Table 1. Nitrate-N leaching values for different land use types (relative to a base case). From Lilburne *et al.*, 2010.

Land use/management	Relative ratio
Base = Nitrate-N load (mass) of 4 cows/ha winter off (12.5 mg/L Nitrate-N drainage water concentration, cumulative loss of 50 kg N/ha/year)	
3 cows/ha winter off	75% of base
3 cows/ha winter on	= base
4 cows/ha winter on	= base + 25%
5 cows/ha winter off	= base + 15%
Beef 100% (irrigated)	= base
Sheep 100% (irrigated)	50% of base
Deer 100% (irrigated)	60% of base
Dairy Support (irrigated)	= base + 25%
Dairy Support (dryland)	= base + 25%
Pigs (dryland)	= base

Table 2. Summary of 2011 land use in the Central Plains area (from Robson *et.al*, 2012)

Land Use Type	Area (Ha)	Percentage of Total area (%)
Sheep, beef and deer	123,380	48.4
Dairy and dairy support	49,459	19.4
Arable	28,647	11.2
Horticulture, viticulture	1,375	0.5
Other, lifestyle	16,880	6.6
Forestry	12,597	4.9
Urban, non-productive	22,657	8.9

2.3. Historical groundwater Nitrate-N concentrations

As discussed in Section 1.3, groundwater Nitrate-N concentrations are the primary groundwater quality issue associated with development of the CPWL scheme. To provide consideration for

evaluation of current and future groundwater quality, the following section provides an overview of historical Nitrate-N concentrations in the Central Plains area.

2.3.1. Environment Canterbury groundwater quality data

Assessment of historical groundwater Nitrate-N concentrations in the Central Plains area in this report utilises data stored in the Environment Canterbury groundwater quality database. This data set (to the June 2013) comprises just over 6,000 individual Nitrate-N samples collected from around 870 wells. It is important to note this data set is derived from wells of varying depths, sampled at varying frequencies between the 1950s and late 2012.

Sampling sites

Figure 12 shows the spatial distribution of wells sampled in the Central Plains area. The figure shows a majority of shallower bores (<40 metres) are located east of SH1 or along the Selwyn River reflecting the depth to groundwater illustrated in **Figure 6**. A significant number of intermediate depth wells (40 to 80 metres) are clustered in the West Melton/Burnham area while a majority of wells >100 metres are located in the Darfield/Kirwee and Te Parita area or along the northern margin of Lake Ellesmere.

Figure 13 shows a plot of the depths of wells sampled for Nitrate-N included in the Environment Canterbury groundwater quality database. These data indicate a majority (approximately 70%) of bores sampled are less than 50 metres deep, with Nitrate-N data available from comparatively few bores deeper than 150 metres (approximately 2.5% of the total number of sites sampled). However, as illustrated in **Figure 14**, ongoing development of the groundwater resource has seen an increasing number of deeper bores (100+ metres) drilled, particularly in inland areas. This is reflected in the increasing proportion of deeper wells sampled over time.

Given the potential for vertical differences in groundwater quality due to recharge source and residence time, an arbitrary depth of 50 metres has been adopted in the following section to illustrate relative spatial and temporal changes in shallow and deep groundwater across the Central Plains area.

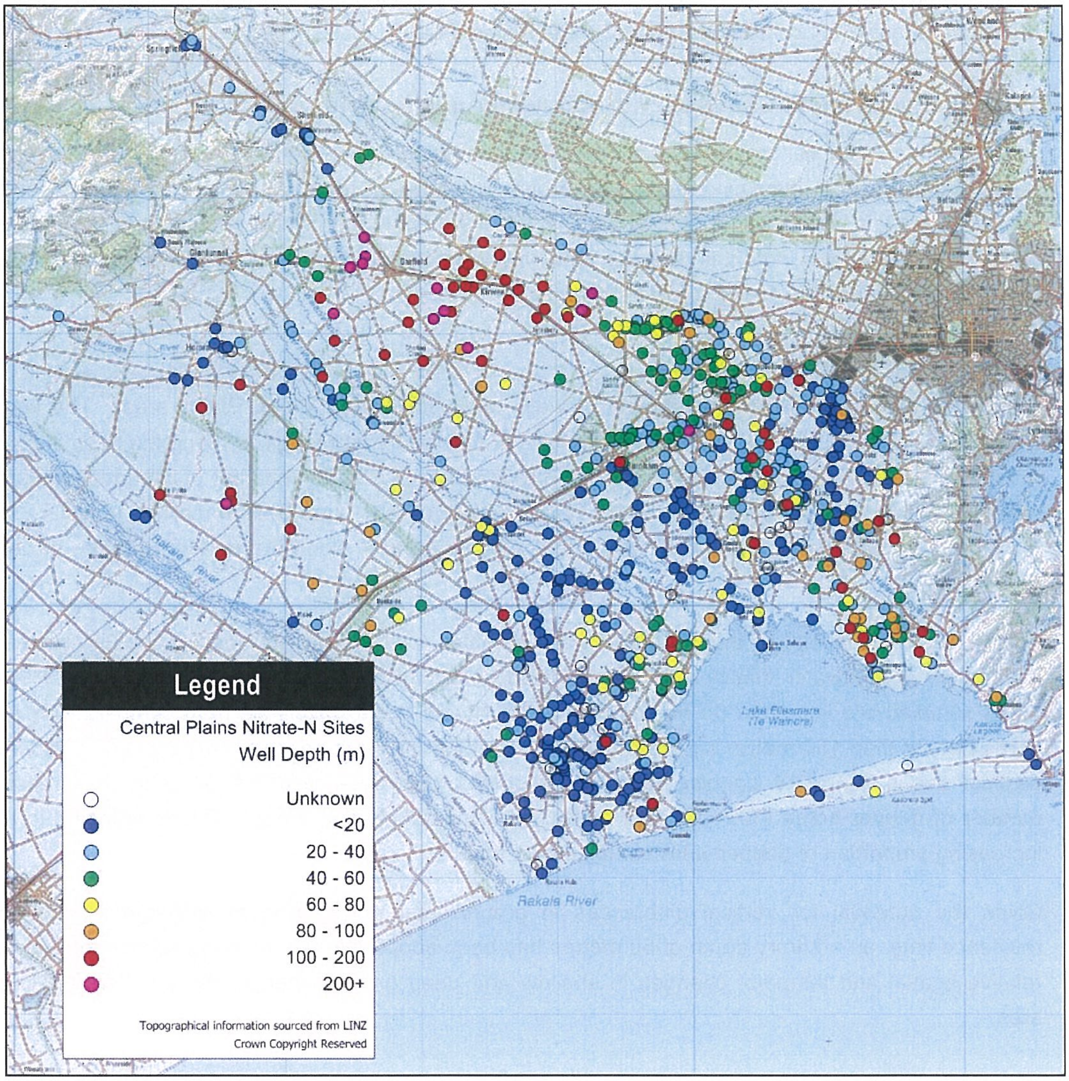

Figure 12. Location and depth of wells sampled for Nitrate-N recorded in the Environment Canterbury groundwater quality database

