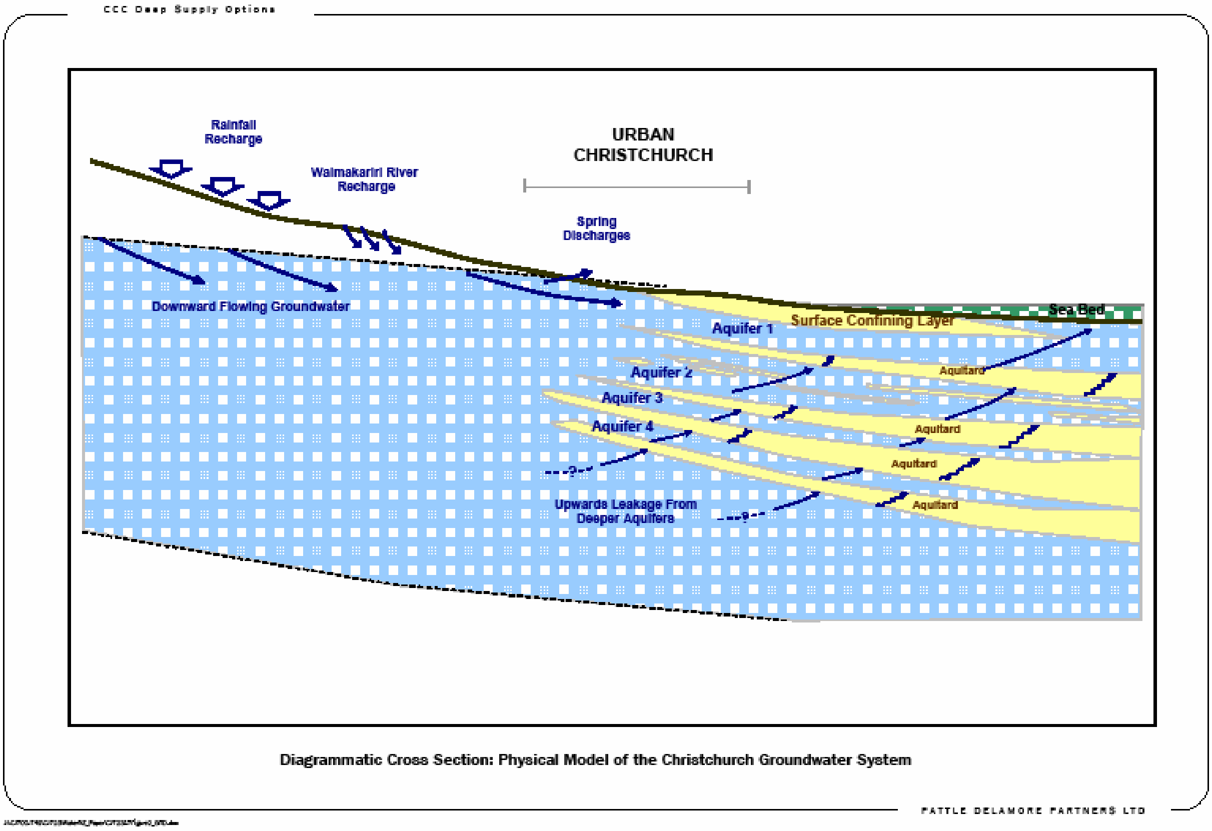
Figure 3 Inland extent of confining layers above aquifers – modified from NCCB 1986



The natural discharge system for the aquifers occurs via seepage into the spring fed streams which emerge near the western edge of the fine grained surface confining sediments. Further west a slow discharge seepage occurs upwards and eastwards into the sea.

As a consequence of these patterns there is a relatively rapid through flow of shallow groundwater in the western areas of the city as Waimakariri River seepage and infiltrating rainwater move through permeable strata to discharge into the spring fed streams. Further east and at greater depth the groundwater flow occurs at a slower rate due to the longer migration pathways, lower hydraulic conductivity of the strata and the absence of a permeable discharge route. A cross-section through the Christchurch aquifers demonstrating the difference between these shallow-rapid and deep-slow flow paths is shown in Figure 4.

Figure 4 Diagrammatic Cross Section: Physical Model of the Christchurch Groundwater System



2.1 TODAY’S WATER SUPPLY CONFIGURATION

The CCC drinking water supply consists of 165 wells ranging in depth from 16 to 222 m. There are fifty four pumping stations, and seven pressure zones with the reticulation comprising of over 1,600 km of pipes. One hundred and fifty five of the wells have been granted secure status from the Ministry of Health (MoH).

Christchurch’s drinking water system supplies approximately 50 ML/day on a typical day. This is largely an on-demand system and includes some storage with the Port Hills area. Pump stations are operated remotely from a central control room facility at Shuttle Drive. Some of the pump stations operate constantly, supplying a base load, while others are operated intermittently. Figure 5 shows the extent of the water supply reticulation, with Figures 6 an 7 illustrating a typical pump station site (Burnside).

