

**National Groundwater Quality Indicators Update:
State and Trends 1995-2008**

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**GNS Science Consultancy Report 2009/145
September 2009**

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BIBLIOGRAPHIC REFERENCE

Daughney, C.; Randall, M. 2009. National Groundwater Quality Indicators Update: State and Trends 1995-2008, *GNS Science Consultancy Report 2009/145*. 60p. Prepared for Ministry for the Environment, Wellington, New Zealand.

Prepared for the Ministry for the Environment by GNS Science
September 2009
CR number: 78

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EXECUTIVE SUMMARY

This report provides a summary of groundwater quality state and trends in New Zealand based on data collected from 973 sites over the period 1995 to 2008. The dataset includes sites in State of the Environment (SOE) monitoring programmes operated by regional councils and the National Groundwater Monitoring Programme operated by GNS Science. This report updates a previous report on groundwater quality at the same sites and based on data collected from 1995 to 2006 (Daughney and Wall, 2007).

This report focuses on ambient groundwater quality. Some of the monitoring sites considered in this report are used to supply single dwellings or small communities with water supply, but many other monitoring sites considered in this report have non-potable uses (e.g. irrigation, stock drinking water). Drinking water guidelines are used in this report to provide context for assessment of ambient groundwater quality, but for focused assessment of drinking water quality in New Zealand, readers are directed to the Annual Review of Drinking Water Quality reports produced by the Ministry of Health (e.g. Ministry of Health, 2009).

Median values and trend magnitudes for key groundwater quality indicators reported here are very similar to those reported previously (Daughney and Wall, 2007). Nationally, ambient groundwater quality in New Zealand is similar to other countries such as Finland, Canada and the Netherlands. New Zealand has two main groundwater quality issues:

- Contamination with nitrate and/or microbial pathogens (of presumably human or agricultural origin) occurs in many regions, particularly for shallow wells in unconfined aquifers. Nationally, median concentrations of nitrate and *Escherichia coli* exceed their respective health-related standards for human consumption at 5% and 23% of the monitoring sites considered in this report, respectively.
- Naturally elevated concentrations of ammonia, iron and/or manganese are found in many regions, especially for deeper wells in confined aquifers. Nationally, 4%, 21% and 27% of the sites considered in this report have median concentrations of ammonia, iron and manganese above their respective aesthetic guidelines for human consumption, and 10% of sites have median manganese concentration above the health-related standard (there are no health-related standards for ammonia or iron).

Groundwater quality is either constant over time or changing slowly (parameter values change less than 2-5% per year) at about three quarters of the sites considered in this report, probably due to the natural process of water-rock interaction. Changes in groundwater quality over time are more rapid at the remaining sites, with patterns that suggest human influence. With respect to nitrate, significant time trends are detectable at roughly one third of the monitoring sites considered in this report, and of these, roughly twice as many sites show increasing nitrate concentration over time compared to sites that show decreasing nitrate concentration over time. In general however, this report shows that attempts to identify and interpret time trends in groundwater quality are complicated by year-by-year changes in the structure of the various groundwater monitoring programmes operated by regional councils.

This report has revealed certain significant relationships between groundwater quality and well depth and/or aquifer characteristics. In contrast, this report has not revealed any systematic or significant relationships between groundwater quality (state or trends) and land use or land cover around the monitoring sites. This is in fact a common result that has been observed in several previous studies in New Zealand (e.g. Daughney and Wall, 2007) and overseas—it is hard to identify and understand relationships between groundwater quality

and land use unless the age and source of the groundwater being monitored are accurately known.

The main recommendation from this report is that similar studies should be conducted at a regular interval in the future, in order to identify changes in the status of groundwater quality in New Zealand. Future studies will require national and regional commitment to regular (quarterly) monitoring of key groundwater quality indicators (nitrate, *Escherichia coli*, ammonia, iron, manganese, electrical conductivity) via standardised sampling and analytical methods, on an on-going basis, and at a consistent network of monitoring sites, all having adequate well-head protection.

The main sources of bias in the aggregated regional and national statistics are, in order of influence:

- changes in sampling procedure, such as collection of field-filtered instead of unfiltered samples;
- addition or removal of a large proportion of sites from an SOE network; and
- changes in analytical procedure, such as replacement of total coliform counts with *Escherichia coli* counts.

In order to elucidate the drivers of groundwater quality, there is also a need to determine the age and origin of the groundwater that is actually being sampled at each monitoring site, to permit meaningful comparison to current and past land use.

1.0 INTRODUCTION

The Ministry for the Environment is committed to routinely updating groundwater quality indicator data for New Zealand, as part of its National Environmental Reporting Programme. The Ministry for the Environment contracted GNS Science to collect and groom groundwater quality data from regional authorities, undertake state and trend analyses covering the period 1995 to 2008, and produce a brief technical report and summary statistics that can be used as the primary basis for national reporting.

1.1 Previous investigation

This report updates the report by Daughney and Wall (2007), which provided an assessment of state and trends in groundwater quality in New Zealand based on data collected from 1068 sites over the period 1995 to 2006 through State of the Environment (SOE) monitoring programmes operated by regional councils and through the National Groundwater Monitoring Programme (NGMP) operated by GNS Science. The main conclusions from the report of Daughney and Wall (2007) were as follows:

- Two major national-scale groundwater quality issues were identified: 1) contamination with nitrate and/or microbial pathogens and 2) naturally elevated concentrations of iron, manganese, arsenic and/or ammonia:
 - At 39% of the monitoring sites, the groundwater quality data revealed some level of human influence, with nitrate and/or sulphate concentrations above natural background levels. Such monitoring sites were found across New Zealand, especially in Waikato and Southland, and were usually situated in shallow unconfined aquifers.
 - At 30% of the monitoring sites, the groundwater quality data showed little or no evidence of human influence, but due to high levels of oxygen in the aquifer, any introduced nitrate or sulphate would likely persist and accumulate.
 - At 31% of monitoring sites, the groundwater was found to be oxygen-poor and hence was not likely to accumulate significant nitrate; however, the groundwater may accumulate high concentrations of iron, manganese, arsenic and/or ammonia due to natural processes. Such monitoring sites were found in many regions of New Zealand, particularly Gisborne, Auckland and Manawatu-Wanganui, and especially for deep wells in confined aquifers.
- At about two thirds of the monitoring sites, groundwater quality was found to be either constant over time or changing slowly (parameter values change less than 2-5% per year), probably due to the natural process of water-rock interaction. Changes in groundwater quality over time were more rapid at the remaining sites, with patterns that suggested human influence. Time trends in parameters such as nitrate and sulphate suggested either increasing or decreasing levels of human or agricultural impact at 12% and 10% of all sites, respectively.
- There were relationships between groundwater quality and well depth and aquifer characteristics, but no detectable relationships between groundwater quality (state or trends) and land use or land cover around the monitoring sites. This is a common result that has been observed in several previous studies in New Zealand and overseas—it is hard to identify and understand relationships between groundwater quality and land use unless the age and source of the groundwater being monitored are accurately known.

1.2 Scope of work

Following the methods of Daughney and Wall (2007) and in accordance with the scope of work detailed by Ministry for the Environment, this current project involved the following:

- Data analysis:
 - **State:** determine median and other percentile statistics for key indicators of groundwater quality (e.g. nitrate, *E. coli*) by region and nationally, with analyses conducted 1) for the entire period from 1995 to 2008, and 2) separately for each calendar year from 1995 to 2008;
 - **Trends:** identify and quantify time-trends for key indicators of groundwater quality for the entire period 1995 to 2008, by region and nationally; and
 - **Land use and aquifer confinement relationships:** evaluate relationships between land use, aquifer confinement and state and trends of key indicators of groundwater quality, by region and nationally;
- Outputs:
 - **Summary tables:** following the convention of Tables 7, 8, 11 and 12 in Daughney and Wall (2007), but 1) split statistics by year (for the state analyses) and region and 2) limit data presentation to key indicators of groundwater quality;
 - **Summary spreadsheets (for mapping):** tabulation of location details (eastings, northings) and site-specific median values of key indicators of groundwater quality for most recent year of record (2008) and for the entire period of data record (1995 to 2008); and
 - **Report:** brief explanation of methods, results and conclusions, including discussion of necessary caveats, for example, the extent to which regional differences or focuses in SOE monitoring network design might bias results for that region towards particular groundwater conditions, etc.

For the sake of brevity, this report does not reproduce background information provided by Daughney and Wall (2007). Readers are referred to the earlier report for the following:

- a detailed description of the SOE and NGMP datasets, including characterisation of land cover / land use, and associated data limitations;
- a background discussion of the general chemical characteristics of groundwater; and
- a survey of previous regional, national and international assessments of groundwater quality.

2.0 Methods

2.1 Groundwater quality data

2.1.1 Monitoring sites and data sources

To facilitate comparison to the results in Daughney and Wall (2007), this report made use of the same set of monitoring sites (Table 1). SOE groundwater monitoring data were extracted from 14 different regional council databases by regional council personnel. SOE data from Gisborne District Council were not provided within the timeframe necessary for this

investigation, and so are not tabulated or discussed in this report. In addition to the 14 regional SOE datasets, groundwater quality data collected through the National Groundwater Monitoring Programme (NGMP) (Daughney and Reeves, 2005) were provided by GNS Science. For the remainder of this report, the data from the NGMP sites are grouped together with the SOE data from the relevant region. Information pertaining to site location, bore depth, aquifer lithology and surrounding land use and land cover is available as a spreadsheet, downloadable from the Ministry for the Environment website.

It is important to note that data from the SOE and NGMP networks cannot be considered as representative of drinking water quality in New Zealand. Many of the monitoring sites considered in this report are not used for potable water supply, but rather are used for other purposes such as irrigation, stock watering, manufacturing, etc. For those monitoring sites considered in this report that are used for small scale supply of potable water, it is possible that water treatment methods may be used to improve water quality after abstraction and before human consumption. For detailed assessment of drinking water quality in New Zealand, readers are directed to the Annual Review of Drinking Water Quality reports produced by the Ministry of Health (e.g. Ministry of Health, 2009).

Table 1. Sources of groundwater quality data and number of sites considered in this investigation.

