NATURAL WATER TREATMENT FOR DWS COMPLIANCE AND WATER QUALITY IMPROVEMENT – GROUNDWATER SOURCE ENGINEERING INVESTIGATIONS FOR TWO NZ AQUIFERS

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ABSTRACT

Many New Zealand water suppliers are facing significant financial burdens to achieve compliance with NZ Drinking Water Standards (DWS). This paper presents studies that URS New Zealand Ltd has undertaken for Central Otago District Council in Alexandra and the NZ Defence Force in Woodbourne, to seek alternatives to high cost treatment plants.

The studies demonstrate the use of groundwater science to investigate the causes of water quality issues, and how the treatment properties of the ground can potentially be optimised by understanding and capitalising on these natural systems.

UV filtration offers a cost effective means to achieve 3 log credits under the DWS, which is sufficient to meet the protozoal compliance requirements for some water sources. These credits are only applicable, however, if turbidity remains below the prescribed limits. Higher turbidity can mean filtration plant is required, with significant cost implications. The source and transport of suspended particles were investigated at both study sites, and conclusions drawn on how the water supplies could be engineered to achieve low turbidity sources.

Hardness is a significant source of dissatisfaction for the Alexandra town water supply. The cause of hardness was investigation, and groundwater source engineering options put forward for development of a low hardness supply.

KEYWORDS

DWS compliance, turbidity, hardness, water treatment, riverbank filtration.

1 INTRODUCTION

Compliance with the Drinking-water Standards for New Zealand 2005 (Revised 2008) was mandated by the Health (Drinking Water) Amendment Act 2007, which requires that water suppliers achieve compliance with the Drinking Water Standards (DWS) by a given date. The cost to upgrade existing infrastructure to achieve compliance is high in many instances, and has presented particular issues for smaller suppliers where the cost of upgrades must be borne by a low number of ratepayers.

The standards include protozoal compliance criteria, comprising a log credit system based on protozoa concentrations in the source water. Land use intensification in many parts of NZ has increased the risk of protozoa contamination in surface and groundwaters, and hence achieving protozoal compliance is a key aspect of delivering safe drinking water to consumers.

UV treatment can deliver up to three log credits and offers a cost effective means to achieve protozoal compliance. UV can be used in combination with bag or cartridge filtration to provide up to 4 and 5.5 log credits respectively. UV filtration only qualifies for protozoal treatment credits when turbidity levels are below prescribed limits, however, and cartridge and bag filtration are only practical treatment options for relatively low turbidity source waters.

The log credit requirement for protozoal compliance can be determined from protozoa monitoring or from the source type and catchmnet land use. Shallow groundwater drawn from wells with secure headworks requires three log credits of protozoa treatment under the latter approach, as do surface waters drawn from catchments with no agricultural activity. Surface waters and groundwaters with unsecure headworks drawn from pastoral catchments with low animal and human activity require four log credits; five log credits are required where animal poluations are high or where waste water treatment outfalls discharge upstream of the source. Protozoal compliance criteria can therefore be met at relatively low cost if source turbidity levels are low.

The New Zealand Defence Force’s (NZDF) RNZAF Base Woodbourne in Marlborough is supplied by a number of shallow wells, which deliver water to a permanent population of around 700 people, plus a larger daytime population of contractors and airport staff and users. The water supply will require three log credits if the well headworks are considered secure. Turbidity levels are periodically elevated, however, to the extent that filtration plant would be required to achieve protozoal compliance; cartridge filtration is not a viable option. Filtration plant capital costs are significant, estimated at around $800-900K.

Alexandra in Central Otago (population ~5000) is supplied by a shallow wellfield on the banks of the Clutha River. Water drawn from the wellfield, which is located close to a former landfill, suffers from elevated hardness and occasional taste and odour issues and is a significant source of dissatisfaction amongst the local population. An option to draw water from the Clutha River has been considered, but capital costs for the required treatment plant alone have been estimated at $6.5M due to river turbidity levels and the high peak demand. This again represents a substantial investment for the relatively small population base.

These high treatment plant costs provided a driver for investigation into the source of the water quality issues and of options that could deliver naturally high quality water.

2 RNZAF BASE WOODBOURNE WATER QUALITY INVESTIGATIONS

2.1 BACKGROUND

The potable water supply at RNZAF Base Woodbourne is currently sourced from two wells, with a third currently used for irrigation. Metering data indicates a peak water demand of around 1000 m^3/d and an average demand in the order of 450 m^3/day.

Woodbourne Base has a history of water supply difficulties. Severe water shortages were experienced in 1981, following a decline in aquifer water levels over the course of a very dry summer. This culminated in damage to one of the pumps and the subsequent construction of a new well. Water conservation measures over the following summer reduced demand by up to 30%, although no readily discernible improvement in groundwater levels was recorded. Pumps were lowered to the base of the boreholes and one well was deepened in order to improve supply capacity.

In addition to periodic water shortages, the base water supply does not currently meet the latest drinking water standards, although compliance is not yet mandatory. UV plant with the capacity to deliver three log treatment credits has been installed, but this treatment is compromised by high turbidity levels. This is illustrated in Figure 1 below, which plots turbidity data over time at the treatment plant. The 1 NTU limit (turbidity should be <1 NTU for 95% of the time) and 2 NTU limit (turbidity must not exceed 2 NTU for any three minute period) are highlighted.