Figure 5 Christchurch Water Supply Network

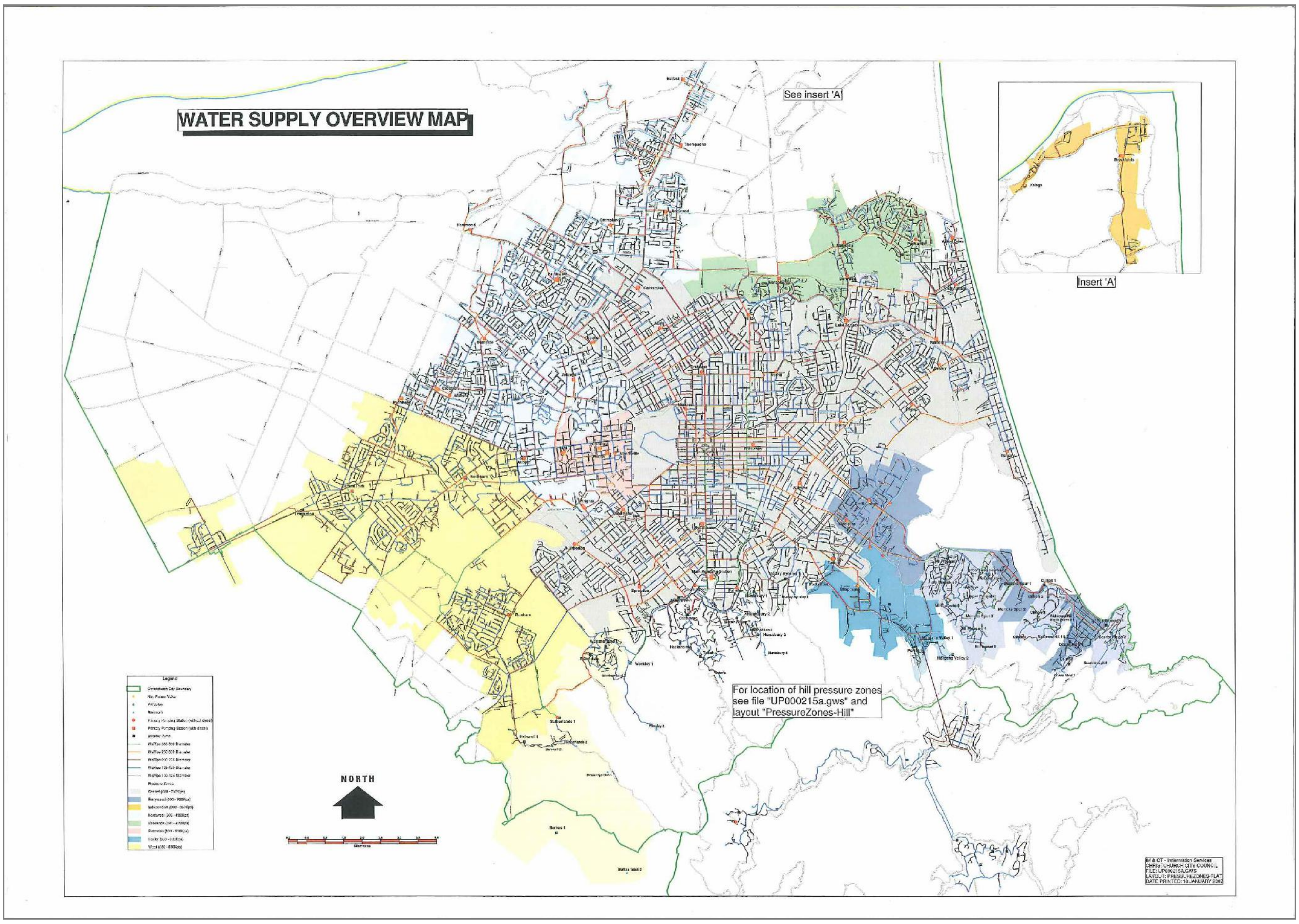
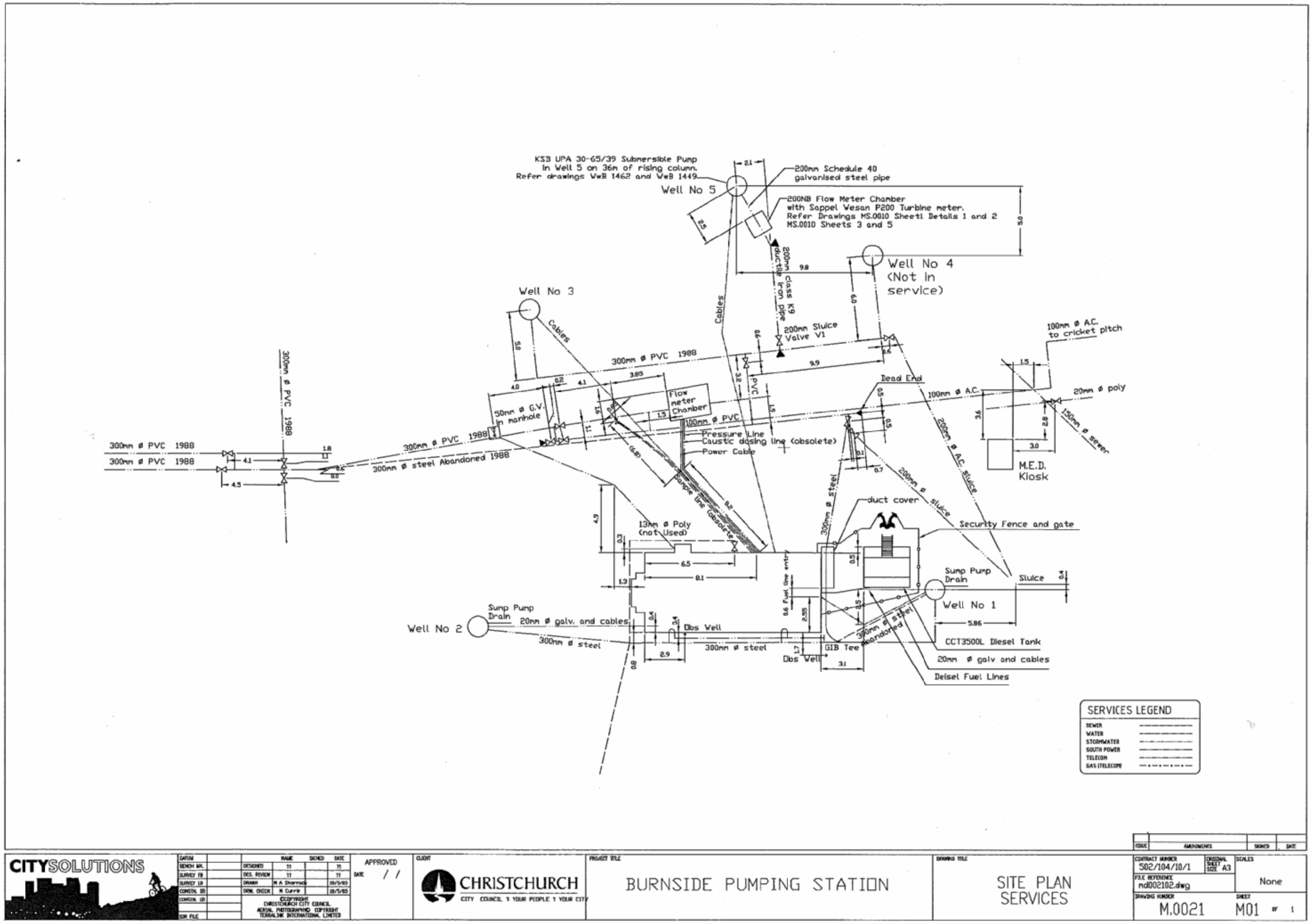