Abbreviation	Data Source	SOE ¹	NGMP ¹	Other ²	Total
ARC	Auckland Regional Council	18	6	0	24
EBOP	Environment Bay of Plenty	56	6	0	62
ECAN	Environment Canterbury	273	6	0	279
ES	Environment Southland	57 ³	8	0	65
EW	Environment Waikato	102	9	5	116
GDC	Gisborne District Council	0 ⁴	6	0	6
GWRC	Greater Wellington Reg. Council	56	15	0	71
HBRC	Hawke's Bay Regional Council	42	8	0	50
MDC	Marlborough District Council	11	13	0	24
MWRC	Manawatu-Wanganui Reg. Council ⁵	28	4	0	32
NRC	Northland Regional Council	29	7	12	48
ORC	Otago Regional Council	94	7	0	101
TDC	Tasman District Council	6	10	0	16
TRC	Taranaki Regional Council	65	6	0	71
WCRC	West Coast Regional Council	0	8	0	8
Total		837	119	17	973

¹ Total number of SOE and NGMP sites considered in each region; includes a small proportion of sites that are no longer actively monitored.

² Certain regional datasets provided for and considered in this report included information from a small number of non-SOE wells that are monitored for site-specific investigations.

³ Daughney and Wall (2007) list 78 SOE sites in the Environment Southland dataset, but only 57 are unique (21 "sites" in the Southland dataset represent duplicate quality control sampling events at the main 57 SOE sites).

⁴ SOE data from Gisborne District Council were not provided within the timeframe necessary for this investigation

⁵ Trading name Horizons Regional Council.

2.1.2 Key indicators of groundwater quality and guidelines used

This report makes use of two water quality guidelines, the Drinking Water Standards for New Zealand (DWSNZ) (Ministry of Health, 2005) and the Australia and New Zealand Environment Conservation Council (ANZECC) guidelines for fresh and marine water quality (Australia and New Zealand Environment Conservation Council, 2000). The DWSNZ defines health-related maximum acceptable values (MAVs) and aesthetic guideline values (GVs) related to taste, odour, or colour. The ANZECC guidelines define trigger values (TVs) based on specified protection levels for aquatic ecosystems. This report uses TVs that correspond to the 95% protection level for freshwater ecosystems. Some ANZECC TVs (e.g. for heavy metals, ammonia) are directly related to toxicity to biota, whereas other TVs (e.g. for nutrients) are not directly related to toxicity, but if exceeded may lead to adverse ecological changes. The ANZECC guidelines also define TVs for stock drinking water, which are referred to in some sections of this report. Comparisons to both water quality standards are performed on a per-parameter basis, to determine the number and percentage of monitoring sites at which calculated medians exceed the relevant MAVs, GVs, or TVs.

It is important to note that exceedence of a DWSNZ threshold does not always indicate a threat to human health, because some DWSNZ guidelines are purely aesthetic, and in the case of health-related standards, water treatment methods can often be employed to remove or reduce the concentration of the parameter of concern. Similarly, exceedence of an ANZECC TV in groundwater will not necessarily lead to adverse ecological consequences in adjacent surface waters on all occasions, because groundwater discharging to a surface water body may mix with the surface water, leading to dilution and reduction of the concentration of the parameter of concern.

In this report, analytical results from the different databases were compiled into 32 parameter categories in order to facilitate assessment of groundwater quality at the national scale (Table 2, cf. Daughney and Wall, 2007). Overview statistics are provided for all 32 parameters. However, detailed interpretation is focussed on only the following six key indicators of groundwater quality:

- **Nitrate-nitrogen** ($\text{NO}_3\text{-N}$). $\text{NO}_3\text{-N}$ is routinely monitored for health and environmental reasons. The DWSNZ specifies a health-related MAV of 11.3 mg/L. High concentrations can lead to blood disease, particularly in infants (commonly known as “blue baby syndrome”) (Ministry of Health, 2005). The ANZECC guidelines specify a TV of 7.2 mg/L, which is defined on the basis of direct toxicity to biota, and a TV of 0.17 mg/L, which is defined for protection of aquatic ecosystems. $\text{NO}_3\text{-N}$ is one of the two core indicators of groundwater quality employed by the Ministry for the Environment in their most recent national SOE report (Ministry for the Environment, 2007).
- **Ammoniacal-nitrogen** ($\text{NH}_4\text{-N}$).¹ Nitrogen in oxygen-rich groundwater exists predominantly as $\text{NO}_3\text{-N}$, but under the oxygen-poor conditions that exist at about one third of the monitoring sites considered in this report (Daughney and Wall, 2007), nitrogen

¹ There are two main naming conventions for this parameter. This report uses the name and abbreviation ammoniacal-nitrogen ($\text{NH}_4\text{-N}$) because it is consistently employed by regional councils in New Zealand. However, many overseas guidelines recommend the use of the parameter name ammonia-nitrogen ($\text{NH}_3\text{-N}$). The distinction is largely semantic, and the two parameters are directly comparable in terms of units of analysis.

is converted to $\text{NH}_4\text{-N}$ by natural processes.² $\text{NH}_4\text{-N}$ is therefore a useful indicator of groundwater quality because it shows whether the absence of $\text{NO}_3\text{-N}$ signifies a lack of human or agricultural impact on groundwater quality, or if the natural conditions in the aquifer might make evidence of such impact difficult to detect. The DWSNZ specifies an aesthetic GV for $\text{NH}_4\text{-N}$ of 1.5 mg/L to minimise odour. The ANZECC guidelines define two thresholds for $\text{NH}_4\text{-N}$: a TV of 0.9 mg/L is set to protect against direct toxicity to biota, and a TV of 0.01 mg/L is set for protection of aquatic ecosystems.

- ***Escherichia coli* (*E. coli*).** *E. coli* is a species of bacteria that indicates the presence of faecal matter in groundwater. The DWSNZ specifies a MAV of 1 colony forming unit (cfu) per 100 ml for water that is used for human consumption, and the ANZECC guidelines include a TV of 100 cfu/100 ml for water that is used for livestock consumption. *E. coli* is the second core groundwater quality indicator used by the Ministry for the Environment (Ministry for the Environment, 2007).
- **Iron (Fe).** Elevated concentrations of dissolved Fe can impart an unpleasant taste to drinking water, and so DWSNZ includes an aesthetic GV of 0.2 mg/L. There are no recognised health or ecosystem risks associated with Fe, and so there is no MAV defined in DWSNZ or TV specified in the ANZECC guidelines. However, elevated concentrations of dissolved Fe in groundwater may indicate the possible occurrence of arsenic (Smedley and Kinniburgh, 2002), which itself is not routinely monitored in groundwater in New Zealand. Fe is also a useful indicator because it is only soluble under oxygen-poor conditions, so complements $\text{NH}_4\text{-N}$ to understand measured concentrations of $\text{NO}_3\text{-N}$.
- **Manganese (Mn).** Elevated concentrations of dissolved Mn can also impart an unpleasant taste to drinking water and cause staining of laundry and whiteware, and so DWSNZ includes an aesthetic GV of 0.04 mg/L. Due to risks to human health and freshwater ecosystems, the DWSNZ include a MAV of 0.4 mg/L, and the ANZECC guidelines include a toxicity-related TV of 1.9 mg/L. Mn is also only soluble in oxygen-poor groundwater, so it is a useful indicator for understanding measured concentrations of $\text{NO}_3\text{-N}$.
- **Electrical conductivity.**³ Electrical conductivity provides a measure of the total dissolved solids (TDS) concentration in a groundwater sample, and so it provides a useful indicator for spatial and/or temporal changes in abstraction, salt water intrusion, recharge mechanism, etc. There are no health- or ecosystem-related standards for electrical conductivity specified in DWSNZ or ANZECC, however, there are aesthetic guidelines for TDS in the DWSNZ.

² Whilst $\text{NH}_4\text{-N}$ is the dominant form of nitrogen under oxygen-poor conditions, it is important to note that microbially mediated reactions can lead a small proportion of $\text{NH}_4\text{-N}$ to be converted to $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$ or N_2 even under oxygen-poor conditions.

³ Some overseas guidelines recommend the use of the parameter name “conductivity”. However, this report uses the parameter name electrical conductivity because it is the common parameter name used by regional councils, and also to clearly differentiate from hydraulic conductivity, thermal conductivity, etc., which are common parameters also used in hydrology.

Table 2. Parameter category names, units and the abbreviations used in this report (cf. Daughney and Wall, 2007). Abbreviations in bold text are for the six key indicators of groundwater quality used in this report.

Class	Abbrev.	Units	Parameter Category Name
Major Constituents	Ca*	mg/L	Calcium
	Cl*	mg/L	Chloride
	HCO ₃ * ¹	mg/L as HCO ₃	Bicarbonate ¹
	K*	mg/L	Potassium
	Mg*	mg/L	Magnesium
	Na*	mg/L	Sodium
	NO₃-N*	mg/L	Nitrate
	SiO ₂	mg/L	Silica
	SO ₄ * ²	mg/L	Sulphate
TDS*	mg/L	Total Dissolved Solids ²	
Minor Constituents and Microbial Indicators	B**	mg/L	Boron
	Br	mg/L	Bromide
	F	mg/L	Fluoride
	Fe*	mg/L	Iron
	Li	mg/L	Lithium
	Mn*	mg/L	Manganese
	NH₄-N*	mg/L	Ammonia
	PO ₄ -P	mg/L	Phosphate
	<i>E. coli</i>	cfu/100 ml	<i>Escherichia coli</i> ³
Trace Constituents	Al	mg/L	Aluminium
	As**	mg/L	Arsenic
	Cd	mg/L	Cadmium
	Cr	mg/L	Chromium
	Cu	mg/L	Copper
	Ni	mg/L	Nickel
	NO ₂ -N	mg/L	Nitrite
	Pb	mg/L	Lead
	Sn	mg/L	Tin
Zn	mg/L	Zinc	
Other	Cond*	uS/cm	Electrical Conductivity
	pH*	pH units	pH
	Temp	°C	Temperature

* Parameters in the “base suite” that are recommended for regular SOE monitoring by Environment Waikato (2006) and agreed by the Regional Groundwater Forum.

** Parameters in the “base suite” that are recommended for at least occasional SOE monitoring by Environment Waikato (2006) and agreed by the Regional Groundwater Forum.

¹ This category includes alkalinity results, after conversion of units.

² Where TDS has not been measured, it is estimated by summation of major and minor element concentrations.

³ *E. coli* is the only microbiological parameter that is considered in the drinking water standards (Ministry of Health, 2005). Where *E. coli* concentrations are not known, this report makes use of a proxy variable such as faecal coliforms or total coliforms. Results reported as cfu/100 ml and MPN/100 ml are assumed equivalent.