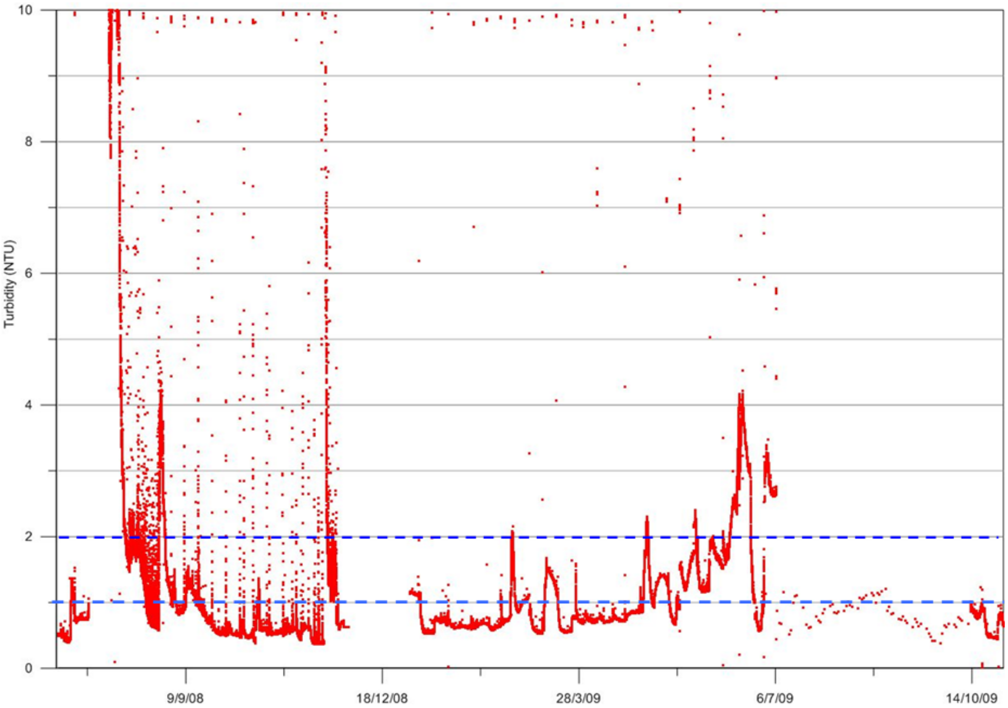

Figure 1: Woodbourne Water Supply Turbidity

2.2 PROBLEM DEFINITION

An evaluation of water supply options at Woodbourne indicated that the reliability of supply could be improved significantly by development of a new groundwater source to the north, closer to the Wairau River. Seepage from the Wairau River is considered to comprise a significant and consistent component of groundwater recharge in this area. Groundwater level data from a monitoring well to the north of the base show a reduced seasonal range compared to the current base wells, consistent with more sustained groundwater recharge. A pilot well drilled in this area achieved high well yields and good quality water. However, since no pumping plant were installed in the well, and given that elevated turbidity levels are periodic in the existing base wells (meaning that long term monitoring would be required), uncertainty remained over the turbidity levels in a new production well if drilled at this location. The likelihood that an $850k filtration plant would be required was unknown. The decision on how best to develop a reliable, DWS compliant water source for the base also faced other uncertainties: whether elevated turbidity is confined to the upper aquifer, such that development of a deeper well could yield low turbidity water; and whether development of a well in an alternative location could deliver sufficiently low turbidity levels for UV treatment work effectively. Development of a deeper well also faces potential issues: well yields are more uncertain and generally lower in the deeper aquifer, and new deep abstractions have been discouraged by MDC in the Woodbourne aquifer and the aquifer to the south due to concerns over impacts on the already stressed shallow aquifer system. On this basis the option to address the turbidity issue by drilling a deep well would not necessarily provide an easy solution.

2.3 INVESTIGATION METHOD

Options considered to investigate the turbidity issue included desk top study of existing data, installation of pumping equipment in the pilot well coupled with water quality data loggers and a sampling programme, and water sampling in neighbouring wells. Turbidity has been monitored continuously at the Woodbourne Base treatment plant since mid 2008; groundwater levels have been recorded on a weekly basis and total abstraction on a daily basis for a number of years. Rainfall records from the site and daily Omaka River flow records were also accessible. On this basis a good set of data, that could potentially yield valuable insights into the source of groundwater turbidity at Woodbourne, was available. A low cost desk study investigation of existing information was therefore undertaken.

2.4 ENVIRONMENTAL SETTING

Figure 2 shows Woodbourne Base, the current water supply wells, the pilot well to the north of the Base, the Omaka River to the west and groundwater contours interpolated from a piezometric survey in March 1983. As noted above, the base water supply wells are relatively shallow (approximately 20m). Soils in the area are well drained, with the shallow geology comprising a mixture of unconsolidated coarse grained material, either free or within a clay matrix. The Omaka River flows in a northerly direction and passes within 1km of the base at its closest point to the west of the married quarters, and frequently exhibits high turbidity levels. Groundwater contours indicate flow from the west.

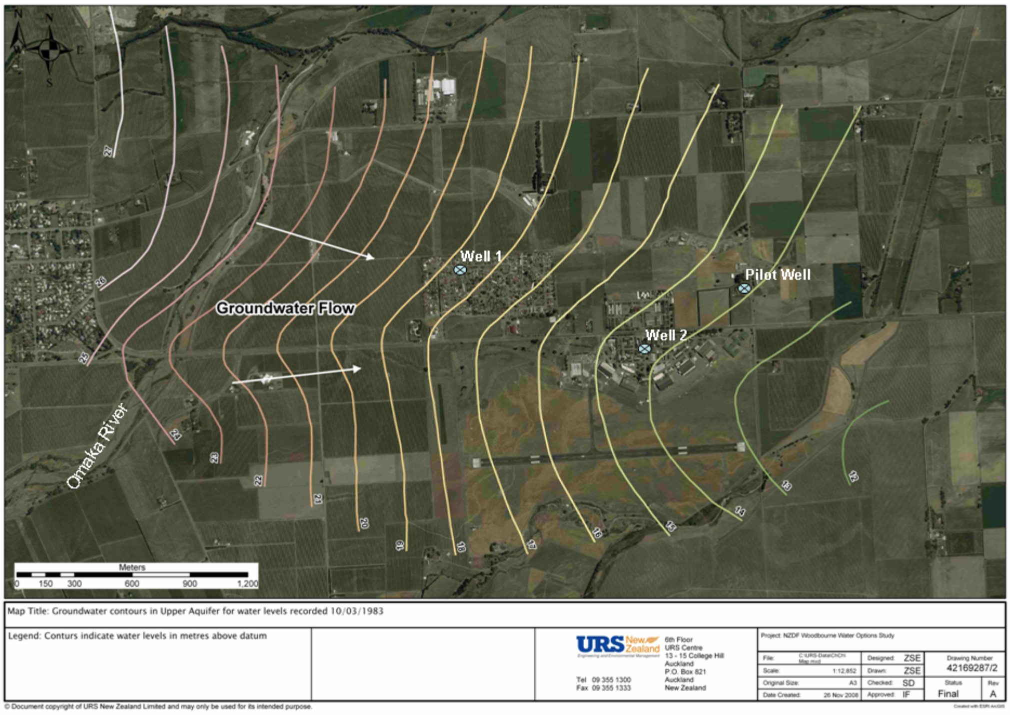

Figure 2: Woodbourne Location Plan

The information summarised above suggest two possible sources for groundwater turbidity: erosion of soil in the upper ground profile by rainfall recharge infiltrating down to the shallow aquifer, and/or seepage from the turbid Omaka River to the groundwater system.