Figure 6 Burnside PS, 3 ML/d output (average)

Figure 7 Burnside PS, CCC Layout Plan



3 INVESTIGATION IN TO COMPLIANCE WITH DWSNZ 2005 (REVISED 2008)

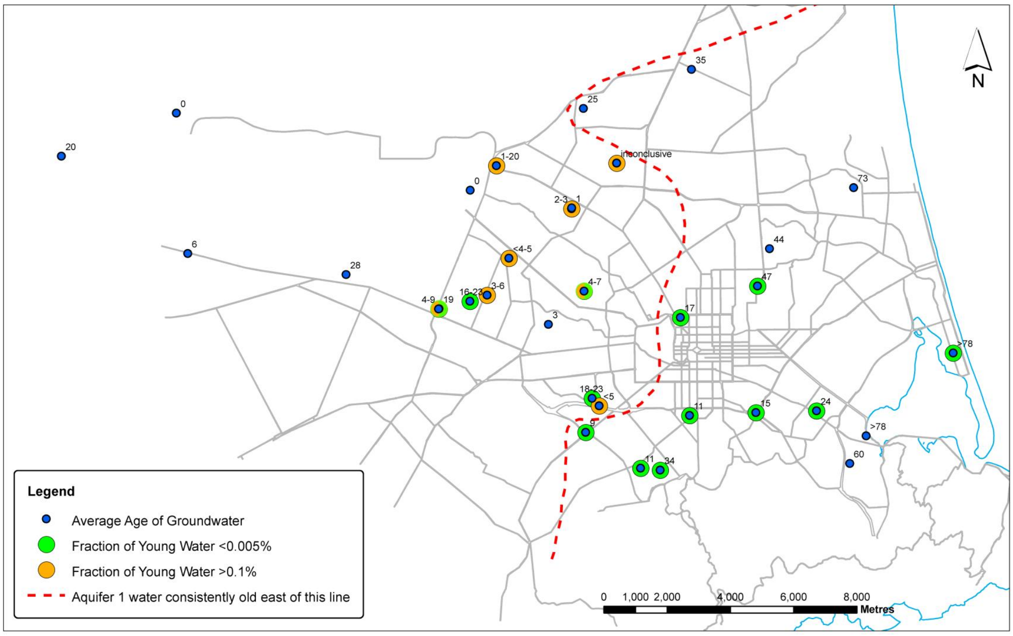
The DWSNZ require that community water supplies require treatment for micro-biological contaminants unless they draw their water from a secure groundwater source. For a groundwater source to be classified as “secure” it must meet the following three criteria:

- 1. less than 0.005% of the water drawn from the bore has been in the aquifer for less than one year
- 2. the bore must have a secure borehead that prevents the infiltration of surface water
- 3. there must be no *E. coli* detected in accordance with the prescribed monitoring schedule

Item 2) is a matter of bore construction operation and maintenance and item 3) is expected to be achieved provided that items 1) and 2) are met. Therefore secure groundwater can be achieved by constructing bores that draw water from strata that has a recharge path that takes longer than one year. If that is not achieved then the water supply must be treated.

Age determinations have been undertaken on bores within the Christchurch area. For bores within the shallowest aquifer, Figure 8 shows a boundary line between bores that meet secure criteria (to the east) and bores that may have younger water (to the west). Bores deeper than 50 m, even in the western city have also shown water that has been in the groundwater system for longer than one year.

