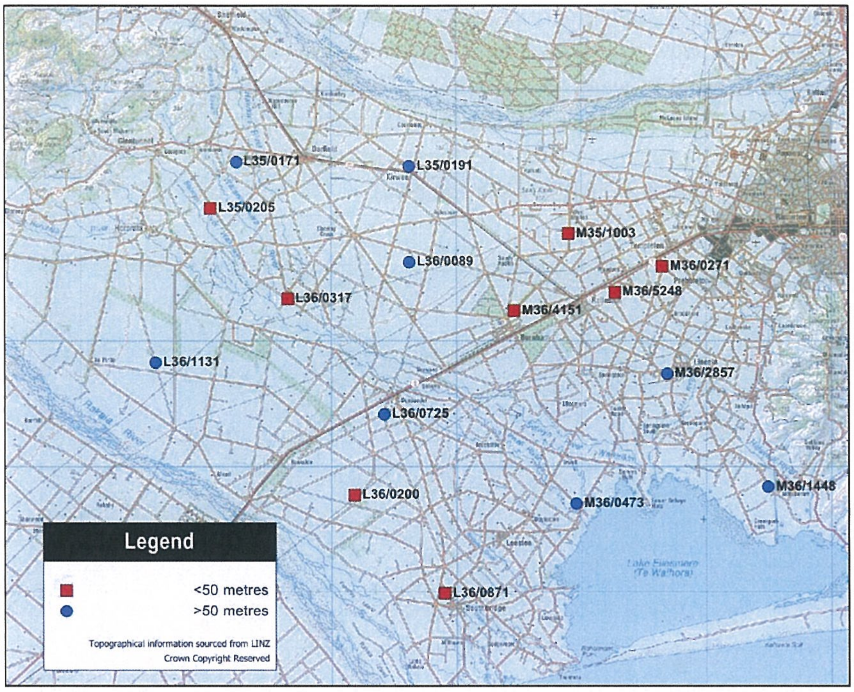

Figure 27. Location of wells used to illustrate the temporal variations in Nitrate-N concentrations shown in Figure 25 and Figure 26.

2.4. Baseline groundwater Nitrate-N concentrations

2.4.1. Current baseline

As discussed in **Section 2.2**, groundwater quality varies not only spatially and with depth across an aquifer system but also over time. The following section attempts to quantify current baseline water quality in the Central Plains area in terms of the spatial and depth distribution of observed Nitrate-N concentrations since 2010, as well as longer term (8-year) temporal trends measured since 2004.

Figure 28 and **Figure 29** show maps of the median and maximum observed Nitrate-N concentrations recorded in the Environment Canterbury groundwater quality database between January 2010 and June 2013. These data show an overall median Nitrate-N concentration of 5.3 mg/L (5.9 mg/l in wells <50 metres and 3.6 mg/L in wells >50 metres). The data also show Nitrate-N concentrations exceeded the DWSNZ MAV of 11.3 mg/L Nitrate-N in 20 samples (3% of samples collected) at a total of 11 sites (8% of wells sampled). A total of 278 samples (43%) exhibited concentrations exceeding 50% of MAV at a total of 54 sites (38% of wells sampled).