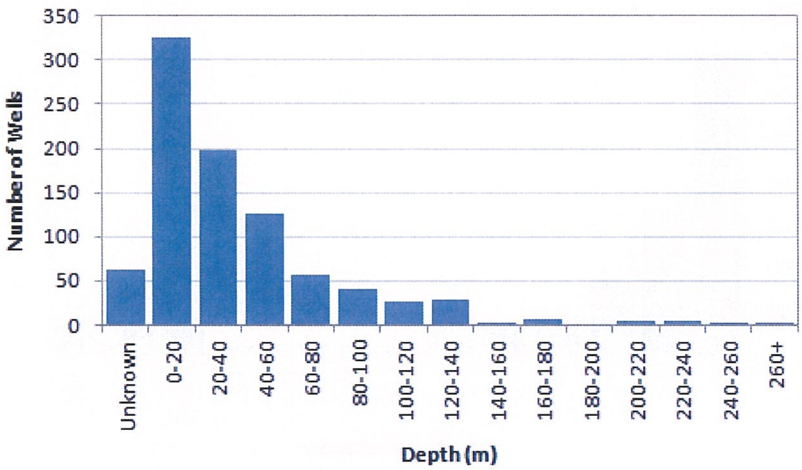

Figure 13. Depth distribution of wells sampled for Nitrate-N included in the Environment Canterbury groundwater quality database

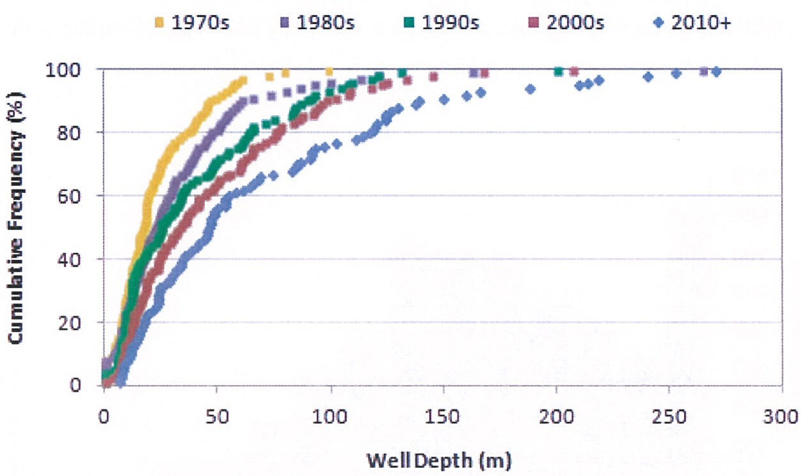

Figure 14. Cumulative frequency plot of the depths of wells sampled between the 1970s and post-2010

Figure 15 shows the sampling frequency for wells for which Nitrate-N data is held on the Environment Canterbury database. The data shows approximately 40% of wells have been sampled on a single occasion, while only 12% of wells have been sampled on more than 10 occasions. Eighteen sites have been sampled on more than 50 occasions and six more than 100 times, with a maximum of 253 samples collected at a single site in the West Melton area.

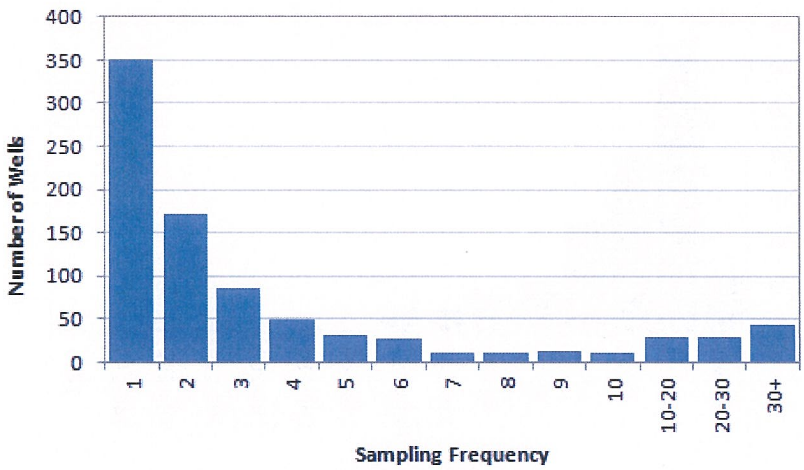

Figure 15. Sampling frequency for wells included in the Environment Canterbury database

Sample results

Figure 16 shows a histogram of Nitrate-N sample results from the Central Plains area between 1950 and 2012. The data show a significant number of samples (13%) with Nitrate-N concentrations less than 1 mg/L, with the remaining samples exhibiting a positively skewed distribution with a median of 5 mg/L.

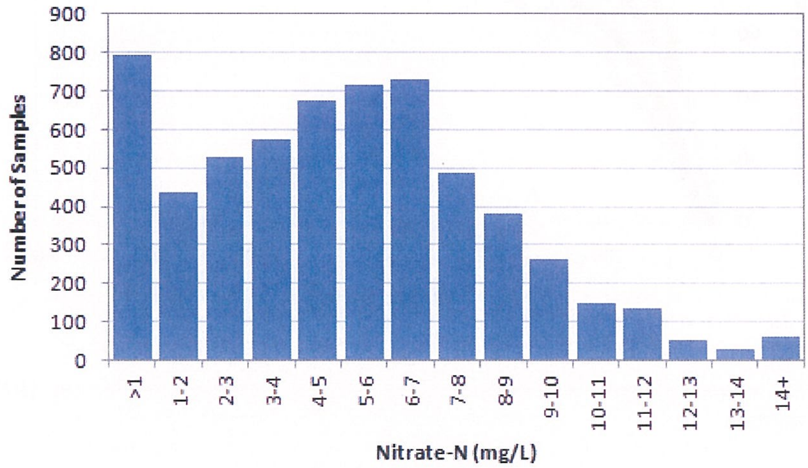

Figure 16. Histogram of Central Plains Nitrate-N sample results

Table 3 provides summary statistics for the Environment Canterbury Central Plains Nitrate-N data, utilising the complete data set as well as arbitrary subdivisions for well depth and time. These data

are also presented in terms of cumulative frequency plots of median nitrate concentrations for wells less than and over 50 metres deep in **Figure 17** and **Figure 18** below.