Figure 8 Average Age of Groundwater in Aquifer 1



At the present time some of the bores that supply twelve pumping stations in western Christchurch may not meet secure criteria in the DWSNZ. Therefore CCC need to consider whether to seek a new deep “secure” groundwater source, or provide treatment to the existing potentially “non-secure” shallow bores in western Christchurch.

3.1 CONSIDERATION OF DEEP GROUNDWATER SOURCES (THE NON-TREATMENT OPTION

There are several factors that need to be evaluated for the consideration of deep groundwater sources.

3.1.1 ABSTRACTION RATES

Most of the CCC pumping stations are supplied by multiple bores. For those stations containing bores that may not meet the “secure” criteria, in most cases there are other (deeper) bores present that are classified as “secure”. As a result some consideration of peak pumping requirements and an optimisation of how that pumping load is distributed between bores is required.

For each bore, it’s available yield is determined by the hydraulic conductivity of the strata, the screened depth and groundwater pressure (which determine the available drawdown) and the efficiency of the screen and the pumping system. Bore yields are also constrained by the abstraction rates allowed by resource consents.

3.1.2 BORE DEPTHS

As with most groundwater systems, the Christchurch aquifers exhibit significant heterogeneity so the consideration of deep bore options is not simply a matter of defining a minimum target depth (e.g. >50 m).

To the west of the coastal confining layers drillers logs of bores do not provide sufficient description of the strata to differentiate between high yielding and lower yielding strata therefore the best means of determining the most productive strata is from the results of previously drilled boreholes. Figure 9 shows a general pattern of bore yields versus depth. It indicates a large degree of variability, but quite high yields can be achieved in bores in the 100-200 m range (although yields greater than 30 L/s only represent 31% of all bores drilled in this depth range), therefore there is no guarantee that a successful bore will be achieved.

Figure 9 Yield vs Depth Plot for North-West Christchurch

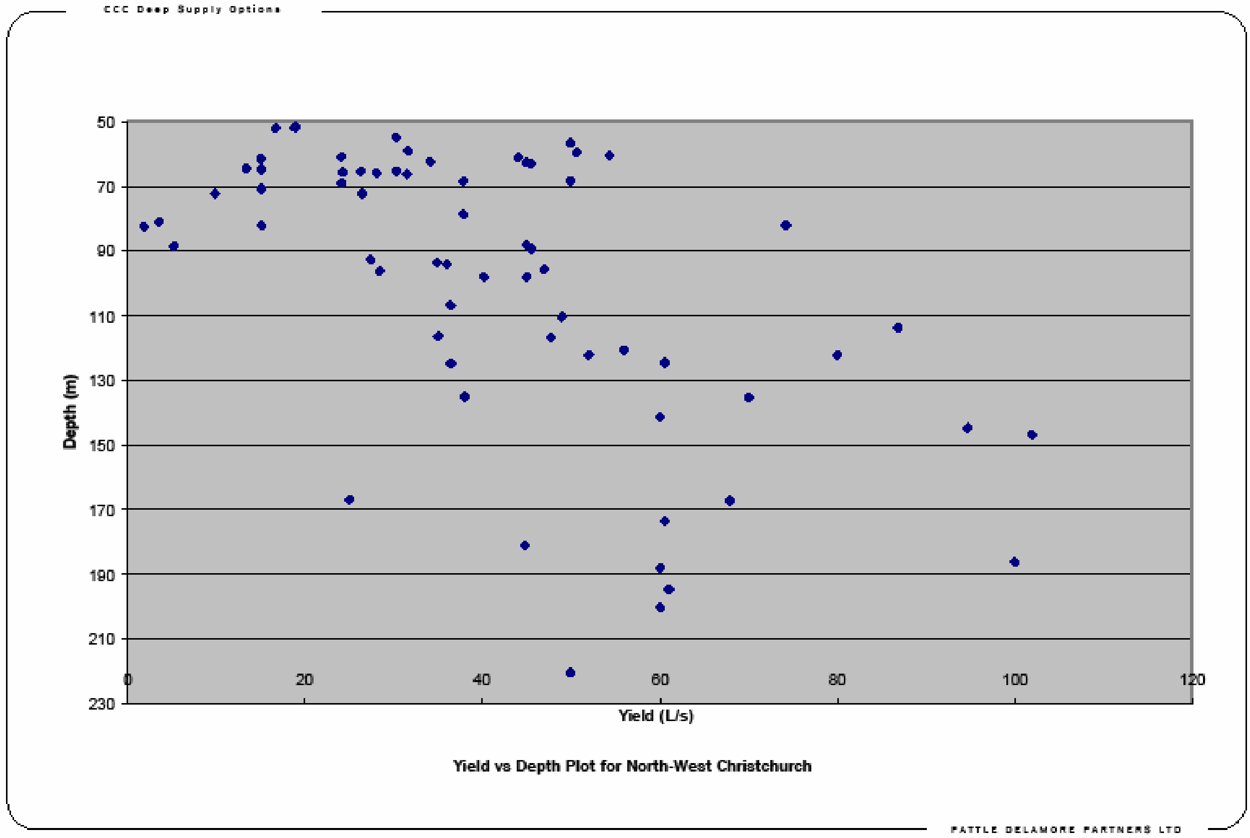
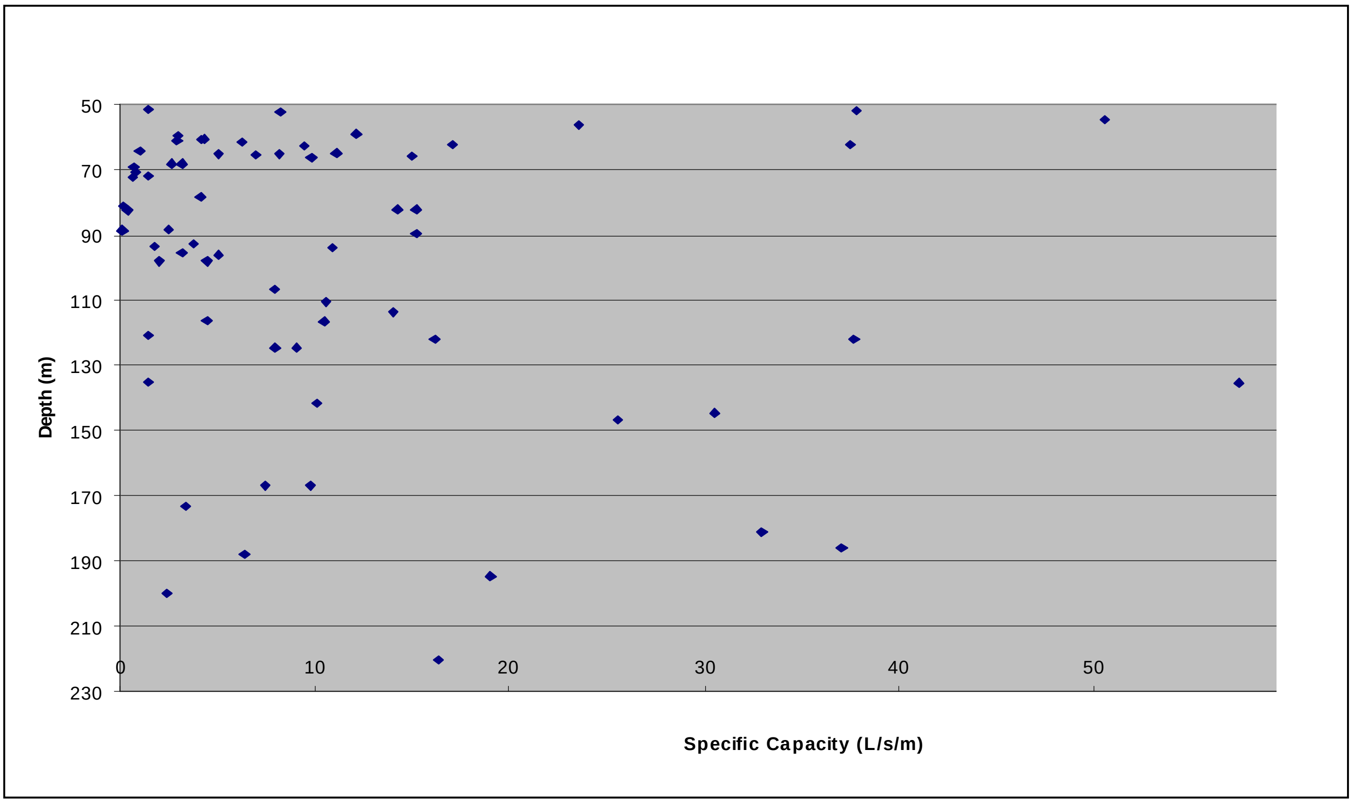