2.5 DATA ANALYSIS

Turbidity, groundwater abstraction and levels, rainfall and river flow data were analysed with the aim of determining the source of turbidity in the Woodbourne Base water supply. Simple correlation plots of turbidity versus rainfall and turbidity versus river flow indicated that all three parameters were correlated; this analysis therefore provided no useful insights for this investigation. The first part of the analysis therefore focused on evaluation of time series plots of the above parameters. The second component of data evaluation comprised assessment of potential particle travel times between the Omaka River and the base wells. Analysis of the morphology of the turbidity breakthrough curves formed a third component of the assessment.

2.5.1 TIME SERIES DATA ANALYSIS

Figure 3 below plots turbidity, hourly rainfall, hourly Omaka River flow, South Well groundwater levels, the seven day moving average of Base water use and the 30 day moving average of Omaka River flow between July

2008 and October 2009. A potentially key and unavailable data set is the location of the Omaka River wetted front (i.e. the point at which surface flows disappear due to seepage to ground). The location of the wetted front varies seasonally according to river flow, extending further downstream in winter or spring and receding in summer or autumn (Marlborough District Council 2008). The location of the wetted front is potentially significant for Woodbourne Base turbidity levels, since a river located many kilometres away would be unlikely to cause significant turbidity in groundwater at the base due to dilution and filtration along the flow path. The Omaka River was flowing at the Hawksbury Road bridge (located approximately 4km upstream of Woodbourne Base) for approximately 80% of the time during frequent wetted front surveys undertaken by Marlborough District Council in 2006. Flow was only recorded at Middle Renwick Road, (located approximately 1km from the Base and representing the closest point of the Omaka River channel to the Base) for approximately 30% of the time. If the Omaka River is the source of turbidity at Woodbourne, higher turbidity levels would be expected in the winter and spring months when the Omaka River is flowing at Middle Renwick Road and conversely lower/less frequent turbidity levels/events in the summer and autumn months.

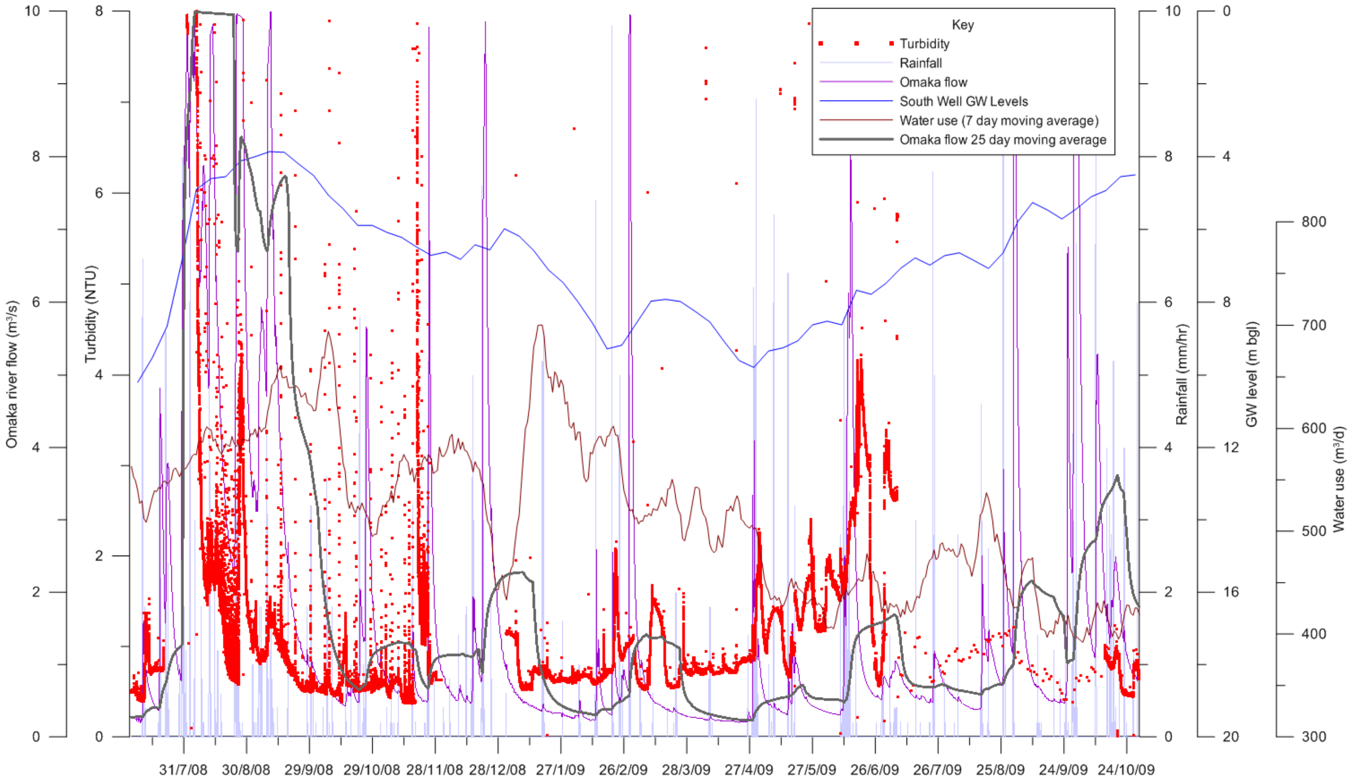

Figure 3: Turbidity Analysis - Time Series Data

The following observations can be drawn from these data:

a) Elevated turbidity levels are highly correlated with rainfall events and high river flows, as noted above;
b) One significant rainfall event occurs without an associated high river flow event (January 2009); this event has no discernible impact on groundwater turbidity;
c) A period of generally low turbidity is observed between early December 2008 and late March 2009;
d) Turbidity levels are high in August, September and November 2008 and in May and June 2009 (after which the turbidity logger failed); and
e) Turbidity levels progressively increase between late March and late June 2009.

The picture is complicated by the switching of pumping wells (not shown above), which is done on a weekly basis. This is discussed further below.

The broad coincidence of higher turbidity levels in the winter, spring and autumn months and lower levels in the summer months is consistent with the Omaka River as a source. However, more rainfall recharge also occurs in these months, and reduced vegetation cover outside of the summer months could potentially increase the rate of transport of fine material through the ground profile into the aquifer. So although the time series analysis suggests that the Omaka River as the more likely source of turbidity, this part of the evaluation did not provide a firm indication of the likely turbidity source.