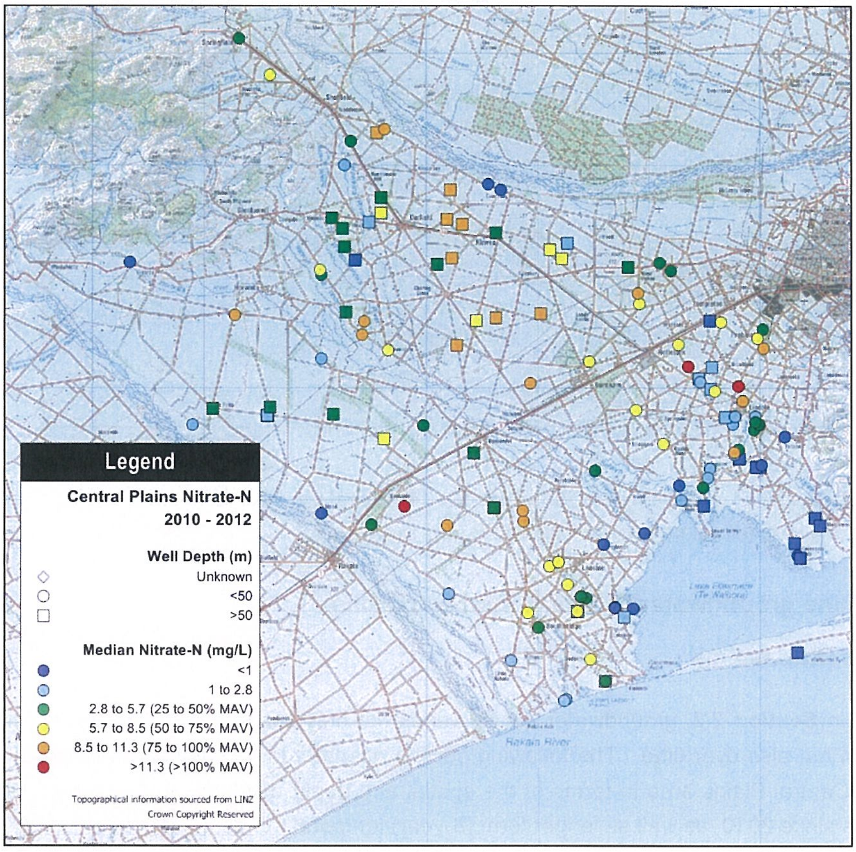

Figure 28. Median Nitrate-N values 2010 to 2013

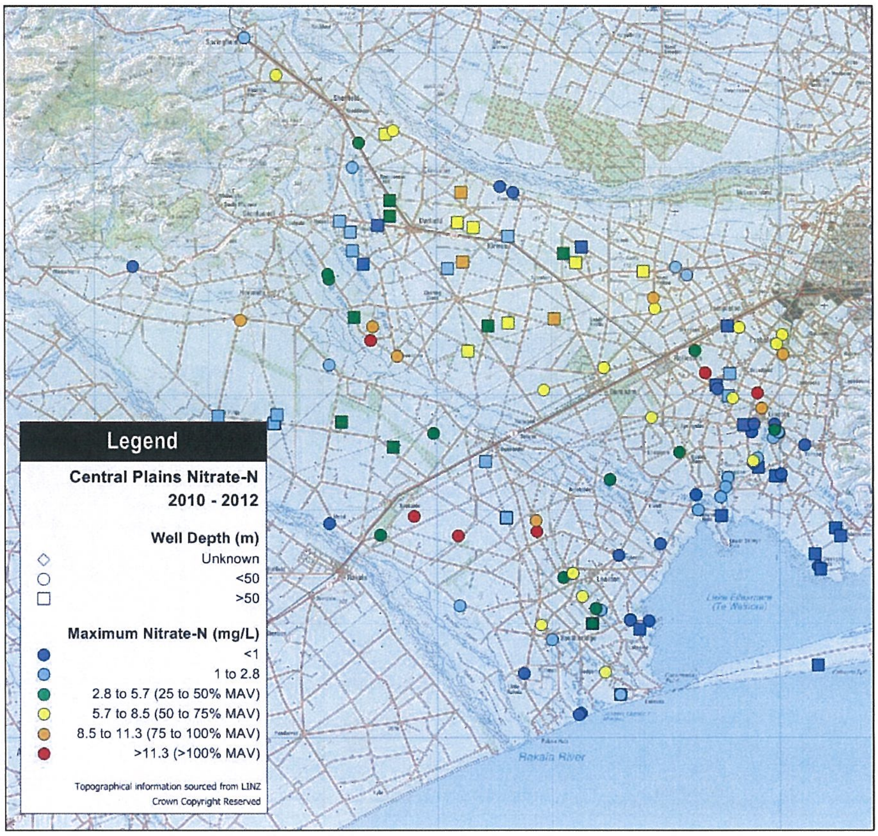

Figure 29. Maximum Nitrate-N concentrations 2010 to 2013

Figure 30 shows an interpolated coverage of median Nitrate-N concentrations measured between January 2010 and June 2013 in wells less than and greater than 50 metres deep. These figures are inferred to approximate current the baseline in terms of the spatial and depth distribution of Nitrate-N concentrations. As noted **in Section 2.3**, the spatial distribution of Nitrate-N is likely to evolve over time as the groundwater system equilibrates to current and future nutrient inputs and other factors (such as climate) which influence temporal variability in groundwater quality.