Figure 10 is a similar plot to Figure 9 but the horizontal axis is specific capacity (yield/drawdown). This indicates that the deeper strata (100-200 m deep) is not necessarily any more permeable than the medium depth (50-100 m deep) strata, so the higher yields evident in the deeper bores in Figure 4 are largely due to the greater available drawdown in the deeper bores.

Figure 10 : Specific Capacity Plot for Wells in North-West Christchurch



3.1.3 SEPARATION DISTANCE BETWEEN BORES

Due to the presence of several bores at each pumping station drawdown interference between bores must be considered for the siting of new bores in close proximity. At the very least this drawdown interference increases pumping costs (due to the greater lift required) and at worst it may cause reduced bore yields. An indicative separation distance of up to 100 m may apply for instance, but the extra benefit of small increases in distance beyond 100 m is may not be significant. Of more significance will be to achieve a vertical offset between bore screens, particularly if there is a low permeability silty zone between the different screened zones.

Ultimately the separation distance between bores needs to be considered on a site specific basis taking into account the aquifer characteristics of the local area and the sensitivity of the other pumping station bores to drawdown interference.

3.1.4 WATER QUALITY

In general the majority of groundwater in Christchurch is of very good quality in both shallow and deep bores. Deep bores tend to have a more stable water chemistry and a higher pH (more within the DWSNZ range) due to the less direct effect of rainfall recharge. In terms of dissolved chemicals the key issue is to avoid screening the bore near organic deposits (primarily peat) which may cause anaerobic conditions resulting in dissolved iron, manganese and perhaps arsenic in the ground water supply.

Another important issue in screening, development and the choice of pumping rates is to avoid the inflow of sedimentary particles through the bore screen creating wear on the pumps and turbidity issues which impair water quality.