2.5.2 TRAVEL TIME ANALYSIS

The Omaka River is located approximately 1250m from the Wodbourne Base Well 1 at its closest point and 2250m from Well 2, as indicated in Figure 2. A review of available hydraulic gradient data from surveys undertaken in November 1982 and March 1983 indicates a general hydraulic gradient in the order of 0.005 to the east. Assuming a high transmissivity for this area (2500 m^2/d) and a low aquifer thickness of 1m yields a hydraulic conductivity of 2500 m/d. This is towards the upper end of the range for gravels reported by Domenico & Schwartz (1990). If an effective porosity of 0.01 were assumed, this would equate to a maximum particle velocity of 1250 m/d. The travel times from the Omaka River to the Well 1 and Well 2 would be 24 and 43 hours respectively under this velocity. Gravels typically have a porosity (analogous to saturated water content) of around 0.3 however. Modelling results based on lab column tracer tests presented by Stephens et al., (1998) yielded effective porosities varying between 7% and 93% of the saturated water contents, for samples comprising sand, silica and a sand/silica mix. The minimum effective porosity for sand calculated in the study was 0.1. Numerical modelling of a field tracer test in a sand and gravel aquifer comprised a second component of the Stephens et al. (1998) study of estimated and calculated effective porosity. Model calibration root mean squared error was minimised with an effective porosity of 0.17, compared to estimates of 0.25-0.32 based on literature data and professional judgement. A minimum effective porosity of 0.15 would be considered reasonable from the results of this study; this would equate to a particle velocity of around 80 m/d, and travel times of 15 and 27 days to the base wells.

Figure 4 below plots turbidity, Omaka River Flow, rainfall and the pumping status of the Well 1 in April to May 2009, at the time of an isolated turbidity event. Note that water is drawn from the Well 2 when Well 1 is not in use, and that the switch times are subject to some uncertainty. The following observations can be made:

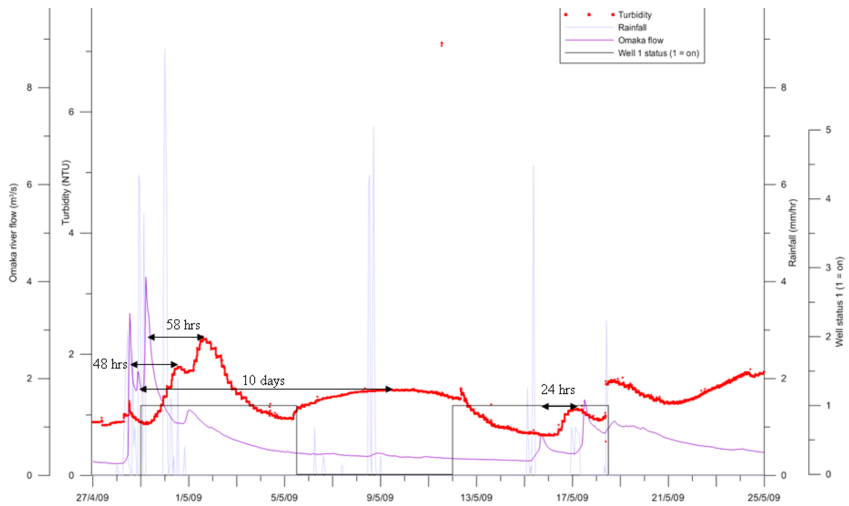

Figure 4: Turbidity Breakthrough Curves

a) Turbidity spikes often occur after well switching due to remobilisation of turbidity in the rising main;
b) Turbidity peaks occur in Well 1 approximately 24-58 hours after Omaka River flow events;
c) Turbidity peaks in Well 2 occur 10-14 days after Omaka River flow events.

Although the significant difference between Well 1 and Well 2 turbidity arrival times fits with the greater distance of the latter from the river, the time lags are shorter than would be expected from the travel time analysis – significantly so in the case of Well 1. High permeability preferential flow paths in former river channel deposits offer a potential explanation for this.

2.5.3 BREAKTHROUGH CURVE ANALYSIS

Breakthrough curves for solutes and particles in groundwater are sharper close to the source and more subdued with increasing distance due to dispersion along the flow path. The turbidity breakthrough curves at Well 1 and

Well 2 are show significant differences: The Well 1 breakthrough curves are sharper, reflecting a lower level of dispersion in line with closer proximity to the turbidity source. The Well 2 turbidity breakthrough curves are more subdued, reflecting a higher level of dispersion over an increased distance from the turbidity source. Both wells are screened at similar depts., with similar material recorded in the overlying ground profile. The Woodbourne well turbidity breakthrough curve morphology is therefore considered to be highly indicative of the Omaka River as the turbidity source.

Overall the turbidity data are therefore considered to be indicative of an Omaka River source.

2.6 RESULTS & DISCUSSION

The Pilot Well site is located approximately 2.5km downgradient of the Omaka River, assuming a consistent easterly groundwater flow direction. This is slightly further from the likely turbidity source than Well 2, but not significantly so. If conditions at the Pilot Well site were similar to those at Well 2 turbidity levels would be expected to be only slightly lower than Well 2. Water level data indicate that the Pilot Well site receives more recharge from the Wairau River, however. The hydrogeology of this site therefore differs from that of the current base wells and on this basis there is currently insufficient data to predict potential turbidity levels. Installation of water quality logging equipment together with periodic sampling would be required to gain an understanding of turbidity at this location.

In terms of non-filtration solutions to the turbidity issue, the following options could be considered:

a) Operation of the Base wells in accordance with turbidity levels: Well 2 (or potentially a new production well at the Pilot Well site) would be pumped in the days immediately following an Omaka River high flow event, with pumping switching over to Well 1 once the turbidity plume had passed that location. Given the 10 day lag between Omaka River flow events and peak turbidity levels in Well 2, this may feasible. However, a brief analysis of the data suggests that the 1 NTU NZDWS turbidity criteria would still be breached during sustained Omaka River high flow periods, such as that of July – August 2008;
b) Development of a new water source to the north east of the Pilot Well site. Issues associated with this option include land ownership, pipeline easements and consenting. The reduction in turbidity with greater distance from the Omaka River is also unknown;
c) Development of a deeper groundwater source, which would be less likely to suffer from turbidity issues due to lower vertical hydraulic conductivity. This well could be used only during times of high turbidity in the shallower aquifer if this were required for consenting purposes.

URS recommended that development of the proposed new water source should incorporate detailed intrusive investigation of turbidity and well yields at different depths in the aquifer to target the well screen installation on a low turbidity horizon.