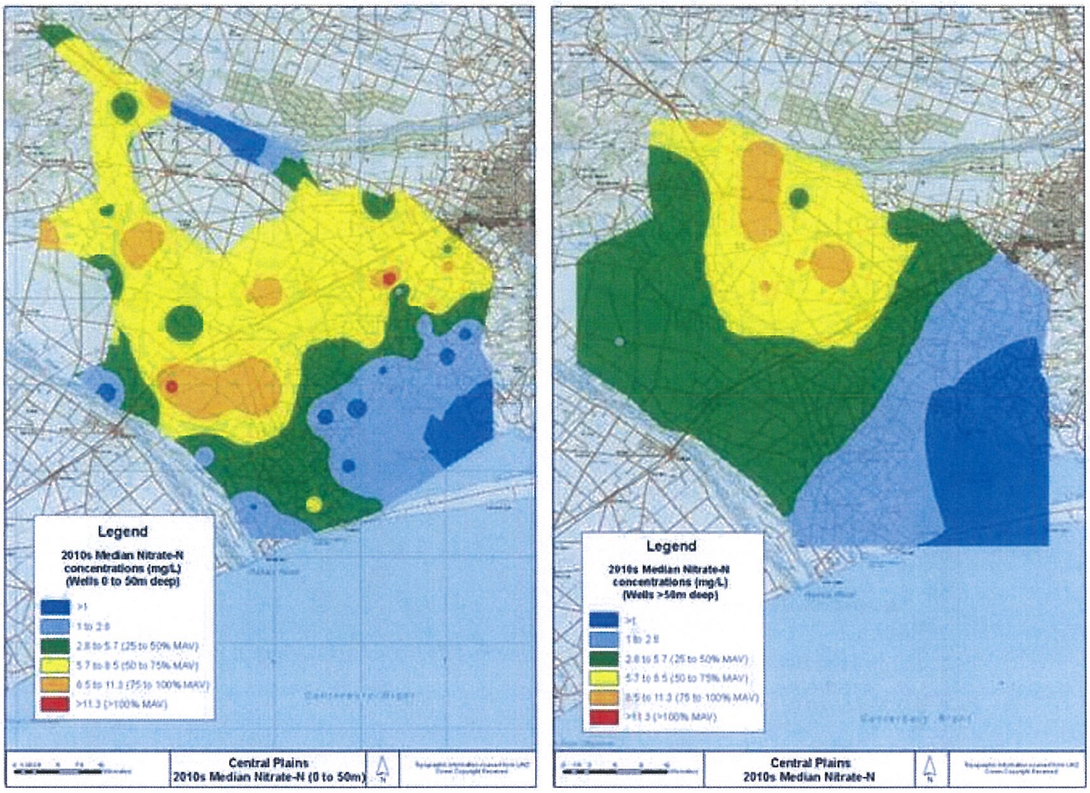

Figure 30. Spatial distribution of 2010 to 2013 median Nitrate-N concentrations in wells <50 metres (left panel) and >50 metres (right panel)

In order to characterise the nature and rate of change in groundwater Nitrate-N concentrations, data from the Environment Canterbury groundwater quality database were analysed using the spreadsheet developed by Daughney (2007). This analysis utilises Sen's slope estimator to quantify temporal trends detectable with the Mann-Kendall test at the 95% confidence interval. A length of 8 years was selected for the analysis to incorporate a number of wells added to the current Environment Canterbury monitoring network in the mid-2000s and ensure calculated trends reflect observed changes in groundwater quality over recent years (rather than historically).

Temporal trends in Nitrate-N concentrations were assessed in a total of 55 wells distributed across the Central Plains area. As listed in Table 4 below, of the wells analysed, a total of 22 (40%) exhibited an increasing Nitrate-N trend with one bore (2%) exhibiting a decreasing trend. The balance of the wells analysed showed no statistically significant trend over the period analysed. Of the wells exhibiting an increasing trend the calculated rate of increase ranged from 0.02 mg/L/year to a maximum of 0.53 mg/L/year[4].

[4] It is noted that for a number of the wells analysed, longer-term trends (i.e. using 10 years+ of available record) exhibit a significantly different magnitude than that calculated for the 2005 to 2013 period.

Figure 31 shows the spatial distribution of wells analysed for temporal trends. The figure indicates a significant number of wells across the mid to lower plains exhibit increasing trends, particularly those less than 50 metres deep. Similarly, increasing trends in deeper bores (>50 metres) are generally observed across the mid to upper plains. This pattern is consistent with the decadal changes in median Nitrate-N concentrations illustrated in the previous section.

Table 4. Temporal trends in Nitrate-N concentrations for wells located in the Central Plains area (2005 to 2013)

Well	Depth (m)	Trend	Magnitude ($g/m^3/year$)
L35/0205	28	Increasing	0.20
L36/0089	68.6	Increasing	0.47
L36/0200	30.8	Increasing	0.47
L36/0224	10.6	Increasing	0.33
L36/0319	85	Increasing	0.20
L36/0871	8	Increasing	0.20
L36/1131	107	Increasing	0.16
L36/1313	120	Increasing	0.28
L36/2122	82.4	Increasing	0.20
L37/0555	6.7	Increasing	0.30
M35/5918	36	Increasing	0.14
M36/0153	14.6	Increasing	0.53
M36/0698	25	Increasing	0.18
M36/2285	36.6	Increasing	0.36
M36/2857	86	Increasing	0.05
M36/3139	34.9	Increasing	0.04
M36/3712	18	Increasing	0.02
M36/4126	34.1	Decreasing	-0.22
M36/4227	12	Increasing	0.14
M36/5248	32	Increasing	0.06
M36/5255	24	Increasing	0.12
M36/7734	30	Increasing	0.20
M37/0462	42	Increasing	0.03