Table 3. Summary statistics for Central Plains Nitrate-N data held on the Environment Canterbury groundwater quality database. Data are analysed by decade for the complete dataset, as well as separated into <50 metre and >50 metre well depths

Time Period	Sites	Samples	Minimum	Maximum	Mean	Median	20th Percentile	80th Percentile
All Samples								
All	885	6024	0	47	5.1	5.0	2.0	7.7
1950s	5	13	0	2.4	1.2	1.6	0	2.2
1960s	16	19	0	3.6	1.2	1.2	0.3	1.9
1970s	293	1277	0	47	6.0	5.6	2.7	9.1
1980s	429	1091	0	36.9	4.1	4.0	1.3	6.0
1990s	182	1316	<0.01	36.4	4.9	5.2	2.0	7.0
2000s	267	1660	<0.025	15.3	5.4	5.4	2.2	7.8
2010+	141	648	<0.002	14.9	5.3	5.3	1.6	8.6
Wells 0 to 50 m deep								
All	593	4846	0	47	5.3	5.3	2.3	7.8
1970s	247	987	0.05	15	5.5	4.8	2.6	8.7
1980s	316	819	0.001	36.9	4.4	4.1	1.5	6.0
1990s	117	1089	<0.01	36.4	5.1	5.5	2.4	7.1
2000s	158	1221	<0.1	15.3	5.5	5.9	2.5	8.1
2010+	63	451	<0.002	14.9	5.8	5.9	2.5	8.8
Wells >50 m deep								
All	230	950	0	13.6	3.8	3.7	1.0	6.2
1970s	24	119	0.2	12.4	6.1	6.4	4.0	8.7
1980s	81	189	0	9.4	3.0	3.7	0.5	4.5
1990s	52	137	<0.0025	7.8	2.5	2.1	0.6	4.3
2000s	102	309	<0.0025	13.6	4.0	3.7	1.3	6.5
2010+	56	161	<0.1	11.5	4.0	3.6	1.3	8.2

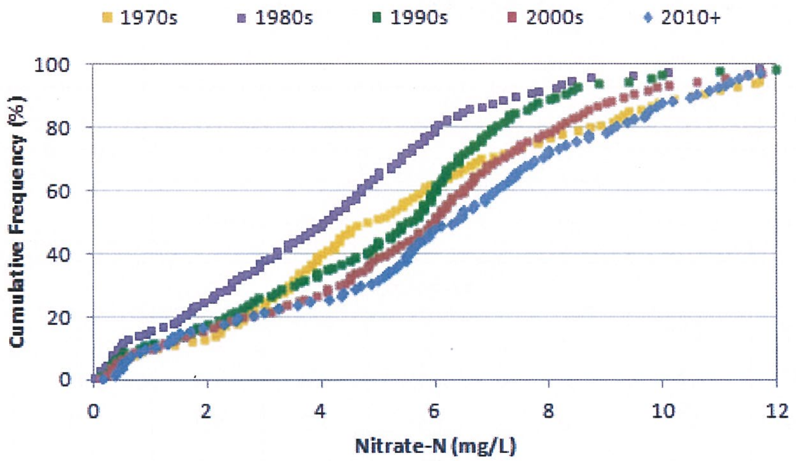

Figure 17. Cumulative frequency plot of decadal mean Nitrate-N concentrations in wells less than 50 metres deep

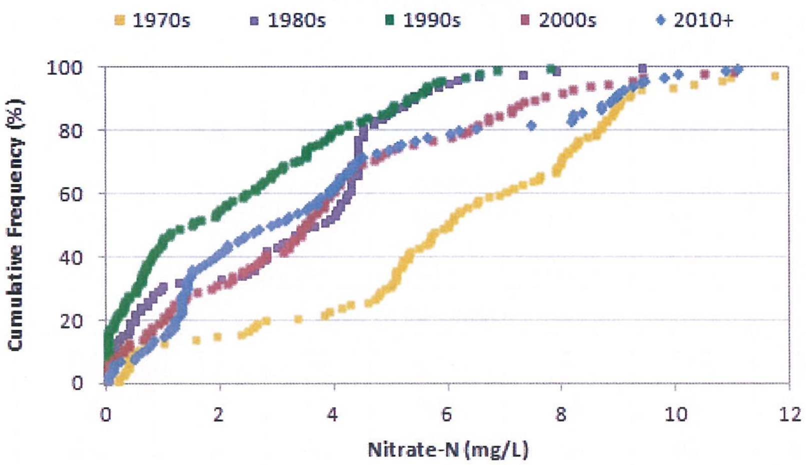

Figure 18. Cumulative frequency plot of decadal mean Nitrate-N concentrations in wells greater than 50 metres deep

Spatial variations in groundwater Nitrate-N concentrations

Figure 17 shows a progressive increase in cumulative nitrate concentrations in wells less than 50 metres deep between samples collected in the 1980s and those post-2010. Despite different combinations of wells being sampled during each decade, the frequency duration curves exhibit a relatively consistent shape. The lower (<10%) of the curve is interpreted to reflect wells receiving a

significant recharge contribution from surface waters containing Nitrate-N concentrations less than 1 mg/L while the apparent deflection in the upper 20% of samples is assumed to reflect an increasing influence from localised contaminant sources. The seemingly anomalous distribution of data from the 1970s is likely to reflect the spatial distribution of wells sampled during this period (further discussed in the following section). In contrast, data from wells deeper than 50 metres exhibit a less uniform distribution which appears to be strongly influenced by the restricted number and spatial distribution of wells sampled.

Figure 19 shows the location and results of Nitrate-N samples collected during the 1950s and 1960s. This relatively limited data set comprises 23 samples from a total of 20 sites generally located in the area south-west of Christchurch (Rolleston/Prebbleton/Lincoln). These data show low to very low Nitrate-N concentrations in all wells sampled with median concentrations of 1.2 mg/L in wells less than 50 metres deep and 1.4 mg/L in wells over 50 metres deep. The maximum recorded concentration was 3.6 mg/L in a 31 metre deep bore at Rolleston.