2.2 Data analysis methods

An automated spreadsheet program (Daughney, 2007) was used to compute site-specific descriptive statistics for individual parameter categories. The following site-specific calculations were performed using 1) all available data for the period 1995 to 2008, and 2) data from each individual calendar year from 1995 to 2008:

- **Median:** a measure of central tendency, calculated using log-probability regression to deal with results reported as being below some analytical detection limit. Median values are calculated for each of the 32 parameter categories.
- **Trend:** rate of change in each parameter, based on Sen's slope estimator for all trends that are detectable with the Mann-Kendal test at the 95% confidence interval (positive numbers indicate increasing trends), or tabulated as "N" for non-significant trends. Trend assessments are performed for 22 parameter categories; trends for trace elements are not determined because they are analysed at relatively few sites and many of the reported concentrations are near or below the detection limit.

Site-specific medians and trends were then used to compute regional and national statistics for individual parameter categories, again on the basis of 1) all available data for the period 1995 to 2008, and 2) data from each individual calendar year from 1995 to 2008:

- **Number of sites:** the total number of sites within the region and time period of interest for which sufficient data were available to determine site-specific medians or trends⁴;
- **Percentiles:** the 5th, 25th, 50th, 75th and 95th percentiles and maximum values in the set of site-specific medians and trends for the region and time period of interest (for the case where percentiles were determined within individual calendar years, trend tests were used to identify significant year-by-year increases or decreases in the percentile values);
- **% Exceedence:** percentage of monitoring sites for the region and time period of interest at which site-specific median values exceed relevant thresholds from the DWSNZ and ANZECC guidelines (for the case where exceedence was assessed within individual calendar years, trend tests were used to detect significant year-by-year increases or decreases in the percentage of sites exceeding guidelines); and
- **% Trend:** percentage of sites within the region at which sufficient data were available to perform trend tests, and at which significant increasing or decreasing trends were detectable (trend tests require several years of quarterly data, and so could not be performed for individual calendar years).

The national and regional statistics were then used to assess the influence of various categorical factors (e.g. aquifer lithology or confinement, surrounding land use, etc.) on calculated medians and trends.

See Daughney and Wall (2007) for a more detailed discussion of statistical methods.

⁴ It is assumed in this study that at least one result per year is required to determine median, and at least three results are required between 1995 and 2008 to determine trend. Median and trend values determined with so few measurements carry significant uncertainty, but these uncertainties are site-specific and have relatively little influence on statistics that are aggregated to the regional and national levels.

2.3 Data limitations

Limitations associated with the data include the following (see Daughney and Wall, 2007, for detailed discussion):

- **Length and continuity of data record:** some sites considered in this report were sampled just two or three times, and other sites were sampled at an irregular interval, both of which complicate trend testing;
- **Coverage of parameters:** the data set used in this investigation did not include potentially important parameters such as pesticides, volatile organic compounds, petroleum hydrocarbons, pharmaceuticals, endocrine disrupting compounds, etc. simply because these are not routinely analysed in SOE groundwater monitoring programmes;
- **Sampling and analytical methods:** details of sampling and analytical methods were not provided, but can influence the data obtained, particularly for parameters such as Fe and Mn that tend to have different dissolved and total concentrations⁵;
- **Representativeness of monitoring sites:** it is not clear whether the sites considered in this report provide an accurate representation of groundwater quality in New Zealand, because many monitoring programmes target contaminated or at-risk aquifers, or aquifers that are used for water supply;
- **Site details:** important information about well construction, aquifer lithology, aquifer confinement, and surrounding land use at some monitoring sites is either not known or could not be provided within the necessary timeframe for this report;
- **Capture zones and travel times:** it is the land use in the capture zone at the time the groundwater was recharged that has the potential to influence current groundwater quality at any given monitoring site, but the capture zone and groundwater age are unknown for most monitoring sites in New Zealand.

3.0 RESULTS

Region-specific statistics and national summary tables (Spreadsheets 1 and 2) referred to in this section are available as downloadable Excel files from the Ministry for the Environment website.

3.1 Site-specific assessments of state and trends

Site-specific median values and trend assessments are compiled in Spreadsheet 1. Site-specific medians and trends do not differ significantly for the time period 1995 to 2008 (this report) compared to the time period 1995 to 2006 (Daughney and Wall, 2007). In general, site-specific medians for the two time periods differ by less than $\pm 10\%$ except for a small proportion of sites where:

⁵ In practice, “dissolved” concentrations are operationally determined by performing the analysis on a filtered sample, and usually the filtration takes place in the field when the sample is collected by passing the sample through a membrane with pore size of 0.2 or 0.45 micrometers. In contrast, “total” concentration is measured in an unfiltered sample and hence is the sum of the dissolved concentration and the concentration derived from suspended solids.

- Few samples have been collected, such that inclusion of data from additional samples collected between 2006 and 2008 leads to a significant change in the calculated median;
- The concentrations are near the analytical detection limit, such that a small change in absolute concentration between individual samples translates to a large relative (%) change; and/or
- There is a significant temporal trend at the site in question.

Similarly, site-specific median values do not differ substantially for the time period 1995 to 2008 compared to the 2008 year alone, except in the cases outlined above.

3.2 National overview of groundwater quality

National-level statistics related to state and trends in individual parameter categories for the period 1995 to 2008 are compiled in Spreadsheet 2 and summarised in Tables 3, 4, 5 and 6 (analogous to Tables 7, 8, 11 and 12, respectively, from Daughney and Wall, 2007). The national-level statistics show:

- National medians for most parameters (Table 3) are very similar to previously reported values (Daughney and Wall, 2007). National medians for major elements are intermediate between the global average for river water and the global average for groundwater, often being closer to the former.
- Only a small percentage of sites have median parameter values in excess of the relevant MAV, GV or TV (Table 4), except for a few previously recognised nationally significant groundwater quality issues, including NO₃-N, Fe, Mn, and *E. coli*.
- A significant increasing or decreasing trend is detectable at about 25% of the monitoring sites for most of the parameter categories for which trends could be calculated, and the proportions of sites showing increasing and decreasing trends are the same to within about 10% (Table 5), in agreement with previous findings (Daughney and Wall, 2007).
- The national median values for absolute trend magnitude are less than 0.5 and 0.01 mg/L per year for most major and minor elements, respectively (Table 6). Compared to relevant median concentrations, this equates to national median relative trend magnitudes of less than ±2% and ±5% per year for most major and minor elements, respectively. Such rates of change are considered to be “slow”, as might occur naturally due to the process of water-rock interaction (Daughney and Reeves, 2006). There are no guidelines as to what rate of change in groundwater quality is acceptable from a resource management perspective, but for context it is relevant to note that a relative rate of change of greater than the arbitrary cut-off of ±1% is considered “ecologically meaningful” in rivers (Scarsbrook, 2006).
- Absolute rates of change are uncorrelated or only weakly correlated to median concentrations. For example, there is no relationship between the median concentration of NO₃-N at a particular site and the rate at which NO₃-N is changing over time.

Table 3. Calculated national percentiles and maximum values for groundwater quality parameters, based on site-specific median values determined for the period 1995 to 2008. Global average concentrations for river water and groundwater are given for comparison. All values in mg/L except *E. coli* (cfu/100 ml), Cond ($\mu\text{S}/\text{cm}$), pH (pH units) and Temp ($^{\circ}\text{C}$).

Parameter	New Zealand Groundwater (this report)						Global Averages ¹		
	n ²	Percentiles					Max.	River Water	Ground Water
		5th	25th	50th	75th	95th			
Major									
Ca	820	3.7	9.4	14.6	23.0	73.1	546.0	15	50
Cl	863	2.9	7.0	14.0	26.2	112.4	1852.5	7.8	20
HCO ₃	799	19.5	38.2	59.8	118.3	303.0	900.0	58	200
K	769	0.6	1.0	1.4	2.8	8.1	37.8	2.3	3
Mg	820	1.2	2.8	4.5	7.3	19.7	616.0	4.1	7
Na	818	4.2	8.8	14.0	25.0	95.6	800.0	6.3	30
NO ₃ -N	920	<0.1	0.1	1.7	4.7	11.0	33.0		0.2-20
SiO ₂	653	8.8	14.0	18.0	34.6	79.8	161.0	14	16
SO ₄	857	0.2	3.3	7.2	14.0	42.8	995.0	3.7	30
Calc TDS ³	868	41.1	84.6	135.2	255.9	745.5	3580.8	120	350
Minor or Biological									
B	367	0.01	0.01	0.03	0.05	0.39	13.50		20-1000
Br	335	0.01	0.05	0.09	0.16	0.59	28.0		<100-2000
F	439	0.02	0.06	0.09	0.17	0.50	21.0		0.1-5
Fe	802	<0.01	0.01	0.03	0.12	4.48	68.40	0.05	0.7
Li	190	<0.01	<0.01	0.01	0.02	0.20	6.63		1-150
Mn	784	<0.01	<0.01	0.01	0.05	0.85	12.70	<0.01	0.03
NH ₄ -N	918	<0.01	<0.01	0.01	0.03	0.97	18.25		
PO ₄ -P	705	<0.01	0.01	0.01	0.04	0.24	4.94		<100-1000
<i>E. coli</i>	701	<0.01	<0.01	<0.01	1.00	22.2	2400		
Trace Constituents									
Al	87	0.0004	0.0026	0.0070	0.0190	0.0925	0.349		
As	575	<10 ⁻⁴	<10 ⁻⁴	0.0005	0.0020	0.0070	0.613		
Cd	145	<10 ⁻⁴	0.0000	<10 ⁻⁴	<10 ⁻⁴	0.0002	0.0005		<1
Cr	95	0.0001	0.0001	0.0001	0.0004	0.0012	0.0030		<1-220
Cu	211	<10 ⁻⁴	0.0005	0.0012	0.0036	0.0151	0.0440		<1-30
Ni	78	<10 ⁻⁴	0.0002	0.0009	0.0020	0.0040	0.0065		<10-50
NO ₂ -N	464	<10 ⁻⁴	0.0020	0.0062	0.0140	0.0200	1.300		
Pb	173	<10 ⁻⁴	0.0001	0.0003	0.0008	0.0019	0.1200		<15
Sn	40	<10 ⁻⁴	0.0002	0.0010	0.0050	0.0200	0.1300		<200
Zn	243	0.0009	0.0055	0.0110	0.0245	0.2202	1.1400		<10-2000
Other									
Cond	915	89.0	141.5	204.0	319.5	807.0	27500		
pH	907	5.9	6.4	6.7	7.1	7.8	9.81		
Temp	498	11.6	13.4	14.4	15.9	20.0	63.0		

¹ Global averages are provided for comparison to 50th percentile values in New Zealand groundwater. Global averages are taken from Turekian (1977), Hem (1985) and Langmuir (1997). Ranges of values are taken from Dragun (1998).