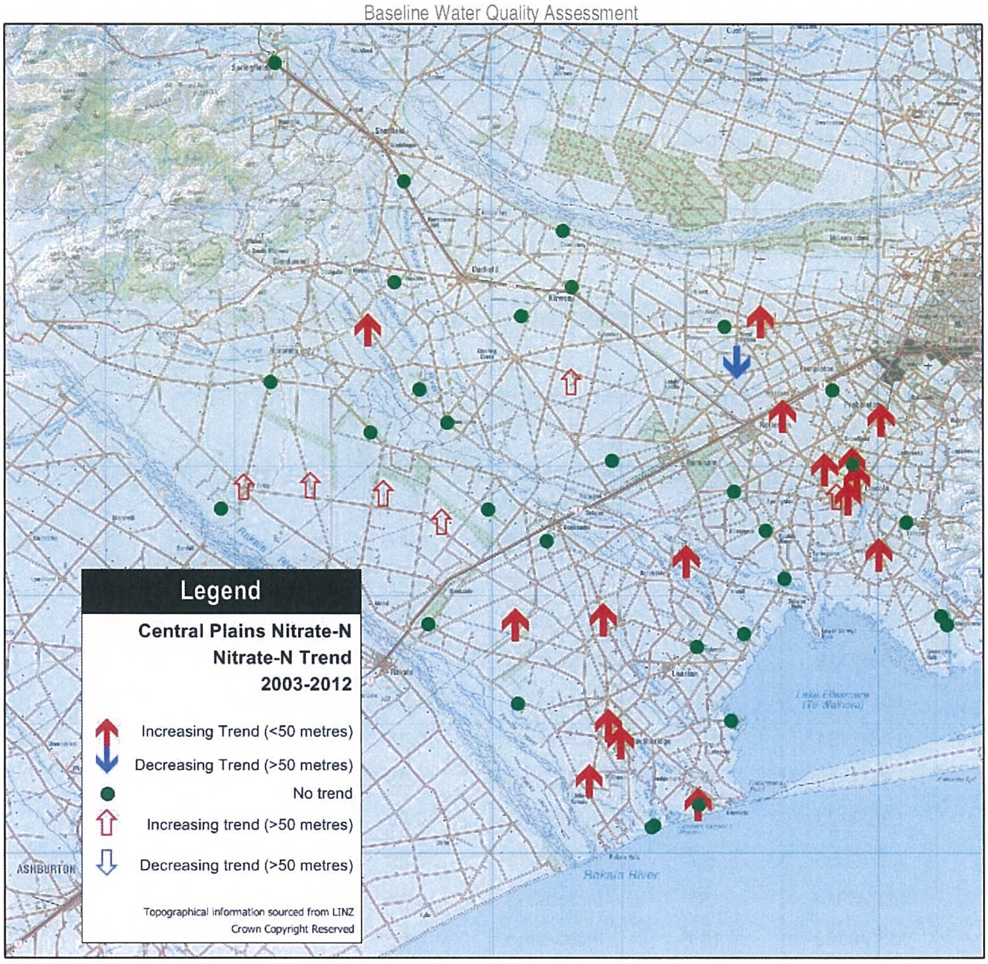

Figure 31. Calculated trends for Nitrate-N concentrations in the Central Plains area, 2005 to 2013

2.4.2. Future baseline groundwater Nitrate-N concentrations

Work undertaken for the Environment Canterbury Selwyn Waihora zone limit setting process includes assessment of the likely impact of a range of future land use scenarios on a range of environmental, economic and cultural values. The scenarios modelled included an evaluation (Scenario 1) of the continuation of existing (2011) land use over a modelling period to 2040. This scenario was intended to explore the impact of current land use on water quality and quantity, accounting for lag times in the system (particularly those associated with unsaturated and saturated zone processes discussed in **Section 2.2** above). This scenario provides a future baseline for water quality in the Central Plains area under current land use so provides the best approximation of future water quality in the absence of the CPWL scheme[5].