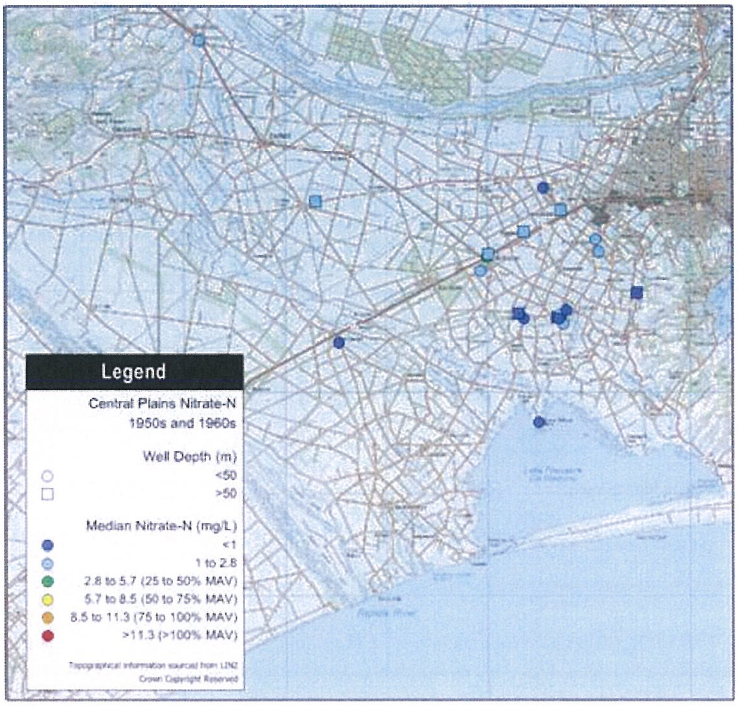

Figure 19. 1950s to 1960s Median Nitrate-N concentrations

Figure 20 shows a plot of median Nitrate-N concentrations recorded during the 1970s. This data set includes a large number of samples collected as part of investigations undertaken by the North Canterbury Catchment Board (NCCB) and Department of Scientific and Industrial Research (DSIR), primarily distributed across the area to the east of SH1.

Observed Nitrate-N concentrations in these samples contrast markedly with the low nitrate concentrations observed in the 1950s and 1960s data. While observed Nitrate-N concentrations were

generally very low (<1 mg/L) around the margins of Lake Ellesmere, significant numbers of bores exhibiting elevated nitrate concentrations are observed elsewhere in the data coverage. In particular, a significant number of bores in the Rolleston/Templeton/Lincoln area exhibited elevated Nitrate-N concentrations >8.5 mg/L (or 75% of MAV). Further inland, the few samples collected indicate a range of Nitrate-N concentrations from 6.5 mg/L near Hororata to less than 1 mg/L at Springfield and Courtenay.

Median Nitrate-N concentrations observed in the 1970s data were 4.6 mg/L in wells less than 50 metres deep and 1.6 mg/l in wells deeper than 50 metres, with approximately 40% of sites showing concentrations in excess of 5.7 mg/L (50% MAV).

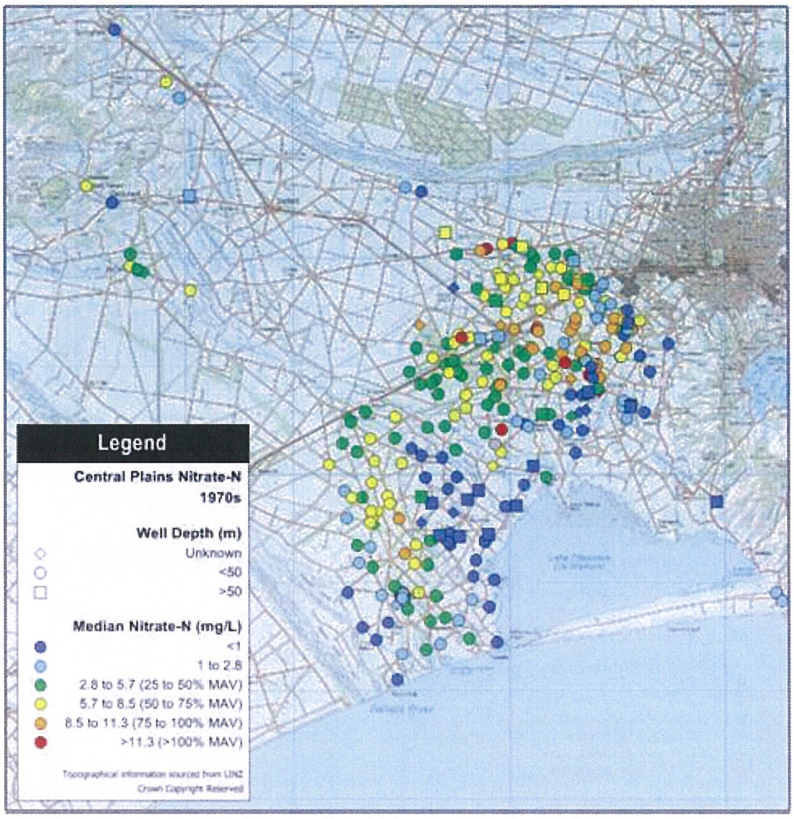

Figure 20. 1970s Median Nitrate-N concentrations

To illustrate spatial variations in groundwater quality across the wider Central Plains area, **Figure 21** shows interpolated decadal median Nitrate-N concentrations in wells less than 50 metres deep between the 1970s and post-2010. The plots were generated by calculating median Nitrate-N values for all sites sampled each decade and interpolating the data by the inverse distance weighted (IDW) methodology using ArcGIS with a mask added to constrain interpolated values to the approximate bounds of the data coverage and exclude areas where the mean depth to groundwater exceeds 50 metres (see **Figure 6**)

Although constrained by the varying spatial distribution of wells sampled over time, the data appear to show a relatively consistent pattern with Nitrate-N concentrations largely below 5.7 mg/L (50% of MAV) in the 1980s. Over subsequent decades, the area of groundwater with Nitrate-N concentrations >50% of MAV gradually expands to occupy a majority of the Central Plains area in the post-2010 data, except for the area immediately surrounding Lake Ellesmere where concentrations decline to less than 2 mg/L. As also indicated on the cumulative frequency plot shown in **Figure 17**, this indicates ongoing increases in Nitrate-N concentrations throughout the Central Plains area since at least the 1980s.

Figure 22 illustrates the relative change in Nitrate-N concentrations between each subsequent decade, and between the 1980s and post-2010 coverages. Possibly reflecting the spatial distribution of wells sampled changes in relative concentrations exhibit a relatively complex pattern over time. However, the 1980 to post-2010 coverage provides a good indication of the relative change in Nitrate-N concentrations in shallow groundwater (<50 metres) over the past 30 years, particularly across the mid-Plains.

Figure 23 and **Figure 24** show equivalent plots of decadal median Nitrate-N concentrations in wells over 50 metres deep. In this case the data appear to show little change between samples collected in the 1980s and 1990s. However, post 2000 there appears to be an ongoing increase in Nitrate-N concentrations commencing in the Darfield/Kirwee area, extending towards Burnham. The data also appear to show an ongoing increase in Nitrate-N concentrations in lowland areas with the extent of groundwater containing low Nitrate-N concentrations (<2.8 mg/L or 25% of MAV) progressively retreating toward the coastline.