3.1.5 CONSENTING ISSUES

All the shallow (potentially “non-secure”) bores have the necessary resource consents for their required water abstraction. The transfer of these allocations to deeper replacement bores represents no increase in the overall allocation of water from the groundwater resource. However the localised effects of the abstraction will change. Shallow bore abstractions cause a more direct drawdown effect on the local water table and a depletion of flow in any nearby streams. Deeper abstractions cause drawdown effects in surrounding deep bores and drawdown cone effect are likely to be more widespread than shallow bores, due to the lower storage coefficient in the deeper strata. Due to the leaky nature of the strata these drawdown effects transmit upwards resulting in a smaller, but more widespread effect on the water table and spring fed streams compared to an equivalent shallow abstraction. As a result the change in abstraction from shallow to deep strata needs to be considered on a case-by-case basis, although in general it is expected that deeper abstraction will lead to a smaller magnitude of direct drawdown effects, which should be a beneficial change.

3.1.6 COSTINGS

An important comparison between the “treatment” and “non-treatment” options is a consideration of costs. The change from shallow to deep bores involves consideration of the following costs:

- Bore Drilling
- Pumping Tests
- Resource Consents
- Completion of Borehead
- Piping to Pump Station
- Power Supply
- Flowmeter and Telemetry
- Pumps
- Decommissioning and grouting of shallow bores

It is assumed that the bores can be sited on land already owned and/or controlled by the CCC. Operational costs have assumed similar power costs to the current shallow bore situation and pump replacement every 20 years. All costs are presented as Net Present Value over a 60 year horizon for comparison with the treatment option.

3.2 TREATMENT: ULTRAVIOLET (UV) IRRADIATION

3.2.1 WHY UV?

Benefits of installing UV treatment for the inactivation of protozoa and other pathogens in drinking water include:

- No chemicals added to the water
- No moving parts
- Proven technology
- Power efficiencies have improved in recent years with low pressure high output (LPHO) type lamps
- Good track record in New Zealand and overseas, 100+ installations in New Zealand.
- Widening supplier base in New Zealand

3.2.2 GENERAL UV REQUIREMENTS

UV systems are designed as enclosed vessels referred to as reactors or as gravity in-line channel type. The former type is used for drinking water in view of the validation standards whereas channel type systems are more common in wastewater treatment.

The following sections outline briefly the general water quality, installation, operational and maintenance requirements for a standard UV installation.

Figure 11 UV Reactor (in line pressure type)

3.2.3 WATER QUALITY REQUIREMENTS

Water to be treated by UV irradiation needs to meet certain water quality standards to ensure that the amount of UV irradiation, or light, required to inactivate protozoa is transmitted and received by the target microorganisms.

UV Transmittance (UVT) is the percentage of light that can pass through a specified column of water under controlled conditions. The lower the UVT percentage, the greater the UV dose required to treat the water.

For DWSNZ, the feed water turbidity must not exceed 1 Nephelometric Turbidity Unit (NTU) for more that 5% of the compliance monitoring period (typically 1 calendar month) and must always be less than 2 NTU. All of CCC’s wells meet these criteria.

3.2.4 INSTALLATION REQUIREMENTS

Ideally, the UV reactor needs to be located in a building or enclosure. While pipe trench or chamber installations are possible, the control panel needs to be housed in a vented building or enclosure.

Enough horizontal clearance is required to ensure that the lamps can be removed for replacement. This space depends on the type and size of the reactor, but for installations at the 12 well sites visited, this is typically between 1.7 and 2.0 m. Note the reactors must be mounted horizontally.

Consideration needs to be given to the length of straight pipe before and after the device to ensure the flow patterns through the reactor meet the design and validation standards. Most electromagnetic flow meters require minimum upstream and downstream straight lengths and this must be observed. This varies depending on supplier.

A non-slam non-return valve may be required downstream of the reactor at some sites to provide protection for the quartz and UV lamps against water hammer effects from the sudden stop of the well pumps (back surge effects).

The system should be designed so that if a UV reactor fails, the pumps stop operating to ensure that all water is treated to meet compliance requirements.

Figure 12 Typical CCC Flowmeter in chamber

UV reactors should be kept free of air to prevent lamps overheating. The use of air release valves, air/vacuum valves, or combination air valves may be necessary to prevent air pockets and negative pressure conditions. The selected UV manufacturer should be consulted to determine any equipment specific air release and pressure control valve needs. The valve locations will be dictated by the specific configuration of the facility.

3.2.5 OPERATIONAL REQUIREMENTS

General requirements for operation of UV reactors includes:

- UV reactors need to be always full of water so that they do not overheat
- A lamp warm up period ("burn time") is usually required before flow commences to ensure that the correct UV dose is administered and that the water is treated to requirements, and
- Consideration must be given to the pumping profile of the pump station. Frequent stopping and starting of UV reactors is not recommended as this can reduce the life expectancy of the lamps.

3.2.6 MAINTENANCE REQUIREMENTS

Regular maintenance requirements include:

- Regular calibration of UV sensors
- Cleaning of quartz sleeves, as required, for example to reduce calcium carbonate fouling
- Replacement of lamps every 8,000 to 12,000 hours (varies dependent on supplier). Used UV lamps are returned to the supplier for recycling and disposal.

Most reputable UV suppliers now use electronic ballasts, which will last for the entire design life of the UV system. These have replaced traditional magnetic ballasts, which in some cases were not reliable.