Analysis of Scenario 1 using the AquiferSim model indicates that nitrate-N concentrations can be expected to increase by up to 32% over current levels as the groundwater system equilibrates to

[5] Although in reality land use is dynamic and will evolve over time in response to changing social, economic and regulatory factors even in absence of the CPWL development.

inputs from existing land use. This is consistent with the prevalence of increasing Nitrate-N concentrations observed in recent monitoring data (described in the preceding section).

Based on this assessment, **Table 5** provides an indication of the percentage of sites likely to exceed nominated Nitrate-N thresholds (in terms of % MAV) under the projected future baseline groundwater quality scenario. **Figure 32** provides an illustration of the projected change in the frequency distribution of median nitrate concentrations between current and projected future baseline groundwater quality.

Table 5. Percentage of sites exhibiting median Nitrate-N concentrations above nominated thresholds (% MAV) for current and future baseline water quality.

	Wells <50 metres		Wells >50 metres		All wells	
Reference Criteria	Current	Future Baseline	Current	Future Baseline	Current	Future Baseline
11.3 mg/L Nitrate-N (MAV)	4	21	0	15	2	19
8.5 mg/L Nitrate-N (75% MAV)	21	38	15	19	19	30
5.7 mg/L Nitrate-N (50% MAV)	43	56	23	33	35	45
2.8 mg/L Nitrate-N (25% MAV)	63	71	52	55	58	63

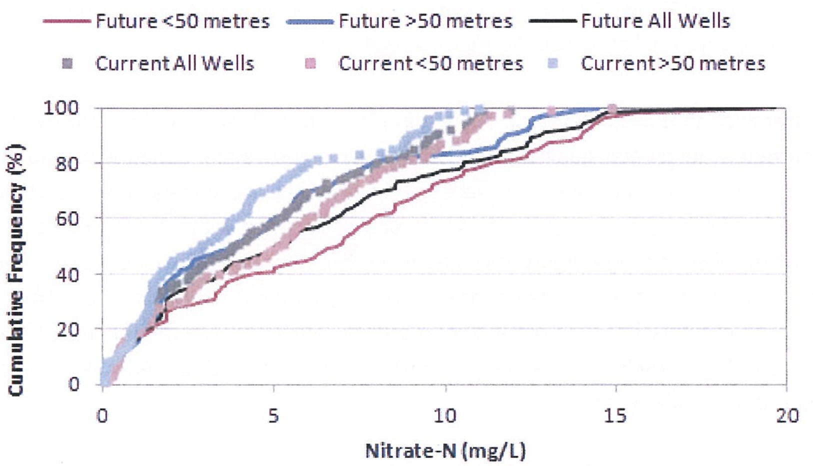

Figure 32. Change in the frequency distribution of median groundwater Nitrate-N concentrations between current and future baseline groundwater quality.

Figure 33 shows a plot of projected future baseline median Nitrate-N concentrations based on the observed distributions from samples collected between January 2010 and June 2013 produced by multiplying the calculated post-2010 decadal coverage shown in **Figure 21** by the projected change in concentrations under Scenario 1.