Again it must be noted that characterisation of the spatial distribution of Nitrate-N in deeper groundwater is influenced in changes in the number and distribution location of wells sampled over time (e.g. the ongoing trend toward an increasing number of wells >50 m noted in **Figure 14** above). However, the interpolated changes in the spatial distribution of Nitrate-N concentrations in wells >50 metres appears consistent with observed temporal trends discussed in the following section.

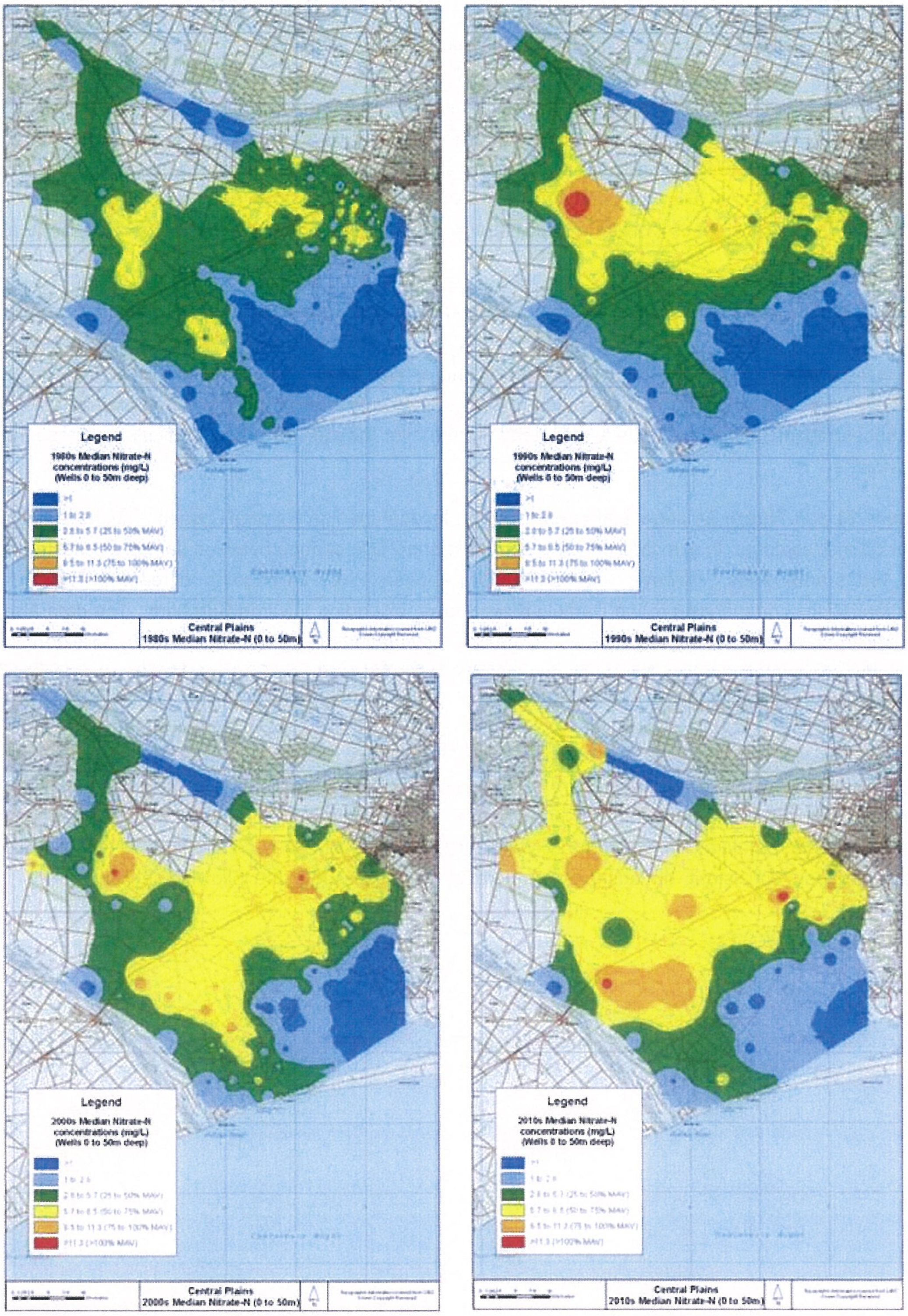

Figure 21. Decadal median Nitrate-N concentrations in wells <50 metres

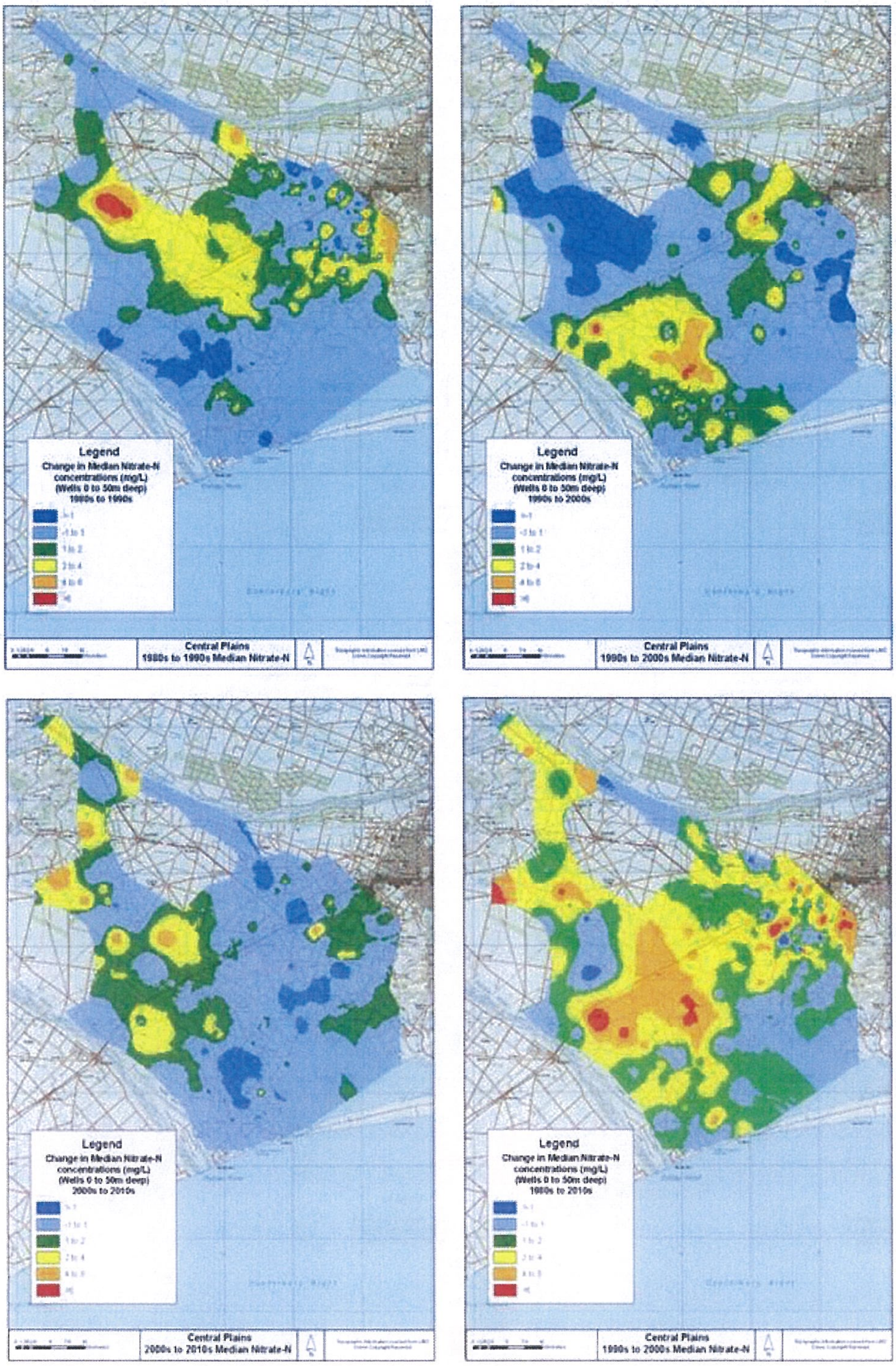

Figure 22. Relative change in decadal Nitrate-N concentrations in wells <50 metres deep, 1980 to post-2010