3 CODC ALEXANDRAWATER QUALIY INVESTIGATIONS

3.1 BACKGROUND

The Alexandra water supply is sourced from six shallow wells located approximately 50m from the Clutha River. The location of the wellfield is indicated on Figure 5. Groundwater in the Alexandra area is typically hard, with concentrations of up to 400 mg/l $CaCO_3$ recorded. A hardness range of 75 – 225 mg/l $CaCO_3$ has been recorded in the town supply.

The wellfield is located approximately 300m from the former town landfill. Although water quality upgradient of the landfill is monitored frequently, and the risk of significant landfill contamination reaching the wellfield is considered to be low, the landfill remains a concern for the local population. Dissatisfaction with the town water supply has been exacerbated by occasional taste and odour issues, the source of which is unknown.

An assessment of water supply options to resolve the hardness and landfill proximity issues undertaken by Opus (2007) concluded that a new borefield to the north of the town represented the most attractive option, assuming that low hardness water could be achieved. Direct abstraction of water from the Clutha River was identified as the second most attractive option. Further evaluation of groundwater options by URS concluded that a riverbank filtration (RBF) system represents the only wellfield option likely to yield sufficient quantities of low hardness water. A river proximal wellfield was identified as the most attractive RBF option.

3.2 PROBLEM DEFINITION

Having concluded that a river proximal wellfield comprised the best option for the Alexandra town water supply, the need to understand why the existing wellfield draws such hard water became evident. Further uncertainties included the proportion of river water required in the wellfield to resolve the scaling issue, whether a wellfield could be designed to draw sufficient river water whilst maintaining low turbidity levels, and the best location for a new wellfield. The potential for river bed clogging to reduce river water infiltration to the proposed new wellfield over time was also identified.

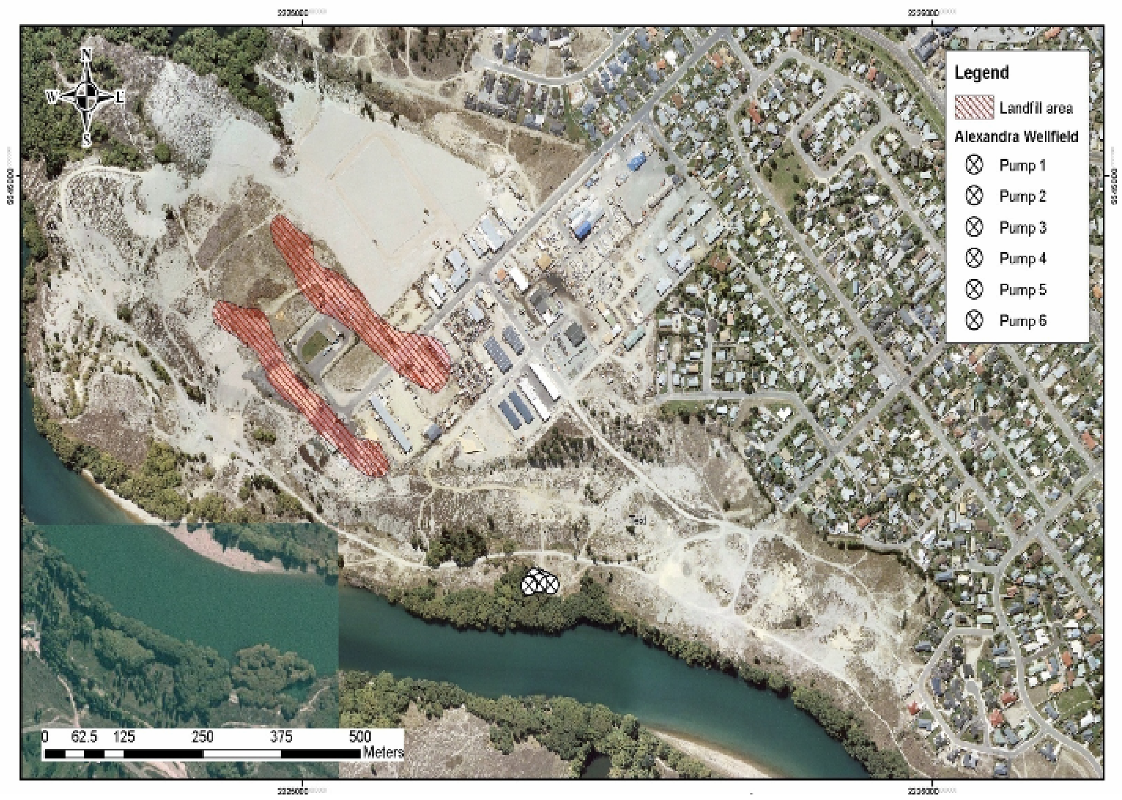

Figure 5: Alexandra Wellfield Location Plan

3.3 INVESTIGATION METHOD

A desk study investigation was designed to address the questions summarised above. The main components of the desk study were:

- Water quality assessment
- A study of Clutha River channel sedimentation and riverbed clogging
- Investigation of the current wellfield

3.3.1 WATER QUALITY ASSESSMENT

A water quality assessment was undertaken to investigate the proportion of river water required to reduce scaling in domestic appliances in Alexandra to a satisfactory level. A literature review indicated that an assessment based on hardness data alone would not necessarily yield a reliable prediction of scaling levels, and hence the study was based on $CaCO_3$ saturation index calculations. Saturation indexes were calculated using the PHREEQC model; simulations were run to estimate the mass of calcite that would be precipitated in a domestic water heater for a range of groundwater-river water blends. Model results indicated that approximately 55-60% river water would be required to reduce scaling to a satisfactory level. Model results were verified by applying water quality data from the nearby Cromwell town supply to the model. Results indicated a satisfactory scaling level, in line with feedback from the local population.

3.3.2 CHANNEL SEDIMENTATION AND RIVERBED CLOGGING

A literature review confirmed that permeability reductions in riverbed materials associated with natural filtration of water flowing through the river bed and banks is a significant issue for riverbank filtration systems. Mechanical, chemical and biological clogging processes can occur, and can reduce the permeability of the upper few centimetres of the bed material to 10^{-8} m/s (equivalent to that of an engineered clay barrier).