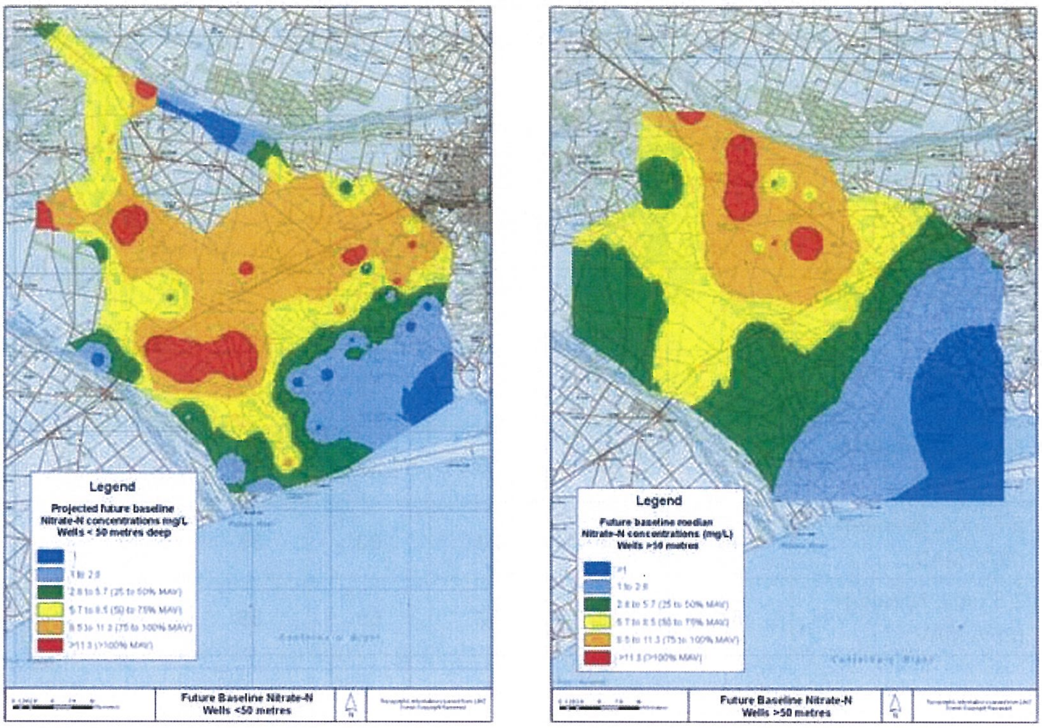

Figure 33. Projected future median baseline Nitrate-N concentrations in wells <50 metres (left panel) and greater than 50 metres (right panel)

It is noted however that projections of future baseline groundwater quality represent an indicative change in current groundwater quality under essentially 'steady-state' conditions. Due to the range of factors influencing spatial and temporal variation in groundwater quality (discussed in **Section 2**), actual changes in future baseline groundwater in any given point within the aquifer system may vary considerably from the 'average' figure calculated by this assessment. Given the complexity of the hydrogeological system and associated contaminant and recharge inputs, such uncertainty is inherent in any projections of future baseline groundwater quality. However, the model projections do however provide a means to characterise the likely magnitude of the overall change in groundwater quality likely to occur at an aquifer scale.

2.4.3. Defining baseline Nitrate-N concentrations

It is noted that the projected future baseline Nitrate-N concentrations illustrated in the preceding section differ from those calculated for the Scenario 1 in Robson *et al.* (2012). This reflects the use of all Nitrate-N data held on the Environment Canterbury groundwater quality database to calculate

median values in this report compared to a subset of wells (the 17 wells sampled on a quarterly basis by Environment Canterbury in the Central Plains area).

This highlights a particularly important point that any statistical measure of groundwater quality in the Central Plains area is highly dependent on the depth and spatial distribution of sampling sites contained in the data set utilised. For example, Figure 34 compares the frequency distribution of Nitrate-N concentrations calculated from all samples collected in the Central Plains area between January 2010 and June 2013 with that derived from the quarterly Environment Canterbury monitoring sites. Clearly there is a significant difference in the statistical distribution of the two data sets with a median Nitrate-N concentration of 5.2 mg/L from all wells sampled compared with 7.2 mg/L from the quarterly monitoring sites. This difference is interpreted to reflect the quarterly monitoring sites mainly comprise wells less than 50 metres deep located on the mid to upper plains.

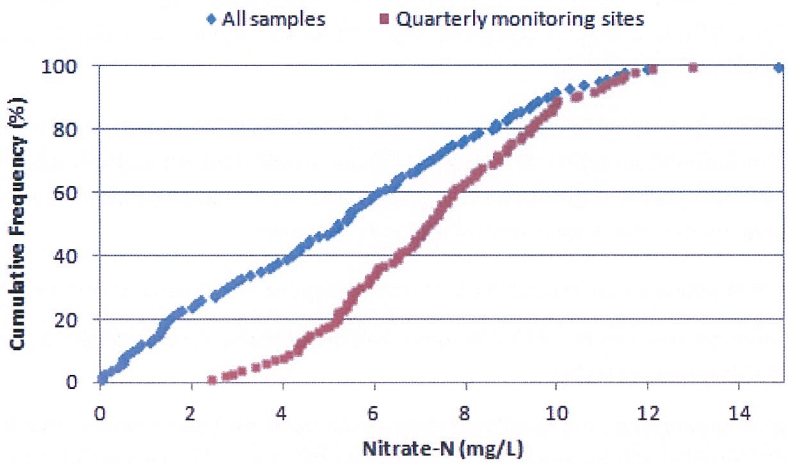

Figure 34. Cumulative frequency plot comparing Nitrate-N concentrations in all wells sampled between January 2010 and June 2013 with that observed in Environment Canterbury quarterly monitoring sites over the same period.