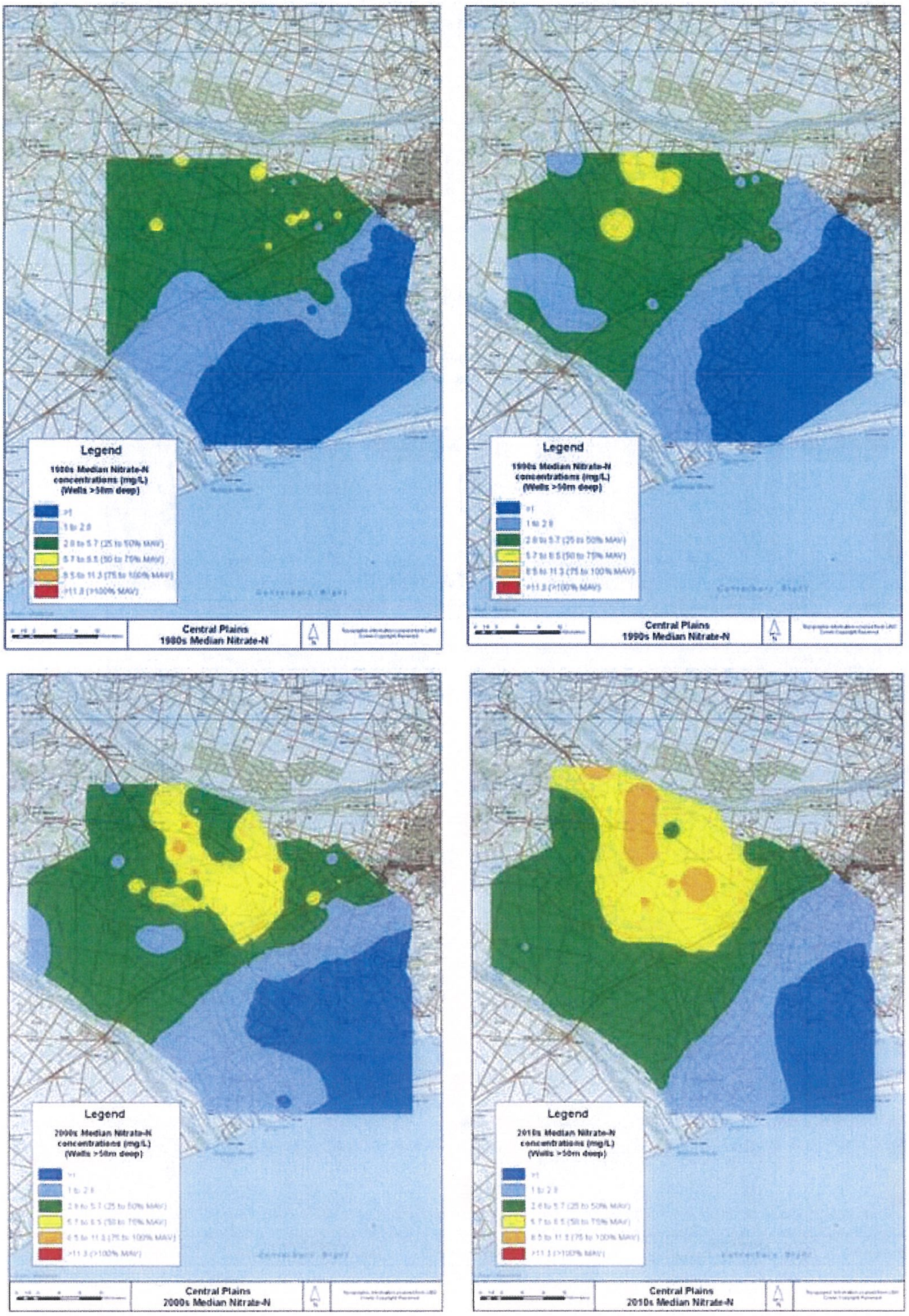

Figure 23. Decadal median Nitrate-N concentrations in wells >50 metres deep

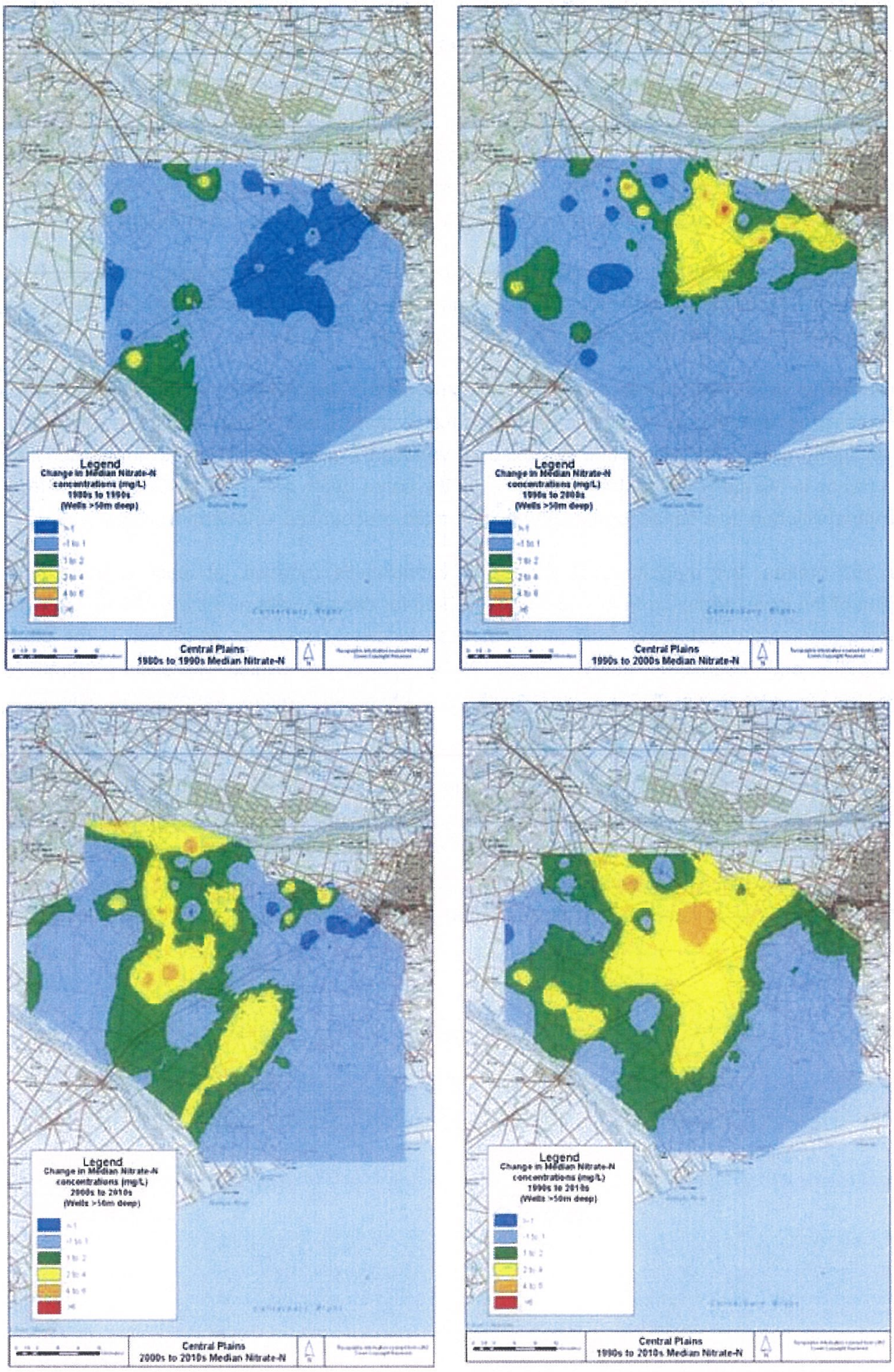

Figure 24. Relative change in decadal Nitrate-N concentrations in wells <50 metres deep, 1980s to post-2010

Temporal variations in Nitrate-N concentrations

As noted in **Section 2.2**, water quality at any given point within a spatially extensive aquifer system such as the Central Plains reflects a complex interaction of factors including land use, climate, geochemistry as well as the physical and hydraulic characteristics of the unsaturated zone across the contributing recharge area and the nature of groundwater flow through the heterogeneous aquifer media. As a consequence, groundwater quality is rarely stable and may vary considerably over time.

To illustrate the nature of the temporal groundwater quality variation, **Figure 25** and **Figure 26** show plots of Nitrate-N concentration over time in a selection of wells distributed across the Central Plains area. The location of the wells illustrated is shown in **Figure 27**.

In general, many wells <50 metres deep west of SH1 exhibit appreciable seasonal variability in Nitrate-N reflecting dynamic variations in land surface recharge and corresponding groundwater levels[3]. In many cases, the magnitude of seasonal variation significantly exceeds any underlying long-term trends in Nitrate-N concentrations. Wells of the same depth east of SH1 tend to show less seasonal variability and as a consequence may exhibit more pronounced long-term trends.

In bores >50 metres, the magnitude of short-term variability is reduced, at least in part, by a combination of the lower sampling frequency typically used for deeper wells and the buffering effect of the overlying saturated/unsaturated zone (depending on location). However, as shown in the plots from L36/0200 and L36/0871, many deeper wells appear to exhibit increasing Nitrate-N concentrations in recent years, consistent with the observed spatial variation in Nitrate-N concentrations illustrated in **Figure 23**.

One important point to note from the plots shown in **Figure 25** and **Figure 26** is that temporal changes in Nitrate-N concentrations are largely unique to individual wells. While similar underlying long-term trends may be present, the exact magnitude and timing of water quality variations can vary considerably between individual sample locations. As a consequence, caution is required when attempting to reliably extrapolate sample results from a given monitoring location (or locations) across the wider aquifer.