3.2.7 SITE EXAMPLE : AUBURN PS

Details of the pump station site are as follows:

- Number of wells in use : 4 (2 secure, 2 non-secure)
- Number of pumps : 4
- Consented Daily Usage : 100 l/s (360 m3/h)
  : 52,920 m3/seven day period
- Average Daily Demand : 571 m3/day (2007 data)

System Description:

Auburn pump station is located off Auburn Avenue in Riccarton. The pump station has five wells, four of which are currently in use. Wells 2, 3 and 5 feed directly under artesian pressure to a suction tank. Well 4 is operated by a centrifugal pump that pumps directly into the reticulation. The pumping system consists of two 30 kW pumps, a 100 kW pump, and a diesel standby pump. All pumps are fixed speed.

UV Upgrade Design Options

The UV equipment design capacity recommended for this site is 490 m^3/h. This covers the total capacity of the site, and allows all three duty pumps to be run simultaneously, but exceeds the resource consent limit.

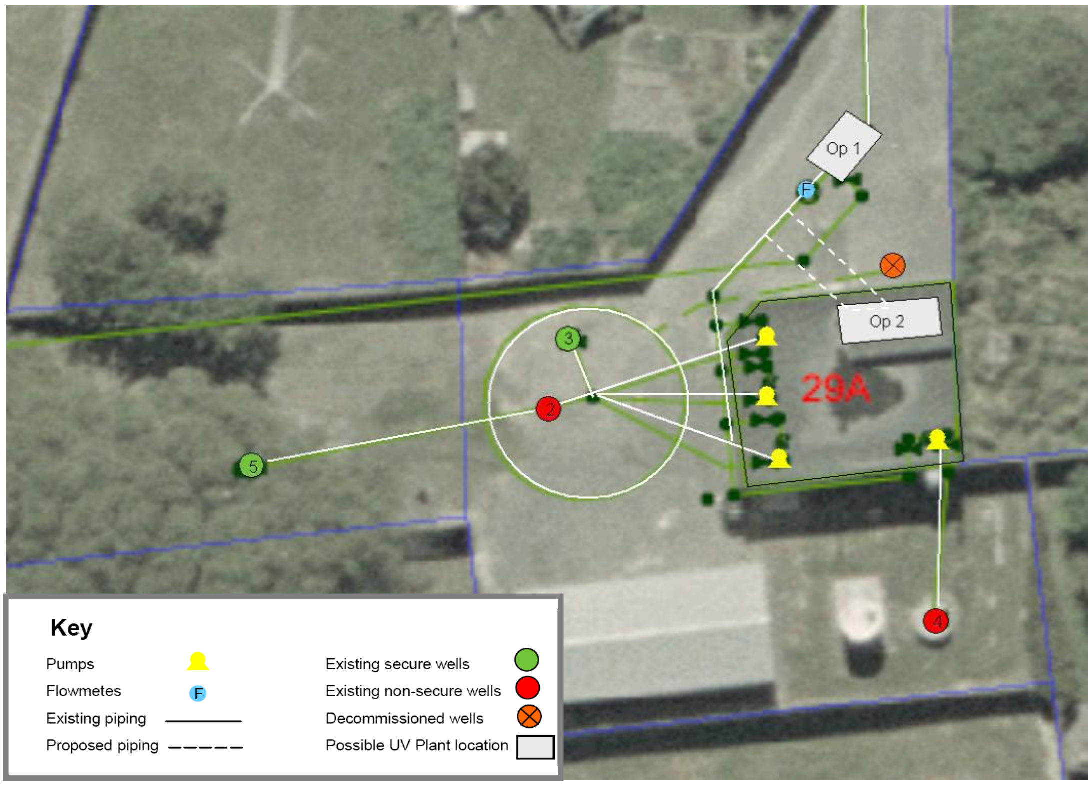
The option of treating only that water deemed non secure was considered. As both Well 3 and Well 5 feed into the suction tank, it is not possible to exclude this secure water from treatment.

There are two possible locations for UV treatment at the Auburn Pumping Station:

- Option 1 UV reactors within a chamber in the driveway to the pump station
- Option 2 UV reactors location in the existing pump station building

These two location options are illustrated in Figure 13.

Figure 13 Auburn PS Aerial Layout



Option 1 UV Reactors Located in Chamber in Road

The advantages and disadvantages of locating the UV treatment reactors in a chamber in the road are summarised below.

Advantages	Disadvantages	Other Comments
» Less pipe work required compared to Option 2 » Easy access for maintenance, though site access compromised at these times	» Realignment of the discharge main and relocation of flow meter required » Access to Orion substation needs to be maintained, so covers need to be suitably rated for traffic. » Lengthy shutdowns for construction and tie-ins. » Conduits for power/signal connections required as UV remote from control panel. Limited by length of power cord between reactor and control panel	» Sealed chamber required due to flooding issues at the site » Control panel requires housing in a separate building  *Figure 14 Chamber Location Area*

Option 2 Reactors Located in a Building

The advantages and disadvantages of locating the UV treatment reactors in the pump station building are summarised below.

Advantages	Disadvantages	Other Comments
» Building provides good location for UV equipment in terms of maintenance and operation » Short shutdown periods for construction and tie ins » Simple power signal connections as UV and control panel in same location	» Challenges in pipe work and connections, multiple levels and change of direction; » Penetration of building structure needed, groundwater ingress could be an issue	» Confirm design details at investigation prior to detailed design

In this option it was decided to locate the UV reactors in the existing pump station building, Option 2 (Figure 15, opposite).