With regard to determining the impact on groundwater quality resulting from a particular pattern of land use change (such as the development of the CPWL scheme), this observation highlights the importance of sampling a consistent set of monitoring bores which can be utilised to quantify the relative change in groundwater Nitrate-N concentrations over time. However, the exact grouping of wells selected for monitoring to identify such changes may depend on both the location and nature of the activity being undertaken and the particular resource management issue being addressed. For example:

- Given that a significant component of the CPWL scheme area overlies areas where the mean water table depth is greater than 50 metres below ground, establishing localised impacts may require sampling of deeper wells situated within and down gradient of the command area;

- Given the relatively complex nature of groundwater flow it may be difficult to directly attribute observed changes in Nitrate-N concentrations in shallower wells situated in the mid-plains area to land use occurring further up the plains;
- To determine potential impacts on groundwater utilised for potable (stock, domestic and public) water supply, wells utilised to determine changes in Nitrate-N concentrations should be selected to reflect the spatial and depth distribution of existing water supply abstraction;
- To characterise potential effects on the surface water environment, monitoring wells should include a mix of shallow and deeper bores distributed across the lower plains.

As previously noted, groundwater quality at any point within the Central Plains aquifer system reflects a complex interaction of a range of factors including land use across the contributing recharge area, temporal variations in recharge flux and the complex nature of groundwater flow through the unsaturated and saturated zones (including changes in natural groundwater flow induced by groundwater abstraction). It is therefore critical that any monitoring programme initiated to determine the effects of the CPWL scheme is designed in a manner which can be utilised to address relevant resource management issues.

However, given the inherent spatial, depth and temporal variability of groundwater quality, even with a well designed monitoring programme it may be difficult to differentiate impacts associated with the CPWL scheme from baseline groundwater quality variations. Identification of such impacts may therefore require the use of a combination of methods including:

- Analysis of temporal variations in Nitrate-N concentrations in individual monitoring wells;
- Analysis and comparison of statistical measures of Nitrate-N concentrations between individual wells and sub-groups of wells;
- Utilisation of quantitative and qualitative data which describe factors which have the potential to contribute to spatial and temporal variations in groundwater quality including actual and modelled nutrient losses, temporal and spatial variations in land use, recharge flux and groundwater level variations. Collection of such data is likely to be of critical importance to enable reliable interpretation of groundwater quality monitoring data.

2.4.4. Maximum Nitrate-N concentrations

As described in **Section 2.2**, Nitrate-N concentrations in some areas of the Central Plains area exhibit significant temporal variability in response to the complex influence of natural (e.g. climate) and anthropogenic factors (e.g. land use and groundwater abstraction) which influence groundwater quality.

As illustrated in **Figure 29**, at the current time a limited number of wells sampled by Environment Canterbury in the Central Plains exhibit Nitrate-N concentrations exceeding the MAV (11.3 mg/L). Across the entire groundwater quality data set (1960 to 2013) approximately 6 percent of samples

analysed exceed the MAV threshold[6]. The rate of exceedance in more recent data tends to be much lower with 3.6% of samples collected between 2000 and 2013 exhibiting concentrations greater than 11.3 mg/L and 3.1% of samples analysed between 2010 and 2013 exceeding this value.

A review of the available water quality data indicates that current (or at least recent historic) exceedances of MAV tend to be of short duration (typically <1 year depending on sampling frequency) and generally appear to be associated with one of three situations:

- Localised contamination associated with inadequate wellhead protection (often associated with the presence of indicator bacteria);
- Elevated Nitrate-N concentrations following episodic recharge events; and
- Wells where background Nitrate-N concentrations approach (or exceed the MAV threshold).

Figure 35 shows a plot of three wells in the Central Plains area which exhibit these characteristics. L35/0009 is a deep well in the Darfield area which exhibited elevated Nitrate-N concentrations (and positive detections for indicator bacteria) until the location of a nearby point source (septic tank) was changed in 2010. M36/4126 shows significant seasonal variations in Nitrate-N concentrations associated with episodic recharge events which increase concentrations by up to 200%. L36/0300 is a well which appears to exhibit a gradual increase in Nitrate-N to a point where concentrations are consistently close to, or above, the MAV.

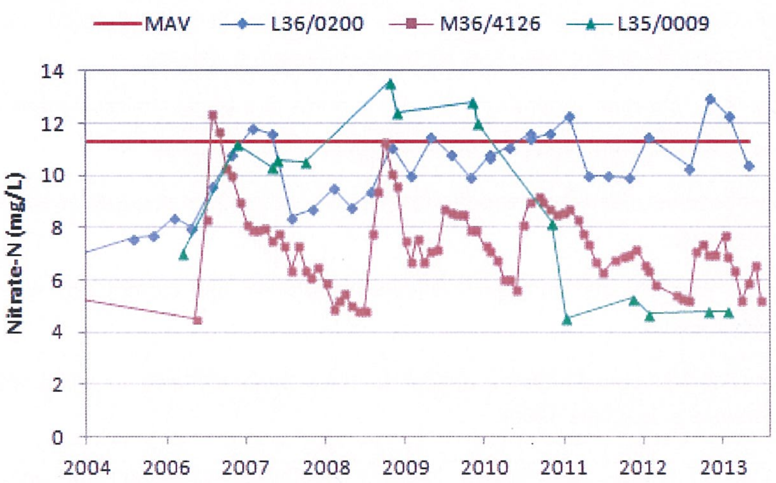

Figure 35. Temporal variations in Nitrate-N concentrations in selected wells in the Central Plains area, 2004 to 2013