RIVERBED HYDRAULIC CONDUCTIVITY ASSESSMENT

The analytical solution for aquifer response to stream stage fluctuations developed by Zlotnik & Huang (1999) was applied to previously recorded groundwater level responses to river stage fluctuations to calculate the hydraulic conductivity of the Clutha River bed adjacent to the wellfield. The analysis yielded a riverbed hydraulic conductivity (k) of 0.028 m/d for an assumed bed thickness of 0.05m. This k value is significantly lower than the aquifer hydraulic conductivity (estimated to be in the order of 1700 m/d from pumping test data), indicating that some degree of river bed clogging with fine sediment had occurred.

SHEER STRESS CALCULATIONS

Bed load mobility was evaluated using sheer stress calculations in order to investigate the self-cleansing properties of the Clutha River bed. The Shields method, as detailed by Gaweesh et al., was utilised with the following input data:

- Clutha River discharge data recorded at Clyde 1995-2008
- Channel cross sections from profile surveys commissioned by Contact Energy (mean channel depth and hydraulic gradient)
- Particle size analysis results from river bed data previously collected by NIWA on behalf of Contact Energy at three locations downstream of the wellfield

The results of the calculations are summarised in Table 1 below.

Table 1 Sediment transport calculation results summary

Cumulative frequency less than flow (%)	Flow	D_{50} (mm)		
	(m^3/s)	D50=3.1	D50=5.3	D50=7.1
3	261	x	x	x
5	275	x	x	x
10	300	x	x	x
20	340	Y	Y	x
30	377	Y	Y	Y
40	415	Y	Y	Y
50	453	Y	Y	Y
60	497	Y	Y	Y
70	541	Y	Y	Y
80	601	Y	Y	Y
90	711	Y	Y	Y
95	834	Y	Y	Y
97	906	Y	Y	Y
99	1118	Y	Y	Y

x denotes flows at which bedload mobility is uncertain due to error margins.

The results indicate that the self cleansing characteristics of the River Clutha in the Alexandra wellfield area are good, with bedload material with a median diameter of 7mm or less predicted to be in motion for 70% of the time. However, riverbed permeability is likely to be a transient parameter, with potentially significant increases in conductivity occurring during and after high flow events.

These calculations do not include infiltration forces associated with the flow of water through the river bed. If the riverbed/aquifer interface is impacted by clogging, additional forces develop from head losses concentrated at the river bed. If the aquifer under the river bed becomes unsaturated, the static force on the overlying water column is exerted directly on the river bed. Hubbs et al. (2006) note that these forces can be significant and can impact on both the hydraulic conductivity and shear resistance of the river bed. Additional uncertainty is introduced by the fact that the sediment size and channel profile data were collected from 2.5km downstream and 150m upstream of the wellfield respectively, and that the sediment sample was collected from the surface of the bed only. It is possible that the bed material immediately beneath the surface is coarser. Calculations indicate that bedload material with a median diameter of 15mm and above will not be transported even at high flow events.

The spreadsheet model developed to undertake the above calculations could be used as part of the assessment process for considering alternative sites. The above results for the existing wellfield would be used as a baseline for this assessment.

CHANNEL PROFILE SURVEY RESULTS

As noted above, the Clutha River channel profile is surveyed periodically by Contact Energy in association with the Lake Dunstan and Lake Roxborough hydroelectric power schemes. Channel profiles are measured at approximately 20 locations between Alexandra and Clyde, including one cross section approximately 150m upstream of the Alexandra wellfield (Section 4U) and sections approximately 400m upstream (5U) and 475m downstream (3U). Scale drawings of the channel profiles are presented in Figure 6 below.

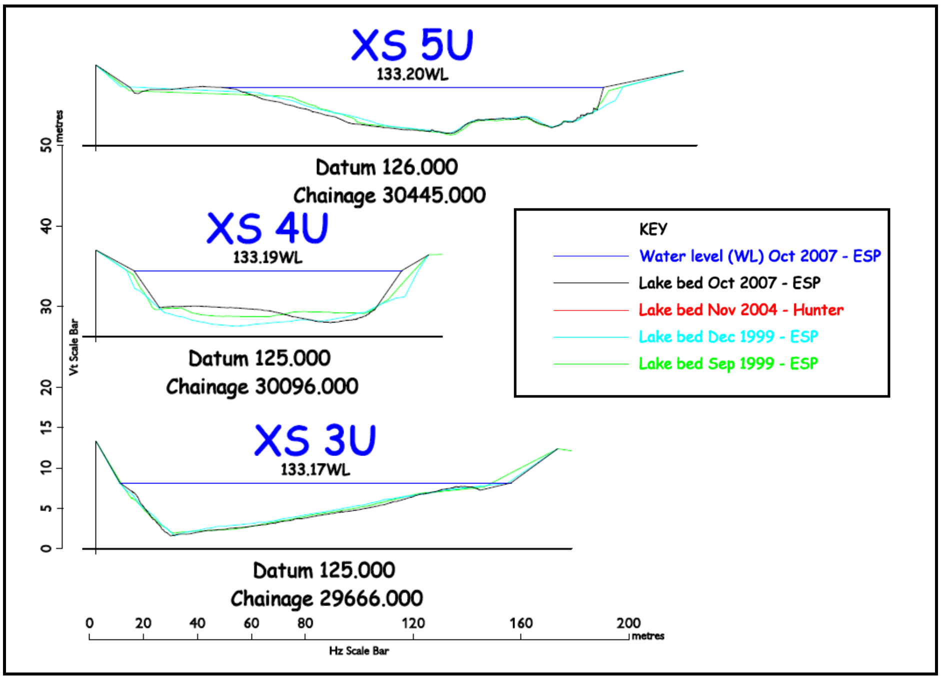

Figure 6: Clutha River channel profiles (courtesy of Contact Energy)

The cross sections above reveal that the mean channel depth adjacent to the wellfield increased significantly between September and December 1999 as a result of the November 1999 flood, which scoured significant volumes of bed material.

Significant sediment deposition occurred between December 1999 and October 2007: approximately 3.6m of sediment was deposited on the true left bank, whilst the channel depth on the right side of the river reduced by 2.4m.

The channel profile at cross sections 3U and 5U have been stable over the monitoring period, indicating that the bedload mobility is low at these locations.

Shear stress calculations were undertaken using average channel depth data. The above information shows that higher resolutions calculations, considering multiple points across the channel section, are required for a reliable assessment of river bed self cleansing potential. Broader scale river sediment transport must also be considered.

3.3.3 INVESTIGATION OF THE CURRENT WELLFIELD

The current wellfield investigation comprised desk study data gathering, literature review, and development of a numerical model of the wellfield and surrounding groundwater system.