² Total number of sites for which statistics could be calculated (i.e. parameter had been measured at least three times).

³ Similar percentiles are obtained for measured TDS, but statistics are based on fewer measurements and so are not tabulated here.

Table 4. Percentage of New Zealand monitoring sites at which median concentrations calculated for the period 1995 to 2008 are in excess of water quality standards or guidelines.

Parameter	Units	Reason	DWSNZ		ANZECC			
			MAV or GV	%Sites Exceeding ¹	Reason ²	TV	%Sites Exceeding ¹	
Major	Ca	mg/L	N/A	-	-	N/A	-	-
	Cl	mg/L	Aesthetic	250	1.7	N/A	-	-
	HCO ₃	mg/L	N/A	-	-	N/A	-	-
	K	mg/L	N/A	-	-	N/A	-	-
	Mg	mg/L	N/A	-	-	N/A	-	-
	Na	mg/L	Aesthetic	200	1.3	N/A	-	-
	NO ₃ -N	mg/L	Health	11.3	4.8	Ecosystem	0.17	73.2
						Toxicity	7.2	13.2
	SiO ₂	mg/L	N/A	-	-	N/A	-	-
	SO ₄	mg/L	Aesthetic	250	0.1	N/A	-	-
	Calc TDS ³	mg/L	Aesthetic	1000	3.8	N/A	-	-
Minor or Biological	B	mg/L	Health	1.4	2.2	Toxicity	0.37	5.2
	Br	mg/L	N/A	-	-	N/A	-	-
	F	mg/L	Health	1.5	1.4	N/A	-	-
	Fe	mg/L	Aesthetic	0.2	21.3	N/A	-	-
	Li	mg/L	Health	1.0	1.6	N/A	-	-
	Mn	mg/L	Aesthetic	0.04	26.9	Toxicity	1.9	1.4
			Health	0.4	9.9			
	NH ₄ -N	mg/L	Aesthetic	1.5	3.8	Ecosystem	0.01	37.7
						Toxicity	0.9	5.3
	PO ₄ -P	mg/L	N/A	-	-	Ecosystem	0.01	54.2
<i>E. coli</i> ⁴	cfu/100 ml	Health	1	23.1	Livestock	100	2.4	
Trace	Al	mg/L	Aesthetic	0.1	5.7	Toxicity	0.055	6.9
	As	mg/L	Health	0.01	3.5	Toxicity	0.024	1.6
	Cd	mg/L	Health	0.004	0.0	Toxicity	0.0002	1.2
	Cr	mg/L	Health	0.05	0.0	Toxicity	0.001	5.0
	Cu	mg/L	Aesthetic	1	0.0	Toxicity	0.0014	3.0
	Ni	mg/L	Health	0.02	0.0	Toxicity	0.011	1.0
	NO ₂ -N	mg/L	Health	0.2	0.4	N/A	-	-
	Pb	mg/L	Health	0.01	2.4	Toxicity	0.0034	0.4
	Sn	mg/L	N/A	-	-	N/A	-	-
	Zn	mg/L	Aesthetic	1.5	0.0	Toxicity	0.008	30.6
Other	Cond	uS/cm	N/A	-	-	N/A	-	-
	pH	pH units	Aesthetic	7.0-8.5	70.7	N/A	-	-
	Temp	°C	N/A	-	-	N/A	-	-

¹ Percentage of monitoring sites at which median exceeds the water quality standard or guideline, relative to the total number of sites for which a median could be calculated for the parameter in question.

² The listed ANZECC TVs pertain either to direct toxicity to biota, or to non-toxicity related threat to aquatic ecosystems, or to the safe threshold for stock drinking water. Note that exceedence of an ANZECC TV in groundwater will not necessarily lead to adverse ecological consequences in adjacent surface waters on all occasions, because groundwater discharging to a surface water body may mix with the surface water, leading to dilution and reduction of the concentration of the parameter of concern.

³ Similar results are obtained for measured TDS, but statistics are based on fewer measurements and so are not tabulated here.

⁴ *E. coli* is the only microbiological parameter that is considered in the drinking water standards (Ministry of Health, 2005).

Table 5. Number of monitoring sites (n) across New Zealand at which trend tests could be performed for the period 1995 to 2008, and percentages without significant trends (%N) or with significant increasing (%INCR) or significant decreasing (%DECR) trends (at 95% confidence level).

	Parameter	n	%INCR	%DECR	%N
Major	Ca	801	16.4%	10.1%	73.5%
	Cl	845	27.2	11.2	61.5
	HCO ₃	742	20.2	11.7	68.1
	K	747	7.1	14.9	78.0
	Mg	800	13.3	8.6	78.1
	Na	793	14.5	12.0	73.5
	NO ₃ -N	886	20.0	11.9	68.2
	SiO ₂	553	7.4	6.1	86.4
	SO ₄	831	28.5	12.6	58.8
	TDS*	250	12.5	1.7	85.8
Minor or Biological	B	276	8.3	13.4	78.3
	Br	254	2.0	19.3	78.7
	F	314	3.5	10.8	85.7
	Fe	597	5.2	10.3	84.5
	Li	70	7.1	5.7	87.1
	Mn	523	7.0	9.9	83.1
	NH ₄ -N	844	13.1	7.8	79.2
	PO ₄ -P	653	16.5	5.5	77.9
	<i>E. coli</i>	367	0.8	1.1	98.1
Other	Cond	906	18.4	13.4	68.2
	pH	891	11.6	12.0	76.4
	Temp	491	4.3	2.6	93.1

Table 6. National absolute and relative rates of change in groundwater quality parameters for sites with statistically significant trends. Relative median rates of change calculated by dividing the median absolute trend by the relevant median concentration from Table 3.

Parameter	Units	Absolute Trend (units per year)			Relative Median Trend (% per year)	
		Minimum	Median	Maximum		
Major	Ca	mg/L	-6.62	0.12	8.44	0.82%
	Cl	mg/L	-66.41	0.18	36.18	1.28
	HCO ₃	mg/L	-25.62	0.73	26.87	1.22
	K	mg/L	-2.54	-0.03	0.77	-2.24
	Mg	mg/L	-0.99	0.05	2.05	1.17
	Na	mg/L	-4.72	0.10	22.51	0.71
	NO ₃ -N	mg/L	-1.62	0.03	2.37	1.70
	SiO ₂	mg/L	-5.63	0.19	4.02	1.06
	SO ₄	mg/L	-5.82	0.16	15.55	2.16
	TDS	mg/L	-45.02	3.21	25.55	2.37
Minor or Biological	B	mg/L	-0.016	-0.001	0.264	-4.36
	Br	mg/L	-0.193	-0.006	0.103	-6.28
	F	mg/L	-1.406	-0.002	0.012	-2.16
	Fe	mg/L	-0.537	-0.005	0.672	-18.1
	Li	mg/L	-0.015	0.000	0.001	2.14
	Mn	mg/L	-0.219	0.000	0.066	-1.74
	NH ₄ -N	mg/L	-0.478	0.001	0.152	7.21
	PO ₄ -P	mg/L	-0.127	0.001	0.046	12.6
	<i>E. coli</i>	cfu/100 ml	-37.03	-0.24	4.16	-
Other	Cond	uS/cm	-110.8	2.0	111.8	0.99
	pH	pH units	-0.44	-0.02	0.18	-0.23
	Temp	°C	-0.53	0.05	0.98	0.32

3.3 Key indicators of groundwater quality

Figure 1 (a-l) displays the national and regional percentiles and exceedence and trend statistics for the six key groundwater quality indicators, based on all available data collected within the period 1995 to 2008. Figure 2 shows the year-by-year change in the percentage of sites exceeding relevant DWSNZ and ANZECC guidelines. Figures 3 (a-o) to 8 (a-o) show the changes in the percentiles of the key indicator parameters, by region and by calendar year. The information displayed in Figures 1 to 8 is also provided in table form in Appendices 1 to 15 (all appendices are downloadable from the Ministry for the Environment website). Table 7 presents the results of trend tests conducted to determine if there are year-by-year changes in the national and regional percentile values, or year-by-year increases or decreases in the percentage of sites exceeding DWSNZ or ANZECC guideline values.

3.3.1 Nitrate-nitrogen

This report has revealed a national median concentration of 1.7 mg/L for NO₃-N based on all data collected in the period 1995 to 2008 (Figure 1a, Table 3), slightly higher than the national median of 1.3 mg/L NO₃-N reported for the period 1995 to 2006 (Daughney and Wall, 2007). The slight increase in national median does not indicate an increase in NO₃-N contamination of New Zealand's aquifers in the period 2006 to 2008, but rather is caused by the unavailability of data from the Gisborne region for this investigation. Gisborne is dominated by oxygen-poor groundwater with low concentrations of NO₃-N (Daughney and Wall, 2007), and the exclusion of the Gisborne SOE data yields a slightly higher national median concentration of NO₃-N. Perspective on the calculated national median is provided by previous studies, which have estimated 0.3-1.0 mg/L for median NO₃-N concentration in unimpacted groundwaters in New Zealand (Burden, 1982; Morgenstern et al., 2004; Daughney and Reeves, 2005). Daughney and Reeves (2005) also defined NO₃-N thresholds of >1.6 mg/L and >3.5 mg/L as "probably" and "almost certainly" indicative of human influence, respectively.