Costs

Capital and operating costs for UV treatment at Auburn pump station are estimated below. The level of accuracy is +/-15%. These costs are for the installation of the UV system in the pump station building (Option 2).

Figure 15 Auburn PS Building

Table 1 Auburn UV Cost Estimate

Capital Cost (CAPEX)		
UV Units (2 units)		$135,000
Piping and Valves		$75,000
Equipment Installation		$40,000
Mechanical and Electrical		$60,000
Civil		$20,000
	Subtotal	**$330,000**
Preliminary and General (10%)		$33,000
Contingency (15%)		$50,000
Engineering (10%)		$33,000
	TOTAL Capital Cost	**$446,000**
Operating Cost (OPEX)		
Lamp replacement – based on 12,000h life expectancy, $510/lamp		$3,000
Electricity (based on 3 kW, 24/7 basis, at 13c/kWh		$3,500
Maintenance		$13,000
	TOTAL Annual Operating Cost	**$19,500**
	Whole of life cost, NPV, 60 Years, 8.25%[1]	**$780,000**

1. Assumes that after 30 years a new UV system will be required, depreciation has not been included

4 COUNCIL DECISION MAKING PROCESS AND DESIRED PROJECT OUTCOMES

Council's desired project outcomes were to determine a cost effective option of obtaining secure groundwater status to meet the requirements of the DWSNZ using chemical free treatment methods for Christchurch City Council's north west zone water supply pumping stations.

To assist Council in the decision making process, NPV figures were determined over a 60 year operating period (which is the predicted asset life of a well) for both the 'non treatment' and 'treatment' options. The respective cost estimates provided for each option were reviewed to assess whether it was preferable to drill and construct deeper wells, or provide UV disinfection at the nominated sites.

4.1 RISK ALLOCATION

Each option carried with it some risk and uncertainty and the following risks were taken into consideration in establishing which option to recommend.

4.1.1 UV TREATMENT

Risks involved with UV treatment include:

- Community perceptions of UV treatment, despite UV not involving chemical treatment of the water, and leaves no residual effects (taste / odour / chemical)
- Space constraints at existing sites to allow sufficient space necessary for the removal and replacement of the lamps. There is a risk that during detailed design space is deemed insufficient, resulting in the requirement for a dedicated building to house the UV reactors (the budget estimates include some allowance to mitigate this risk)
- Availability and quality / reliability of power resulting in power conditioning equipment being a requirement
- Availability of on site generation sets
- Re-routing of existing piping to connect to the UV reactors.

4.1.2 DEEPER WELLS

Risks involved with drilling deeper wells include;

- There is no guarantee that the required yield can be achieved at all sites, as geological information indicates that there are no discrete aquifer layers where high yielding bores can be reliably obtained
- Increasing the number of bores at the target depths will lead to increased drawdown interference between bores with bores located in close proximity. This may effect the sustained long term yields of aquifers
- There are space restraints at some sites, meaning that any new well(s) would have to be located elsewhere (e.g. nearby park)
- The fragile nature of aquifers causing sand sediment collapse and increasing the turbidity of the water.

In addition to NPV estimates, consideration was given to the following factors to establish which option to proceed with;

- Age of existing wells
- Availability of locations for new wells within acceptable distances from pump stations (i.e. electrics, piping)
- Site landownership
- pH issues at existing sites (in this instance the 'deeper wells' option was selected to correct existing pH issue).

Council's site by site interpretation of the two report findings established a cost efficient preferred mix of UV and deep wells that will result in the North West zone being able to:

- comply with the DWSNZ
- achieve a Ba MoH grading
- overcome existing concerns with low pH at some sites, and
- reduce the risk of cost overruns compared with utilising a sole UV or sole deep well solution.

5 CCC WATER STRATEGY AND SYNOPSIS OF LTCCP FOR THIS PROJECT

The recommended solution of UV at some sites and deeper wells at others was submitted as part of Council's 2009 LTCCP which went out for community consultation and has been subsequently been adopted by Council. The first of the upgrade works is to commence on Council's 2011/12 financial year and the upgrade program will be rolled out over a 4 year period.

6 SUMMARY AND CONCLUSIONS

The following conclusions are drawn:

- CCC are in a position to maintain compliance with DWSNZ 2005 (Revised 2008) at the 12 non compliant sites by a combination of drilling deeper to access secure groundwater, and using UV as a cost effective and chemical free means of treatment
- The groundwater system is highly complex, and any new wells on a particular site require dedicated site testing to ensure no negative influence on existing wells
- The wells that marginally do not comply with DWSNZ typically have excellent water quality, and the public health risks are very low in this regard
- CCC has elected to install UV at 4 sites and drill deeper wells at the remaining 8 sites at an estimated capital cost of $9.5 million
- The project has been programmed as part of the CCC LTCCP (2009-19) to take place in 2011/2012 with a duration of 4 years.

ACKNOWLEDGEMENTS

We acknowledge the support of Christchurch City Council in drafting this paper, in particular; Bryan Hickling (CCC Project Manager) and Bruce Henderson (CCC City Water and Waste Investigation and Planning Team Asset Management Team Leader and Project Sponsor). Finally, Helen Ecroyd (GHD) who would otherwise be co presenting the paper however is currently on maternity leave.

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1. Drinking Water Standards for New Zealand 2005 (Revised 2008), Ministry of Health, 2008.
2. US EPA UV Disinfection Guidance Manual (2006).