DESK STUDY DATA GATHERING

Wellfield electrical conductivity (EC) and hardness were analysed for correlation: these parameters were found to be highly correlated, with an r^2 of 0.97 achieved from the 8 sample data set. Continuous EC data from the wellfield SCADA system could therefore be used to create a continuous hardness record. Evaluation of Clutha River, groundwater quality data and EC records from the SCADA system indicated that the current wellfield draws between zero and 65% river water, with a mean of 25%. The data indicate that high proportions of river water enter the wellfield when the river stage is high, and vice-versa. This relationship is shown on Figure 8 below.

Possible explanations for the low average river water proportion included a high rate of natural groundwater flow towards the river and/or clogging of the riverbed and banks with fine material, limiting the rate of river water infiltration through the bed and banks. The configuration of the wellfield was also identified as a possible contributory factor.

The data gathering phase included evaluation of groundwater gradient data from the Alexandra area. Data from a monitoring well in the vicinity of the current wellfield location (i.e. directly 'inland' of the wellfield) and river stage records indicated a hydraulic gradient in the order of $2 – 6 \times 10^{-4}$ towards the river. Water level data from the Clutha River and from monitoring wells to the north of the town indicated an order of magnitude higher gradient, in the $2\text{-}5 \times 10^{-3}$ range. Given that groundwater abstractions draw significantly more of their water from upgradient that downgradient, these data had potentially significant implications for development of a wellfield in the monitored area to the north of the town.

NUMERICAL MODELLING

A three dimensional transient numerical model was developed using the Visual Modflow software to simulate groundwater flow and solute transport processes in the Alexandra wellfield area. The model comprised two layers, with a constant head boundary defined on the northern model border to represent inputs from rainfall and irrigation recharge, and a river boundary on the southern border. The river border properties were defined using the calculated riverbed hydraulic conductivity (see above), river bed profile data and river stage monitoring data recorded at Alexandra Bridge. The model aquifer was defined with homogeneous isotropic properties throughout.

The numerical model was calibrated in the first instance using water level monitoring data recorded as part of a pumping test on the wellfield in 1994. The robustness of this calibration was affected by groundwater level variations associated with river stage variations over the test period. The model was therefore calibrated against a second data set comprising groundwater level responses to river stage changes over an extended period. Figure 7 below plots observed and model heads in one of the three monitoring wells. Although some discrepancies are evident, the model generally replicated the magnitude of groundwater level changes well, and hence the calibration was considered to be sufficient for the purposes of this study.

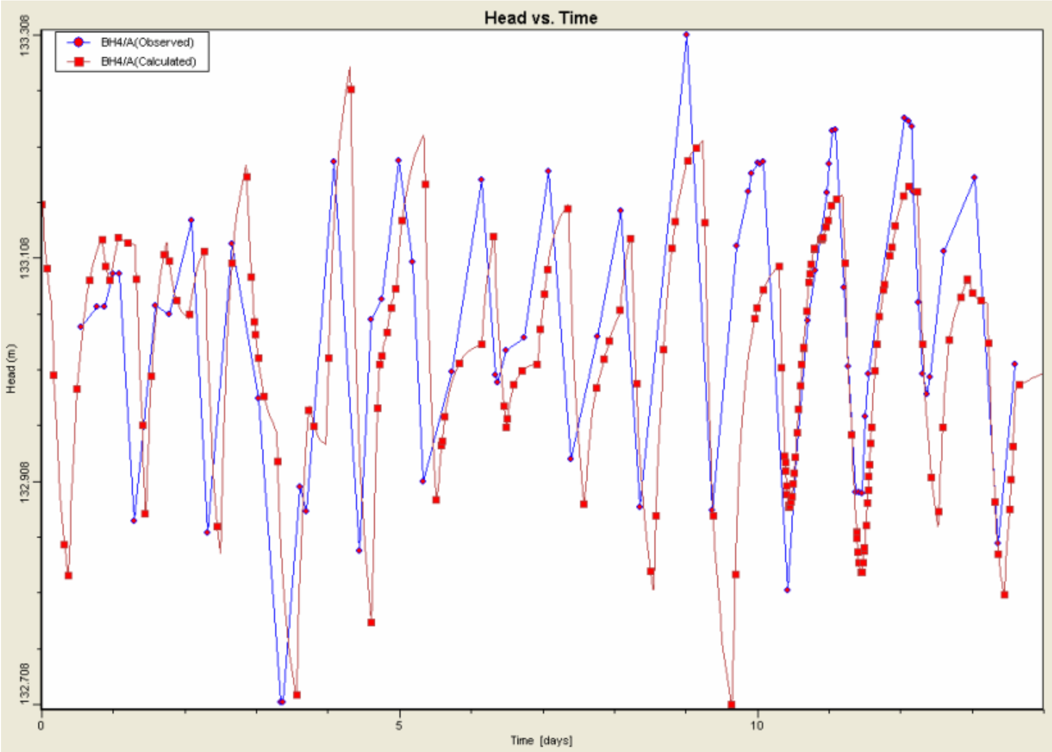

Figure 7: Observed and model well level response to river stage changes

Model verification was undertaking using wellfield EC data recorded over a 120 day period by the SCADA system. Figure 8 below plots the model and measured wellfield EC over the simulation period. The broad pattern and magnitude of wellfield EC responses to river stage changes is replicated. Although the calibration could be improved, the level of fit was considered to be sufficient for this study.