The regions with the highest median NO₃-N concentrations are Waikato (4.2 mg/L), Southland (3.4 mg/L) and Canterbury (3.4 mg/L) (Figures 1a and 3c, j and m). NO₃-N in groundwater is a known concern in these regions, and hence more investigations are being undertaken in at-risk aquifers, and SOE sites with high NO₃-N are being added to these regional monitoring programmes over time. This report also considered data from a small number of non-SOE sites in Waikato and Northland that are sampled specifically to assess NO₃-N contamination in groundwater and/or saltwater intrusion, which may bias the statistical compilations for these regions. Note also that approximately 90% of the SOE monitoring sites in the Waikato, Southland and Canterbury regions are typified by oxygen-rich conditions (Daughney and Wall, 2007), which favour the persistence of any introduced NO₃-N. The lower median concentrations of NO₃-N observed for other regions might indicate a lower degree of human influence, and/or the predominance of oxygen-poor conditions that would cause introduced NO₃-N to be converted to some other form of nitrogen (e.g. NH₄-N, N₂, N₂O). For example, the majority of SOE sites in the West Coast are typified by oxygen-rich groundwater (Daughney and Wall, 2007), meaning that the relatively low regional median NO₃-N concentration (1.1 mg/L) is indicative of a presently generally low level of human influence. In contrast, regions such as Auckland, Manawatu-Wanganui and Hawke's Bay are dominated by oxygen-poor groundwater. The low median NO₃-N concentrations for these

Table 7. Trends in annual percentiles (units per year) and exceedence levels (% sites above standards or guidelines) for selected water quality indicators. Positive and negative numbers indicate rates of change for significant increasing and decreasing trends, respectively (95% confidence level). Null entry (-) indicates that trend test was performed but no significant trend was detected. Blank entries indicate cases where the trend test could not be performed due to lack of data. Green and pink highlights indicate cases where rate of increase or decrease is greater than 0.1 and exceeds 10% of the corresponding median, respectively.

		Rate of change in annual percentile and % exceedence values (units per year)															
Parameter	Percentile or Guideline	All	Auckland	Bay of Plenty	Canterbury	Gisborne	Hawkes Bay	Manawatu-Wanganui	Marlborough	Northland	Otago	Southland	Taranaki	Tasman	Waikato	Wellington	West Coast
		Conductivity	5th	-	-	-	1.6	-	-	18.8	-	<0.1	-	-4.0	-	-5.7	-
	25th	-	-	-	2.7	-	-	15.3	-	-	-4.6	-	-3.7	-2.0	-	1.1	-
	50th	-	-	-3.3	3.5	2.8	-	-	-	-	-16	-	-	-4.1	-	-	-
	75th	-	-	-	5.0	16.8	-	-	<0.1	-62	-	-	-	-3.5	-	4.8	-
	95th	-	-	-	11.7	-	-	-	26.0	0.1	-	-	-	-12	-	28.1	-
	Max	-	-	-	87.5	-	-	-	33.6	0.6	-	-	-	-	-	87.0	-
Nitrate	5th	-	<0.1	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	-	-	-	-	<0.1	-	-
	25th	-	<0.1	-	0.1	-	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-0.1	<0.1	<0.1
	50th	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	0.1
	75th	-	-	-	0.2	<0.1	-	-	0.2	-0.1	-	-	-	-	-	-	0.3
	95th	-	0.5	-	0.3	0.1	-1.3	-	0.5	-1.1	-	-	-	-0.4	-	-0.3	0.4
	Max	-	0.3	-	-	0.2	-2.4	-	1.0	-	-	-	-	-0.5	-	-0.3	0.4
	% > MAV	-	-	-	0.3	-	-	-	-	-	-0.5	-	-	-1.0	-	-1.0	-
	% > TV	0.4	0.7	-	1.1	-	-	-	-	-	-0.6	-	-	-0.9	-0.8	-0.2	-
Ammonia	5th	-	-	-	-	<0.1	<0.1	-	<0.1	<0.1	-	<0.1	-	<0.1	-	<0.1	-
	25th	-	-	-	<0.1	-	<0.1	-	-	<0.1	-	<0.1	-	-	-	-	-
	50th	-	-	-	<0.1	<0.1	-	-	-	<0.1	-	-	-	-	-	<0.1	-
	75th	-	-	-	<0.1	-	<0.1	-	<0.1	<0.1	-	-	-	-	<0.1	-	-
	95th	-	0.1	-	-	-	-	-	0.1	0.1	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	0.6	0.2	0.1	-	-	-	-	0.4	-
	% > GV	-	-	-	-0.1	-	-	-	0.4	0.3	-	-	-	-	-	-	-
	% > TV	-	0.4	-	-	-	-	-	-	0.5	-	-0.8	-	-	-	-	-
Iron	5th	-	-	-	-	<0.1	<0.1	-	<0.1	<0.1	-	-	-	-	-	<0.1	-
	25th	-	-	-	-	<0.1	<0.1	-	<0.1	<0.1	-	-	-	-	-	<0.1	-
	50th	-	-	-	-	<0.1	0.1	-	-	-	-	-	-	-	-	<0.1	-
	75th	-	-	<0.1	-	-	0.3	-	-	<0.1	-	-	-	<0.1	-	-	-
	95th	-	0.3	-	-	-	-	<0.1	0.7	0.2	-	-	-	0.2	-	-	<0.1
	Max	-	-	-	-	-	-	0.1	7.5	0.8	-	-	-	0.2	-	0.7	-0.1
	% > GV	-1.8	-	-	-	-	-	-	-	1.9	-2.3	-	-0.6	-	-2.6	-	-
Manganese	5th	-	-	-	<0.1	<0.1	-	-	<0.1	<0.1	<0.1	-	-	-	-	<0.1	<0.1
	25th	-	-	-	<0.1	<0.1	-	-	<0.1	<0.1	<0.1	-	-	-	-	<0.1	<0.1
	50th	-	-	0.0	-	-	-	-	-	-	-	<0.1	-	-	<0.1	-	-
	75th	-	-	-	-	-	-	-	<0.1	<0.1	-	-0.1	-	-	-	-	-
	95th	-	-	-	-	-	-	-	0.2	0.2	-	-0.1	-0.1	-	<0.1	<0.1	-
	Max	-	-	-	-	0.0	-	-	0.3	0.8	-	-0.1	-0.1	-	<0.1	<0.1	-
	% > MAV	-2.2	-	-	-	-	3.3	-	-	-	-1.7	-	-	-	-	-1.4	-0.3
	% > GV	-1.1	-	-	-	-	-	-	0.6	-	-	-	-	0.5	-	-	-
	% > TV	-0.1	-	-	<0.1	-	-	-	0.7	-	-	-	-0.4	-	-	-	-
E. coli	5th	-	-	-	-	-	-	-	-0.4	-	<0.1	-	-	-	-	-0.1	-
	25th	-	-	-	-	-	-	-	-0.4	-	<0.1	-	-	-	-	-0.1	-0.6
	50th	-	-	-	-	-	-	-	-0.4	-	0.1	-	-	-	-	-0.5	-
	75th	-	-	-	-	-	-	-	-0.4	-	-	-	-	-	-	-1.7	-
	95th	-	-	-	-	-	-	-	-0.4	-	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	-0.3	-	-51	-	-	-	-	-	-
	% > MAV	-	-	-	-	-	-	-	-	-4.2	-	-	-	-	-	-	-
	% > TV	-	-	-	-	-	-	-	-3.5	-1.1	-	-	-	-	-	-	-

regions (<0.1 mg/L – see Figure 3a, e and f) do not necessarily show that the groundwater isn't polluted or never was polluted, but might instead indicate that the evidence of pollution has been "erased" by natural processes.

Nationally, 4.8% and 13.2% of monitoring sites have median NO₃-N above the MAV defined in the DWSNZ (11.3 mg/L) and the toxicity-related TV specified in the ANZECC guidelines (7.2 mg/L), respectively (Figure 1a, Table 4). A much greater proportion of monitoring sites (73.2%) have median NO₃-N above the ANZECC TV defined for ecosystem protection (in surface waters). While the use of ANZECC TV guidelines provides useful context here, it must be emphasised that the actual concentrations of NO₃-N in any surface water body receiving NO₃-N-rich groundwater will be entirely dependent on site specific factors such as dilution potential. The regions with the highest proportion of sites with median NO₃-N concentration above the DWSNZ and/or ANZECC guidelines are Waikato, Taranaki, Southland, and Canterbury (Figure 1a).

Significant time trends in NO₃-N concentration are detectable at roughly one third of the monitoring sites across New Zealand, and of these, roughly twice as many sites display increasing trends compared to decreasing trends (Figure 1b, Table 5). Previous studies in New Zealand and overseas have shown that for parameters such as NO₃-N, the proportion of sites showing increasing trends exceeds the proportion sites showing decreasing trends, presumably due to intensification of agricultural activity (Frappaporti et al., 1994; Daughney and Reeves, 2006). The absolute rates of change are generally slow (cf. Daughney and Reeves, 2006), i.e. less than ±0.3 mg/L NO₃-N per year, for the majority of sites. Nationally, there is no significant year-by-year change in the proportion of sites with median NO₃-N exceeding the MAV, but the proportion of sites exceeding the toxicity-related TV (7.2 mg/L) is increasing slowly at 0.4% per year (Figure 2a, Table 7).

Regional trends are most pronounced in the West Coast, where half of the monitoring sites exhibit significant temporal trends, and all of these reveal increases in NO₃-N concentration over time at rates that are significantly above the national average (Figure 1b). Identification of time trends in NO₃-N concentration in the West Coast region is facilitated by the constancy of the structure of the regional monitoring programme, with few changes in sampling methods or sites within the period 1998 to present. The Canterbury, Waikato and Marlborough regions also display a greater proportion of sites with increasing compared to decreasing trends in NO₃-N, and/or rates of change slightly above the national average. On a year-by-year basis, there are clear increases in the regional percentiles in NO₃-N concentration in the West Coast (Figure 3o) and Canterbury (Figure 3c), and slower increases in the upper percentiles in Hawke's Bay (Figure 3e) and Northland (Figure 3h) (Table 7). Canterbury is the only region with a significant year-by-year increase in the proportion of monitoring sites at which median NO₃-N concentration exceeds the health standard (Table 7).

3.3.2 Ammoniacal-nitrogen

The national median concentration of NH₄-N is 0.01 mg/L, based on all data collected in the period 1995 to 2008 (Figure 1c, Table 3). The regional assessments reveal the expected inverse correlation between NO₃-N and NH₄-N. The regions with the highest median concentrations of NH₄-N are Manawatu-Wanganui (0.3 mg/L), Hawke's Bay (0.1 mg/L) and

Auckland (0.1 mg/L). As noted above, the SOE programmes of these regions are dominated by monitoring sites with oxygen-poor groundwater, in which nitrogen exists predominantly as NH₄-N and NO₃-N concentrations tend to be low. Regions previously noted to have the highest median concentrations of NO₃-N have among the lowest median concentrations of NH₄-N, e.g. Canterbury, Southland, and the West Coast.