As a result of the projected increase in baseline Nitrate-N concentrations (discussed in **Section 4.2.2** above), it is likely that the frequency of MAV exceedance will increase significantly across the Central

[6] Although it is noted that this total includes a significant number of samples collected during the late 1970's and early 1980's which exhibit Nitrate-N concentrations >11.3 mg/L, possibly as a result of inadequate wellhead protection or location of sample sites during this period in and around unsewered townships.

Plains area, particularly in wells <50 metres deep. Given requirements of Condition 31, this has particular significance for the CPWL scheme with regard to the need to provide alternative drinking water supplies where an individual well with a Nitrate-N concentration exceeding 11.3 mg/L supplies water to a dwelling that has infants under the age of six months at the time of the exceedance[7]. In particular, it may be very difficult to differentiate between variations in background nitrate concentrations from those directly associated with the effects of the CPWL scheme or resulting from poor wellhead protection. While ECan and CPWL monitoring can provide a general indication of likely Nitrate-N concentrations in a given area, the actual concentrations occurring in any individual well tend to be highly location specific.

Appendix 1 provides a listing of all wells recorded on the Environment Canterbury groundwater quality database which have exhibited Nitrate-N concentrations exceeding 11.3 mg/L in at least one sample.

2.5. Summary

The assessment of baseline groundwater quality outlined in the preceding section indicates that:

- Groundwater quality varies temporally, spatially and with depth across the Central Plains. The timing and magnitude of such variations are influenced by a complex interaction between natural physical and chemical processes in the unsaturated and saturated zone, exacerbated by the cumulative effects of overlying land use and groundwater abstraction. As a consequence, temporal variations in groundwater quality vary significantly between individual wells. This makes it challenging to interpret groundwater quality data with a view to:
    - Characterising 'baseline' groundwater quality in terms of a single statistical measure;
    - Correlating observed groundwater quality between individual wells;
    - Relating observed changes in groundwater quality to specific changes in land use in the surrounding area;
    - Interpreting localised and cumulative effects of historical and current land use on overall groundwater quality.
- Groundwater Nitrate-N concentrations appear to have been elevated in some areas of the Central Plains since at least the 1970s;
- Wells less than 50 metres deep appear to show a relatively consistent increase in median Nitrate-N concentrations from the 1970s to the present day. The largest increases (>4 mg/L)

[7] The current limit of 11.3 mg/L Nitrate-N specified in the Drinking Water Standards for New Zealand (2005) is established to protect against acute (short-term) effects associated with methaemoglobinaemia in bottle-fed infants (http://www.health.govt.nz/system/files/documents/publications/guidelines-drinking-water-quality-management-for-new-zealand-oct13.pdf

over this period appear to have occurred across the mid-Plains with smaller increases noted in lowland areas;

- Nitrate-N concentrations in many shallow wells (<50 metres) exhibit significant short-term variability in response to land surface recharge flux. Periods of increased recharge due to high rainfall (with an unknown contribution from irrigation) tend to be associated with peaks in Nitrate-N concentrations. In many wells this short-term variability tends to be of a significantly greater magnitude than any underlying long-term trends;

- In deeper wells (>50 metres) the magnitude of changes in Nitrate-N concentrations tend to have been relatively minor prior to 2000 but appear to have accelerated in recent years, particularly across the mid to upper plains;

- Current Nitrate-N concentrations vary spatially and with depth across the Central Plains area. Due to this variability any statistical measure of existing groundwater quality is highly dependent on the individual wells included. The current median Nitrate-N concentration from all wells sampled between 2010 and 2013 is 5.9 mg/L in wells <50 metres deep and 3.6 mg/L in wells >50 metres deep (5.3 mg/L in all wells). Approximately 40 percent of wells sampled exhibit a statistically significant increasing trend in Nitrate-N concentrations.

- Baseline Nitrate-N concentrations are projected to increase by approximately 32% as the groundwater system equilibrates to current land use. However, due to the complex nature of groundwater flow and lags within both the unsaturated and saturated zones, any such change is likely to occur over a relatively long time scale and vary considerable in terms of timing and magnitude in individual wells. This is likely to make it extremely difficult to separate effects associated with CPWL scheme development from those associated with the existing groundwater quality 'baseline', at least over the short to medium term.