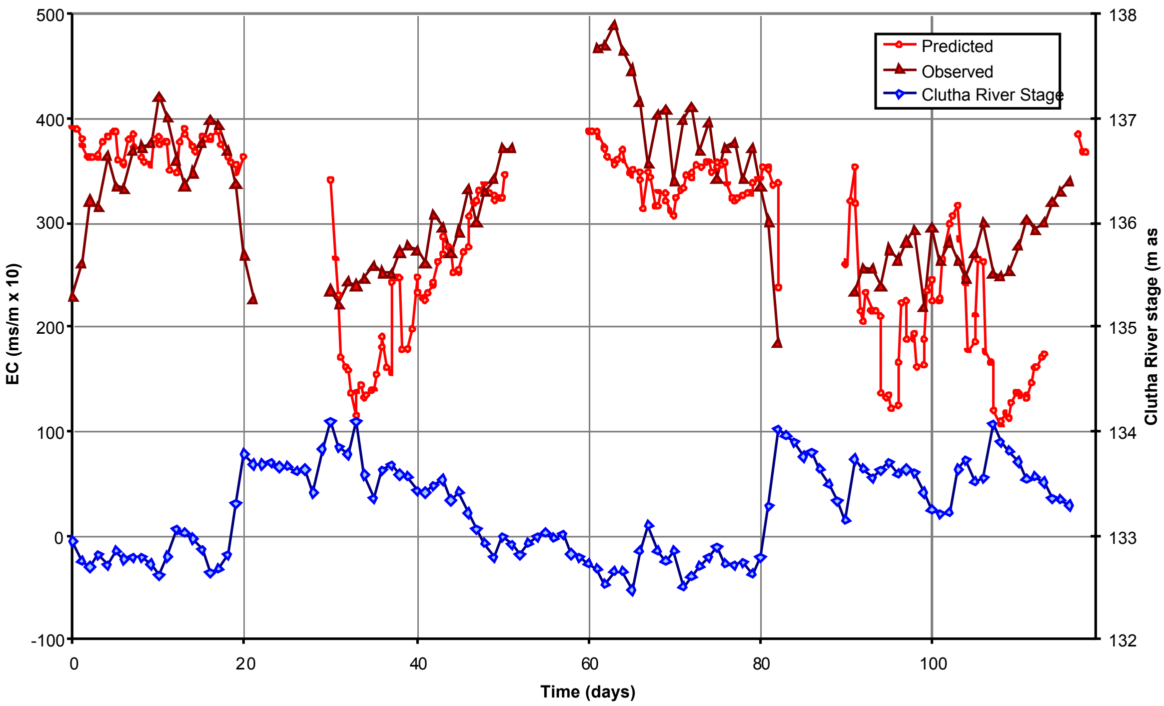

Figure 8: Observed and model wellfield EC response to river stage changes

The calibrated model was used to investigate the generally low proportion of river water in the wellfield. Increasing the hydraulic gradient to a value of the order recorded to the north of the town yielded a significant increase in the predicted wellfield hardness, to around 180 – 200 mg/l $CaCO_3$. Analysis of model results also indicated that the configuration of the current wellfield is likely to be a contributory factor to high hardness levels.

3.4 DISCUSSION

Saturation index calculations and geochemical modelling of lime scale deposition in water heaters provided a target blend of river water and groundwater that should yield a satisfactory hardness level in the town water. Analysis of EC data recorded by the SCADA system indicates that the average river water proportion would need to double to achieve the target blend.

The channel sedimentation and riverbed clogging study indicated that the riverbed adjacent to the wellfield is clogged to some degree, as would be expected. Shear stress calculations indicate that the riverbed adjacent to the current wellfield site has a high self-cleansing potential. Channel profile data indicate that the channel adjacent to the wellfield is active, with significant erosion and deposition over the monitoring period. Cross sections from upstream and downstream appear to be stable. Shear stress calculations and channel profile data can be used to evaluate self-cleansing properties of the riverbed adjacent to possible new wellfield sites in order to minimise the level of riverbed clogging.

The current wellfield investigation indicated that the groundwater gradient is a key control on the proportion of river water entering the wellfield and hence the hardness of the town supply. Data from the area to the north of the town indicate higher gradients here, meaning that hardness levels in a new wellfield installed here could be worse than the current supply.

The location of the current wellfield therefore appears to offer some benefits in terms of riverbed self cleansing capacity and the groundwater gradient towards the river. Options to re-engineer the current wellfield to improve hardness and minimise the contamination risk from the landfill were therefore considered. An engineered barrier comprising sheet piling could potentially be installed and the landward and landfill sides of the wellfield: this could potentially eliminate the transport pathway between the landfill and the wellfield, and also reduce the rate of groundwater inflow. The hydraulic gradient between the river and the wellfield would increase as a result, causing an increase in the rate of river water infiltration. This increase in river water inflow would increase the particle velocities between the river and the wellfield, however, and could potentially result in a significant increase in turbidity. A methodology has been proposed to address this issue, involving modelling turbidity using a retardation coefficient. Although such an approach would represent a gross simplification of filtration processes, it may provide a useful initial insight into the viability of this option.

Development of a hydraulic barrier/aquifer recharge system, comprising pumping Clutha River water to infiltration basins on the landward side of the wellfield has been put forward as an alternative option. The infiltrating river water would be naturally filtered and would both flow directly to the wellfield and provide groundwater mounding beneath the basin, thereby reducing the rate of groundwater inflow. The nest result would be a reduction in wellfield hardness. The feasibility of both of these options could be readily assessed using the numerical model developed as part of this study. The Alexandra Water Supply Project is still in progress at the time of writing; investigation of the wellfield re-engineering options is currently under consideration.

4 CONCLUSIONS

The treatment properties of the aquifer system at Woodbourne could be maximised through further assessment of likely turbidity levels in the aquifer at the location of the proposed new well. Development of the proposed new water source should include investigation of turbidity levels, and the potential to increase the screen installation depth in order to avoid high turbidity horizons. Development of a low turbidity source would allow the UV treatment plant to deliver the three log treatment credits; this in turn would achieve protozoal compliance under DWS. Significant capital and operation cost savings would be delivered compared to the alternative filtration plant option.

Turbidity data from the NZDF Woodbourne Base wells could be analysed to provide further insights into the local groundwater system. For instance, the apparently high particle velocities suggested by the turbidity breakthrough curves have potential implications for source protection.

The Alexandra Water Supply Project is still in progress at the time of writing, and options for either development of a new wellfield or re-engineering the existing wellfield are currently under consideration. For a new wellfield site, the treatment properties of the natural environment at Alexandra could potentially be optimised through:

- Selection of a site with a low hydraulic gradient towards this river: this would maximise the proportion of low hardness river water drawn into the wellfield;

- Configuration of the wellfield such that particle velocities between the river and the wellfield are minimised; this would maximise natural filtration in the riverbank and aquifer material;

- Utilisation of riverbed sedimentation data and shear stress calculations to select a site with a high river bed self-cleansing potential.

If re-engineering the existing wellfield is the preferred option, the engineering design should focus on minimising particle velocities through the riverbank material in order to maximise natural filtration. The re-engineering should be based on a comprehensive understanding of the local hydrogeological system to maximise chances of successfully reducing hardness to acceptable levels and mitigating the risk of contamination from the landfill.

In either instance, riverbank filtration qualifies for up to 1 log credit under the New Zealand Drinking Water Standards, if a number of stringent criteria are met. If a low turbidity source could be developed, UV treatment and riverbank filtration could potentially provide a cost effective means to achieving DWS compliance for the Alexandra town supply.

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