Nationally, 3.8% of monitoring sites have median NH₄-N above the GV defined in the DWSNZ (1.5 mg/L). Nationally, 5.3% and 37.7% of monitoring sites have median NH₄-N above the toxicity-related and the ecosystem protection TVs specified in the ANZECC guidelines (0.9 and 0.01 mg/L, respectively; Figure 1c, Table 4). There is no nationwide year-by-year trend in the percentage of sites exceeding the DWSNZ or ANZECC guidelines (Figure 2b, Table 7). Manawatu-Wanganui, Hawke's Bay and Taranaki are the regions with the highest proportions of sites having median NH₄-N above the DWSNZ and/or ANZECC guidelines.

Time trends in NH₄-N concentration are detectable at 21% of the monitoring sites considered in this report, of which about two thirds show significant increases in concentration over time (Figure 1d, Table 5). Absolute rates of change are generally less than ±0.05 mg/L NH₄-N per year across all regions. The Manawatu-Wanganui region is the exception, where the few sites with increasing trends display a rate of increase in NH₄-N concentration that is significantly faster than the national average. Other notable trend patterns are evident in Canterbury (Figure 4c), Northland (Figure 4h) and Otago (Figure 4i), where there are observable year-by-year increases in the percentile values and, for the latter two regions, also year-by-year increases in the percentage of sites exceeding DWSNZ and/or ANZECC guidelines (Table 7). For these latter three regions, the trend patterns appear to reflect the addition of monitoring sites with high NH₄-N concentrations to the SOE programmes from about 2000 onwards.

3.3.3 E. coli

Calculated statistics for *E. coli* concentrations must be assessed with caution due to historical differences in sampling records and because proxy microbiological parameters such as total coliforms or faecal coliforms were employed by some regions for some time periods. For example, the Wellington region analysed total coliforms at 3 to 14 sites per year from 1995 to 2002, then switched to analysis of *E. coli* at 40+ sites per year from 2003 onwards (Figure 5). Similarly, the Bay of Plenty (Figure 5b) and Hawke's Bay (Figure 5e) regions have historically measured faecal coliform counts, which may not be directly suitable as a proxy for *E. coli* concentrations. In this report, the main justification for combining *E. coli* counts with other proxy microbiological parameters is to ensure that the maximum amount of data can be used for median and trend calculations. There is no straight-forward reliable method for groundwater samples that can be used to convert total coliform counts into *E. coli* counts. The presence of *E. coli* always indicates faecal contamination by warm-blooded animals, whereas the total coliform group includes organisms of faecal and environmental origin, and hence total coliform counts are always greater than *E. coli* counts. This is clearly visible in the Wellington region (Figure 5n), and hence the grouping of these two variables leads to a calculated regional median that is relatively high compared to other regions (Figure 1e). Some regions have always monitored *E. coli* (as opposed to some other microbiological parameter), but only at a highly irregular interval. For example, *E. coli* data for

the Marlborough (Figure 5g) and Taranaki (Figure 5k) regions were only available for the 2008 and 2006-2007 years, respectively and hence calculated regional medians may not be particularly robust. Canterbury, with a median *E. coli* concentration of 0.7 cfu/100 ml, is really the only case where a sufficient density of data was available over several calendar years.

The national median for *E. coli* is less than 1 cfu/100 ml, based on all data collected in the period 1995 to 2008 (Figure 1e, Table 3). The calculated percentiles of *E. coli* concentration indicate a heavily skewed distribution: the majority of results at most sites are near or below the detection limit (1 cfu/100 ml), but occasionally a much higher result is reported. The rare elevated microbiological counts might reflect a flooding event at a site, for example after heavy rain, or perhaps contamination that has occurred at a site with poor well-head protection or during sampling. The calculated national percentiles are also strongly biased by the irregularity of sampling record and analytical methodology for the various regions (see above).

Nationally, 23.1% and 2.4% of the monitoring sites across New Zealand have median *E. coli* concentrations above the MAV for human consumption (1 cfu/100 ml) and the TV for livestock consumption (100 cfu/100 ml), respectively (Figure 1e, Table 4). For comparison, Daughney and Wall (2007) reported a national exceedence level of 20% based on the MAV and data collected in the period 1995 to 2006, and Sinton (2001) reported exceedence levels of 9-60% for previous regional surveys. *E. coli* is somewhat unusual amongst the key indicators of groundwater quality in that its MAV is the same as its detection limit. Hence compared to the other indicators of groundwater quality, a measured *E. coli* concentration that exceeds the MAV has a greater chance of being caused by contamination during sampling or analysis. The greatest proportions of sites that exceed the MAV and/or TV are found in Taranaki (70%), Auckland (33%), Otago (30.6%), Waikato (25.0%) and Northland (25%) (Figure 1e). *E. coli* is the only microbial indicator parameter that is actually considered in the DWSNZ; all other microbial parameters are considered to be proxies for *E. coli*, and so exceedence data from the Wellington, Hawke's Bay and Bay of Plenty regions must be considered with caution.

Significant time trends in *E. coli* concentration are detectable at only 2% of the monitoring sites considered in this report (Figure 1f, Table 5). Nationally, there is no significant year-by-year change in the proportion of sites with median *E. coli* concentrations exceeding the health standard (Figure 2c). These results likely reflect that trend tests have low power to detect changes in *E. coli* concentration over time because the historical monitoring record is sparse, non-continuous and irregular at most monitoring sites, and because elevated *E. coli* counts tend to occur sporadically, possibly due to flooding events at sites with poor well-head protection or to contamination during sampling or analysis.

Most regions do not have significant time trends in *E. coli* concentration (Figure 5, Table 7). The only exceptions occur for Wellington (Figure 5n), where the observed decrease over time is an artefact of using total coliform counts as a proxy for *E. coli* prior to 2003, and for Northland (Figure 5h) and Otago (Figure 5i), which show a decreasing percentage of sites exceeding the health standard over time, perhaps as a result of improved sampling methods in recent years that minimise the possibility of contamination.

3.3.4 Iron and manganese

Iron and manganese are considered together in this section because they tend to co-occur in groundwater (both are soluble only under oxygen-poor conditions) and hence, as indicators, they yield similar information.

The calculated national medians for Fe and Mn are 0.03 and 0.01 mg/L, respectively (Figure 1g and i, Table 3), in good agreement with previously reported values (Daughney, 2003; Daughney and Reeves, 2005; Daughney and Wall, 2007). The regions with the highest median concentrations are Manawatu-Wanganui (Fe 0.36 mg/L, Mn 0.27 mg/L), Hawke's Bay (Fe 0.16 mg/L, Mn 0.05 mg/L) and Bay of Plenty (Fe 0.10 mg/L, Mn 0.03 mg/L). As noted previously, the SOE programmes of these regions include many sites with oxygen-poor groundwater in which Fe and Mn are soluble; the oxygen-poor conditions mean that these same regional SOE programmes also tend to have high NH₄-N and low NO₃-N. Conversely, regions with low median concentrations of Fe and Mn, such as Canterbury, Southland, Waikato and West Coast, have SOE programmes dominated by monitoring sites with oxygen-rich groundwater in which Fe and Mn are generally insoluble. Note that regional comparisons of Fe and Mn concentrations may be complicated by differences in sampling procedure, particularly in terms of protocols for field filtration. For example, the introduction of field filtration in the Wellington region in 2004 dramatically reduced the measured concentrations of both Fe and Mn (Figures 6n and 7n).

Nationally, 21.3% and 26.9% of the sites considered in this report have median concentrations of Fe and Mn above their respective aesthetic GVs defined in the DWSNZ (Figure 1g and i, Table 4). Overall, 9.9% of sites have median Mn concentration above the health-related MAV specified in the DWSNZ (0.4 mg/L), but only 1.4% of the sites had median Mn above the TV for ecosystem protection defined in the ANZECC guidelines (1.9 mg/L). The regions with the highest proportion of sites with median Fe and/or Mn concentration above the DWSNZ and/or ANZECC guidelines are Manawatu-Wanganui, Hawke's Bay, Bay of Plenty, Auckland and Taranaki (Figure 1g and i).

Significant time trends in Fe and/or Mn are evident at about 15% of the sites considered in this report (Figure 1h and j, Table 5). For Mn, there are roughly equal proportions of sites showing increasing and decreasing trends, whereas for Fe, the proportion of sites with decreasing trends is roughly twice as high, which is unusual compared to other indicator parameters considered in this report and probably arises from the widespread adoption of field filtration of samples to be analysed for Fe and Mn from about 2004 onwards. Rates of change are more variable for Fe than Mn, but are generally less than 0.05 mg/L per year for both parameters at most sites (Figure 1h and j, Table 6). Nationally, there are significant year-by-year decreases in the percentage of sites with median Fe or Mn concentrations exceeding the relevant guidelines (Figure 2d and e). Certain regional trend patterns are evident (Table 7), including a year-by-year decrease in Fe and Mn percentiles in Wellington (Figure 6n and 7n), which is an artefact of the introduction of field filtration in 2004, and a year-by-year increases in Fe and Mn percentiles in Northland (Figure 6h and 7h) and Otago (Figure 6i and 7i), which may reflect modification of the regional SOE programmes from about 2000 onwards to include a greater proportion of monitoring sites with oxygen-poor groundwater.

3.3.5 Conductivity

Electrical conductivity provides a measure of the TDS concentration in a groundwater sample, and so it provides a useful indicator for spatial and/or temporal changes in abstraction, salt water intrusion, recharge mechanism, etc. The national median for electrical conductivity is 204 $\mu\text{S/cm}$, but there are substantial variations between regions (Figure 1k, Table 3). The regions with the highest median values for electrical conductivity are Northland (520 $\mu\text{S/cm}$), Manawatu-Wanganui (464 $\mu\text{S/cm}$) and Auckland (316 $\mu\text{S/cm}$). The SOE programmes of these regions include many monitoring sites that tap coastal aquifers with some level of salt water influence (Northland particularly), or deep and confined aquifers in which groundwater is known to be chemically evolved with relatively high TDS (Daughney and Wall, 2007). The lowest regional median values for electrical conductivity are for West Coast (85 $\mu\text{S/cm}$), Marlborough (151 $\mu\text{S/cm}$) and Canterbury (174 $\mu\text{S/cm}$). The low median electrical conductivity for West Coast groundwater probably reflects the diluting effect of the high regional rainfall. The low regional median electrical conductivity for Canterbury and Marlborough may reflect the importance of river seepage as a recharge mechanism, which tends to have lower TDS than recharge derived from rainfall that accumulates dissolved salts as it passes through the soil zone (Daughney and Reeves, 2005).