---

[3] Groundwater levels in this area may vary by up to 15 metres seasonally

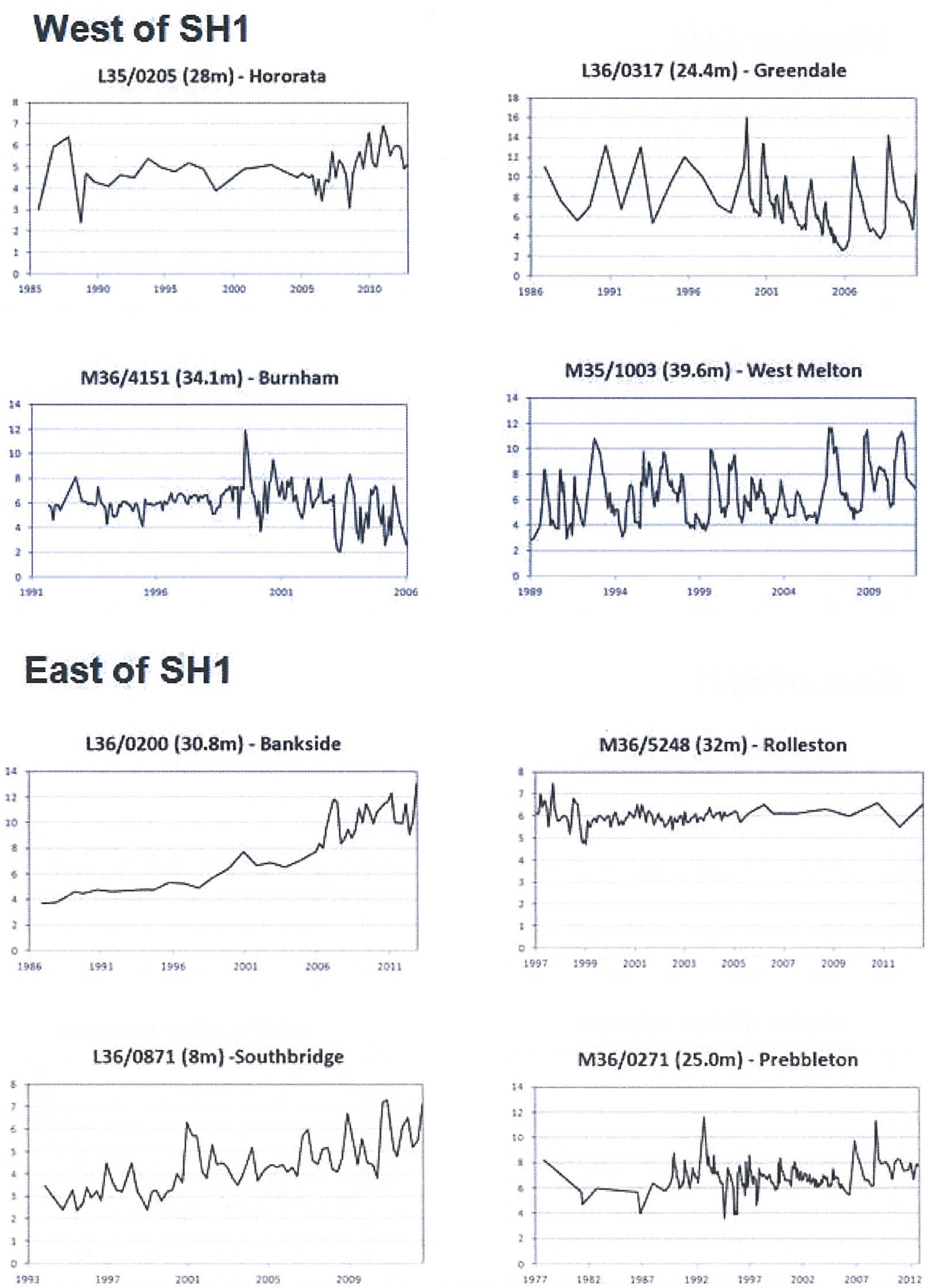

Figure 25. Temporal variation in Nitrate-N concentrations observed in representative wells less than 50 metres deep in the Central Plains area

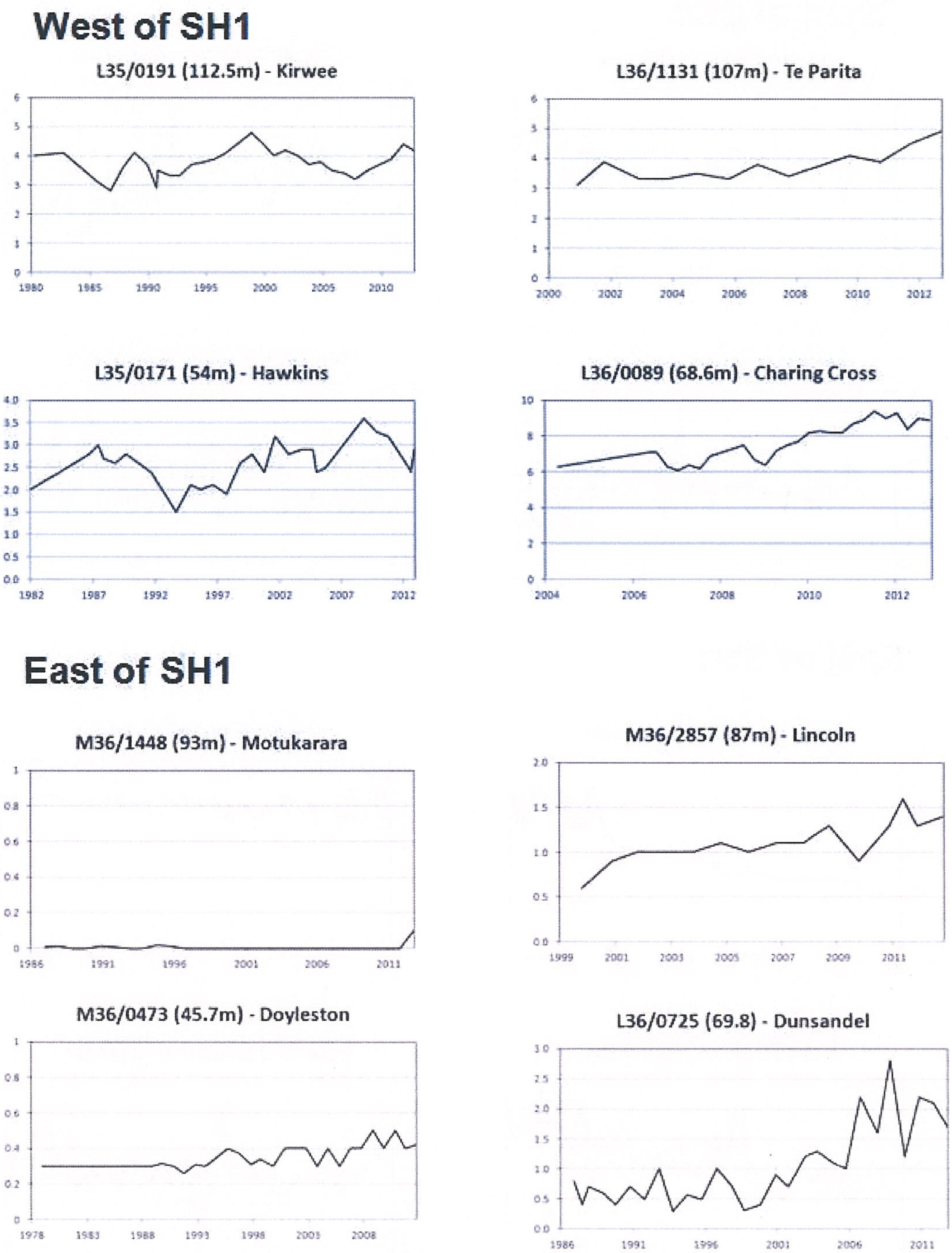

Figure 26. Temporal variation in Nitrate-N concentrations observed in representative wells greater than 50 metres deep in the Central Plains area