There are no DWSNZ or ANZECC guidelines for electrical conductivity (Table 4). However, electrical conductivity is correlated to TDS, and aesthetic guidelines exist for individual parameters such as Cl, Na and SO_4 . High TDS or high concentrations of the aforementioned ions are not pervasive issues in New Zealand aquifers—the relevant aesthetic GVs are exceeded at only 2-4% of all sites (Table 4).

Significant increasing and decreasing trends in electrical conductivity are detectable at 18.4% and 13.4% of monitoring sites considered in this report, respectively (Figure 1l, Table 5). Rates of change are slow at most sites, i.e. less than ± 10 $\mu\text{S/cm}$ per year. Not surprisingly, the median rate of change is positive for regions with a predominance of sites with increasing trends, such as Auckland, Canterbury, Marlborough, Southland and Tasman, and negative for regions with a predominance of sites with decreasing trends, such as Bay of Plenty and Otago (Figure 1l, Table 6). Trends in electrical conductivity in many regions are mirrored (in direction and relative magnitude) by trends in $\text{NO}_3\text{-N}$. More research on these relationships may indicate that electrical conductivity and $\text{NO}_3\text{-N}$ can be used in combination as indicators of human influence.

Year-by-year changes in electrical conductivity are evident in several regions (Table 7). Annual increases in most percentile values occur in Canterbury (Figure 8c), Wellington (Figure 8n), Marlborough (Figure 8g) and Northland (Figure 8h), whereas year-by-year decreases in percentile values are apparent in Otago (Figure 8i) and Tasman (Figure 8l). In all cases, these observed year-by-year changes in the percentiles of electrical conductivity appear to be caused by changes in the set of sites comprising the SOE networks. To illustrate, note that the Tasman SOE network included ten sites from 1995 to 2001, with six additional sites added to the network from 2002 onwards. On average, the six additional sites had lower electrical conductivity than the sites in the original SOE network, and so the percentiles calculated for the set of 16 SOE sites are in general less than the percentiles determined for the original ten SOE sites.

3.4 Factors controlling groundwater quality

The aim of this section is to identify and explain statistically significant relationships between the key indicators of groundwater quality and factors of potential influence such as well depth, aquifer characteristics, or surrounding land use and land cover.

3.4.1 Well depth and aquifer confinement

Well depth and aquifer confinement must be assessed together because they are correlated: for the sites considered in this report, there is a statistically greater proportion of shallow wells (less than 10 m deep) in unconfined than confined aquifers (Daughney and Wall, 2007). There are no statistically significant relationships between rates of change in the key indicator parameters and well depth or aquifer confinement for any of the parameters considered in this report. However, the median values of key indicators are related to well depth and aquifer confinement, as reported previously (Daughney and Wall, 2007):

- NO₃-N concentrations are higher for shallow wells (less than 10 m deep), especially in unconfined aquifers, but there are also many instances where high NO₃-N concentrations are found in deep wells and vice versa (Figure 9);
- *E. coli* concentrations are most often above the detection limit (>1 cfu/100 ml) for wells less than 10 m deep, especially in unconfined aquifers, but there are also many instances where *E. coli* is detected in deep wells and confined aquifers (Figure 10); and
- Electrical conductivity and concentrations of NH₄-N, Fe and Mn are higher for wells more than 50 m deep, especially in confined aquifers, but there are many instances where these parameters are elevated in shallow wells or unconfined aquifers (Figure 11).

The first two relationships almost certainly arise from human influence. On one hand, these relationships are to be expected, because unconfined aquifers are more susceptible to contamination, and proximity to the surface (the source of NO₃-N and microbial pathogens) is logically an important influence. However, it is clear from Figures 9 and 10 that deep wells in confined and semi-confined aquifers can also be susceptible to contamination by NO₃-N and/or microorganisms. Cases of microbial contamination in deep wells or confined aquifers probably reflect poor well-head protection more than the susceptibility of a particular type of aquifer (Sinton, 2001). Cases of NO₃-N contamination in deep wells or confined aquifers may indicate poor well-head protection, but can also arise in certain New Zealand aquifer systems where the groundwater tends to remain oxidised for a long distance along the flow path (e.g. Canterbury), possibly due to a low concentrations of organic matter required as the substrate for microbial denitrification (Langmuir, 1997). In Canterbury, NO₃-N contamination is also observed in deep wells in unconfined aquifers if the well screen is near the water table.

The third relationship probably reflects natural processes of water-rock interaction. Water-rock interaction tends to increase TDS, to which electrical conductivity is correlated (Langmuir, 1997). In addition to increases in TDS as groundwater moves along a flow path, natural processes also often (but not always) lead to the depletion of oxygen, which in turn favours the accumulation of dissolved Fe, Mn and NH₄-N (Langmuir, 1997, Daughney and Reeves, 2005).

3.4.2 Aquifer lithology

There are no significant relationships between aquifer lithology and the rates of change of any the key indicator parameters considered in this report. *E. coli* concentrations are likewise not related to aquifer lithology. However, aquifer lithology controls the persistence of oxygen, which has an indirect relationship on the median concentrations of the indicators NO₃-N, NH₄-N, Fe and Mn, as observed previously (Daughney, 2003, Daughney and Wall, 2007). Specifically, the transition from oxygen-rich to oxygen-poor status in an aquifer is mediated by microbial respiration, which requires the presence of a reductant—organic carbon in most cases. In aquifer lithologies with low concentrations of organic carbon, such as ignimbrite, rhyolite, and some gravels (e.g. Canterbury), the groundwater remains oxygen-rich, and this favours the persistence of NO₃-N and prevents the transformation to or accumulation of NH₄-N and dissolved forms of Fe and Mn. The opposite case applies to lithologies that do contain abundant organic carbon, which is why concentrations of NH₄-N, Fe and Mn are often observed to be high (and NO₃-N concentrations low) in lignite, clay and some sand aquifers.

3.4.3 Surrounding land use and land cover

This report has not revealed any systematic significant relationships between land use or land cover and any of the key indicators of groundwater quality (state or trends). This result applies whether all monitoring sites are considered together, or if the data set is limited to the sites less than 10 m deep (at which the impact of land use would probably be most apparent). The lack of detectable relationship between land use and groundwater quality has been observed in several previous studies (Close et al., 1995; Reijnders et al., 1998; Broers and van der Grift, 2004; Daughney and Reeves, 2005, 2006; Daughney and Wall, 2007). Daughney and Wall (2007) stated that relationships between groundwater quality and land use are difficult to elucidate because:

- land use observations are usually made by eye and may not accurately describe land use or land use intensity;
- the groundwater at the monitoring site might not have entered the aquifer in the area where the land use observation was made;
- impacted groundwater might not have had time to travel all the way from its source area to the monitoring site; and/or
- substances indicative of land use impact (e.g. NO₃-N) might have been transformed or degraded before reaching the monitoring site.

4.0 CONCLUSIONS

The national and regional assessments of groundwater quality made in this report (based on data collected from 1995 to 2008) are in good agreement with the findings of Daughney and Wall (2007) (based on data collected from 1995 to 2006).

At the national scale, groundwater quality in New Zealand is similar to other countries such as Finland, Canada and the Netherlands (Frapporti et al., 1994; Lahermo et al., 1999; Broers

and van der Grift, 2004; Lesage, 2005; Griffioen et al., 2005). New Zealand has two major but mutually exclusive national-scale groundwater quality issues:

- Contamination with nitrate and/or microbial pathogens (of presumably human or agricultural origin) occurs in all regions, but is especially common in Waikato, Southland and Canterbury, and particularly for oxygen-rich groundwater extracted from shallow wells in unconfined aquifers. Nationally, the median NO₃-N concentration exceeds the health-related MAV for drinking water and the TV for ecosystem protection at 4.8% and 13.2% of monitoring sites, respectively. The health-related MAV for *E. coli* is exceeded at 23.1% of the monitoring sites considered in this report, but may be more an indication of poor well-head protection than the vulnerability of any particular type of aquifer.
- Naturally elevated concentrations of NH₄-N, Fe and/or Mn are found in many regions, especially Manawatu-Wanganui, Hawke's Bay and Bay of Plenty, and particularly for oxygen-poor groundwater extracted from deeper wells in confined aquifers. Nationally, 3.8%, 21.3% and 26.9% of the sites considered in this report have median concentrations of NH₄-N, Fe and Mn above their respective aesthetic GVs for human consumption, and 9.9% of sites have median Mn concentration above the health-related MAV (there is no MAV for NH₄-N or Fe). Many groundwaters with elevated NH₄-N, Fe and/or Mn also have high electrical conductivity and hence might exceed aesthetic water quality guidelines for Cl, Na, SO₄ or TDS.

At about two thirds of the monitoring sites considered in this report, groundwater quality was found to be either constant over time or changing slowly (parameter values change less than 2-5% per year), probably due to the natural processes of water-rock interaction. The remaining one third of the monitoring sites show more rapid changes in groundwater quality, with patterns of change that appear to reflect human influence. However, attempts to identify and interpret time trends in groundwater quality are complicated by year-by-year changes in the structure of the various regional SOE programmes. The greatest uncertainties in the regional aggregated statistics are introduced by changes in sampling methodology, because these tend to be applied to all SOE sites at once. For example, the high proportion of sites and regions with decreasing trends in Fe and/or Mn might be caused by improvements in sampling methods between 1995 and 2008: several regional councils started to field-filter samples for Fe and Mn analysis some time around 2004 (e.g. Wellington), whereas in the past an unfiltered sample might have been collected for this purpose. A secondary source of bias in the aggregated statistics is caused by addition or removal of sites to a region's SOE network. Generally, the addition or removal of just one site out of an entire SOE network has relatively little influence on the aggregated statistics, but in certain cases, there are changes made to a substantial proportion monitoring sites. For example, the apparent year-by-year decrease in NO₃-N concentration in the Tasman region is an artefact of the expansion of the SOE network from 10 to 16 sites in 2002. Changes in analytical procedure can also influence the aggregated statistics, as observed for the shift from monitoring total coliform counts to monitoring of *E. coli*.

The factors that control groundwater quality are often difficult to identify. There were observable relationships between groundwater quality and well depth and aquifer characteristics, but no detectable relationships between groundwater quality (state or trends) and land use or land cover around the monitoring sites. This is in fact a common result that

has been observed in several previous studies in New Zealand and overseas: it is hard to identify and understand relationships between groundwater quality and land use unless the age and source of the groundwater being monitored are accurately known.

5.0 RECOMMENDATIONS

The main recommendation from this report is that similar studies should be conducted at a regular interval in the future, in order to identify changes in the status of groundwater quality in New Zealand. The following recommendations can be made with respect to the design of future investigations:

- Future investigations should make use of the six key indicators of groundwater quality employed in this report, namely $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, *E. coli*, Fe, Mn and electrical conductivity, in order to track changes caused by human as well as natural drivers;
- In addition to quarterly to annual monitoring the above-mentioned key indicators of groundwater quality, bi- or triennial surveys should be undertaken to assess the occurrence of emerging contaminants such as pesticides, pharmaceuticals, endocrine disruptors, fertiliser additives (e.g. cadmium), etc.;
- Rates of change in the indicator parameters are generally slow, so a two- or three-yearly interval for repeat investigations of this type is suitable, to allow for detection of significant changes in groundwater quality relative to seasonal variation;
- National and regional commitment is needed to monitoring the indicators of groundwater quality via standardised sampling and analytical methods, at a regular (periodic) interval (ideally quarterly), on an on-going basis, and at a consistent network of monitoring sites, all of which have suitable well-head protection;
- The sites comprising the regional SOE monitoring networks must be selected to provide a representative perspective of groundwater quality for the region, which by necessity will require a certain number of monitoring sites in pristine areas to provide valuable “baseline” (background) data, to determine what threshold should be used to identify groundwater quality issues and trends that are important in a management perspective; and
- The age and origin of the groundwater that is actually being sampled should be determined for each monitoring site, and accurate information pertaining to current and past surrounding land use must be compiled (e.g. from satellite imagery) in order to elucidate the drivers of groundwater quality.

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7.0 ACKNOWLEDGEMENTS

Regional council groundwater scientists are thanked for provision of data and for their reviews of a draft version of this report. Mike Thompson (Ministry for the Environment), Chris Nokes (ESR) and Gil Zemansky (GNS Science) are thanked for reviewing an early version of this report.

FIGURES

Most of the figures in this section show the distribution of data as box and whisker plots. The horizontal lines in the middle of each box are median values and the upper and lower bounds of each box are the 75th and 25th percentiles respectively. The horizontal lines at the upper and lower ends of the whiskers are 95th and 5th percentiles, respectively

Figure 1. National and regional summary statistics for state and trends in key indicators of groundwater quality based on all data collected from 1995 to 2008 (cf. Section 2.2). Numbers above X axes show the number of sites at which state and trend statistics could be calculated for the parameter in question for the region of interest. Colour coding for box-whisker plots shows national-level statistics (blue) or regional-level statistics (red).

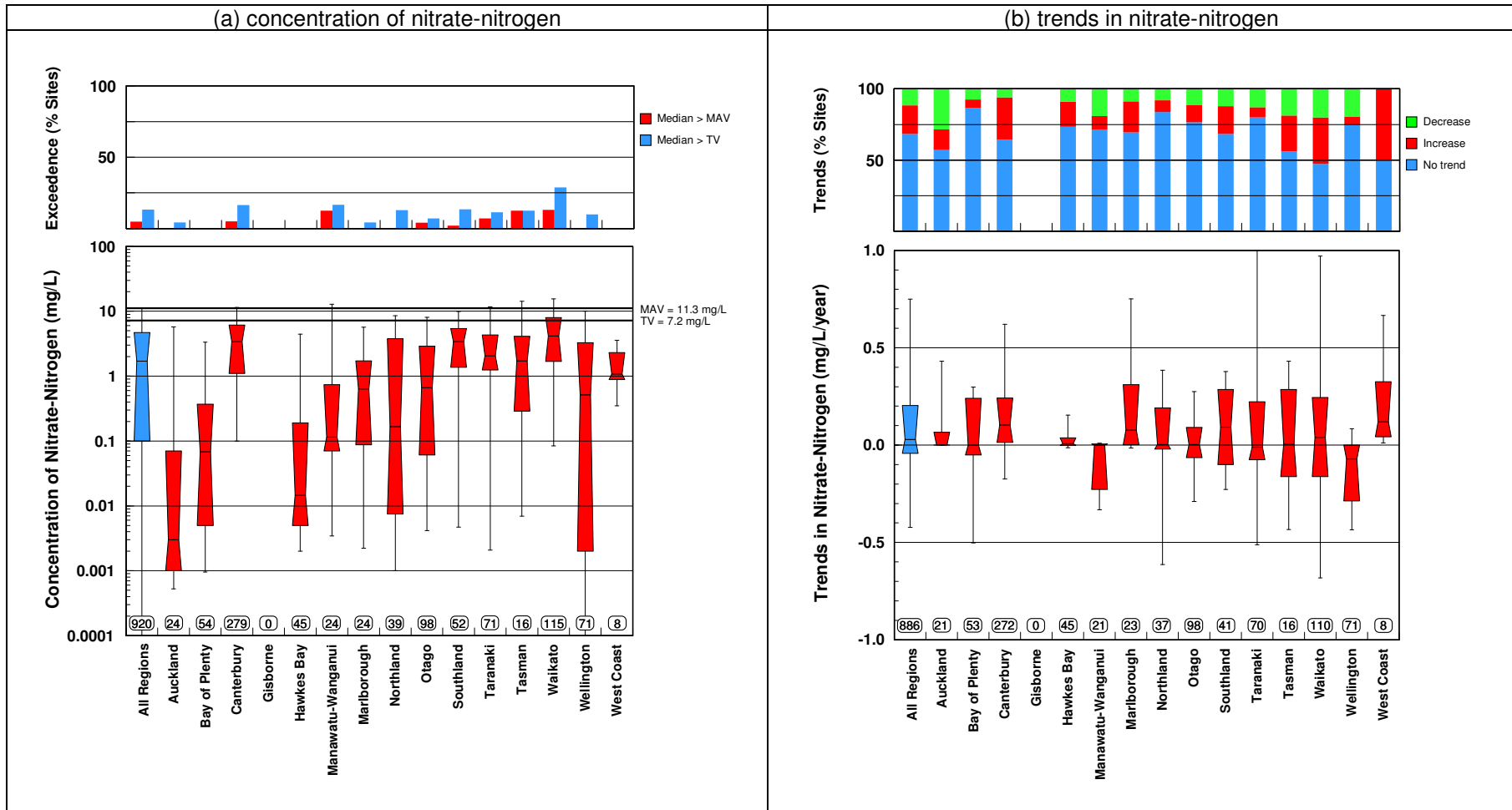


Figure 1. Continued

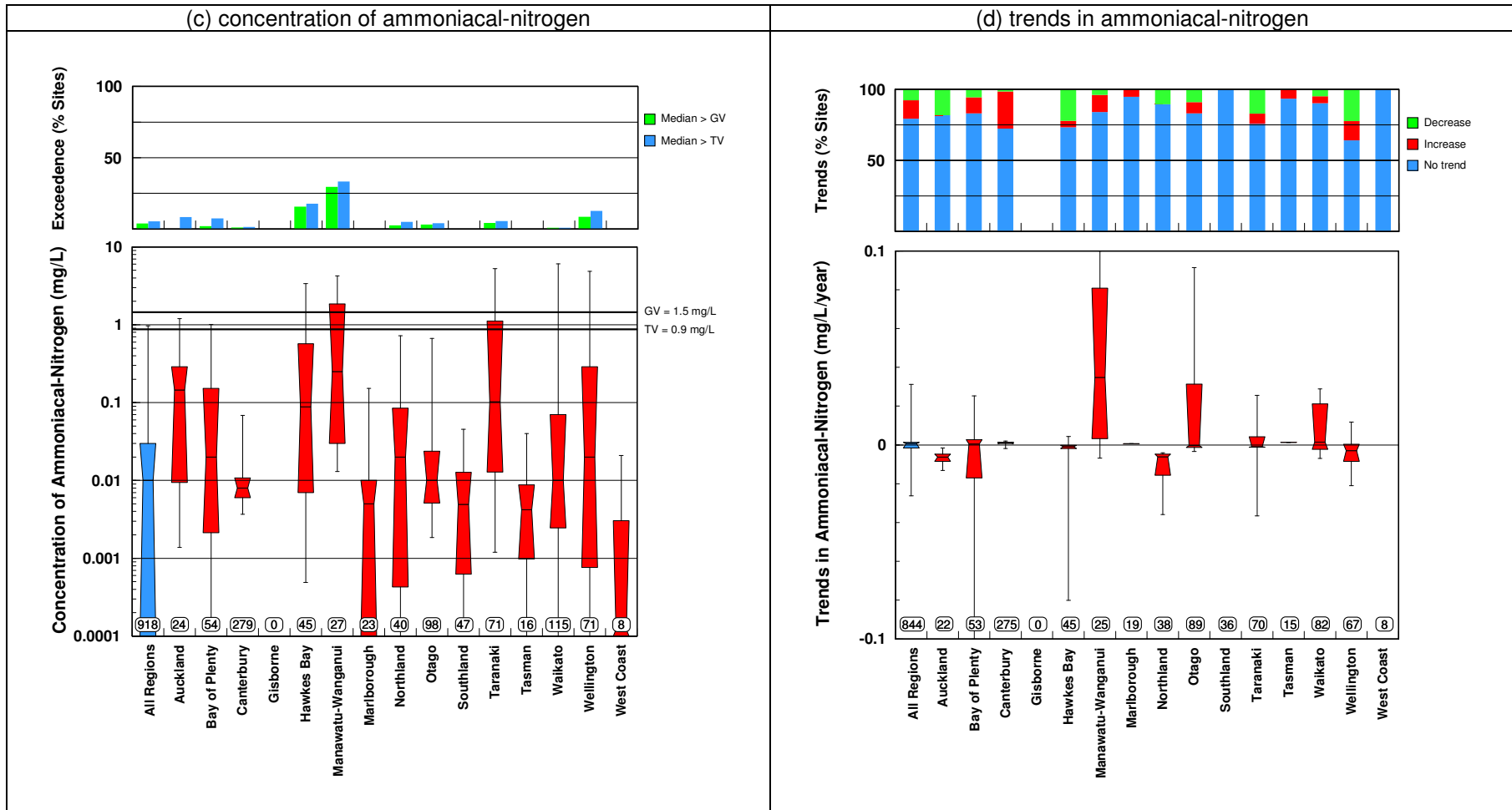


Figure 1. Continued

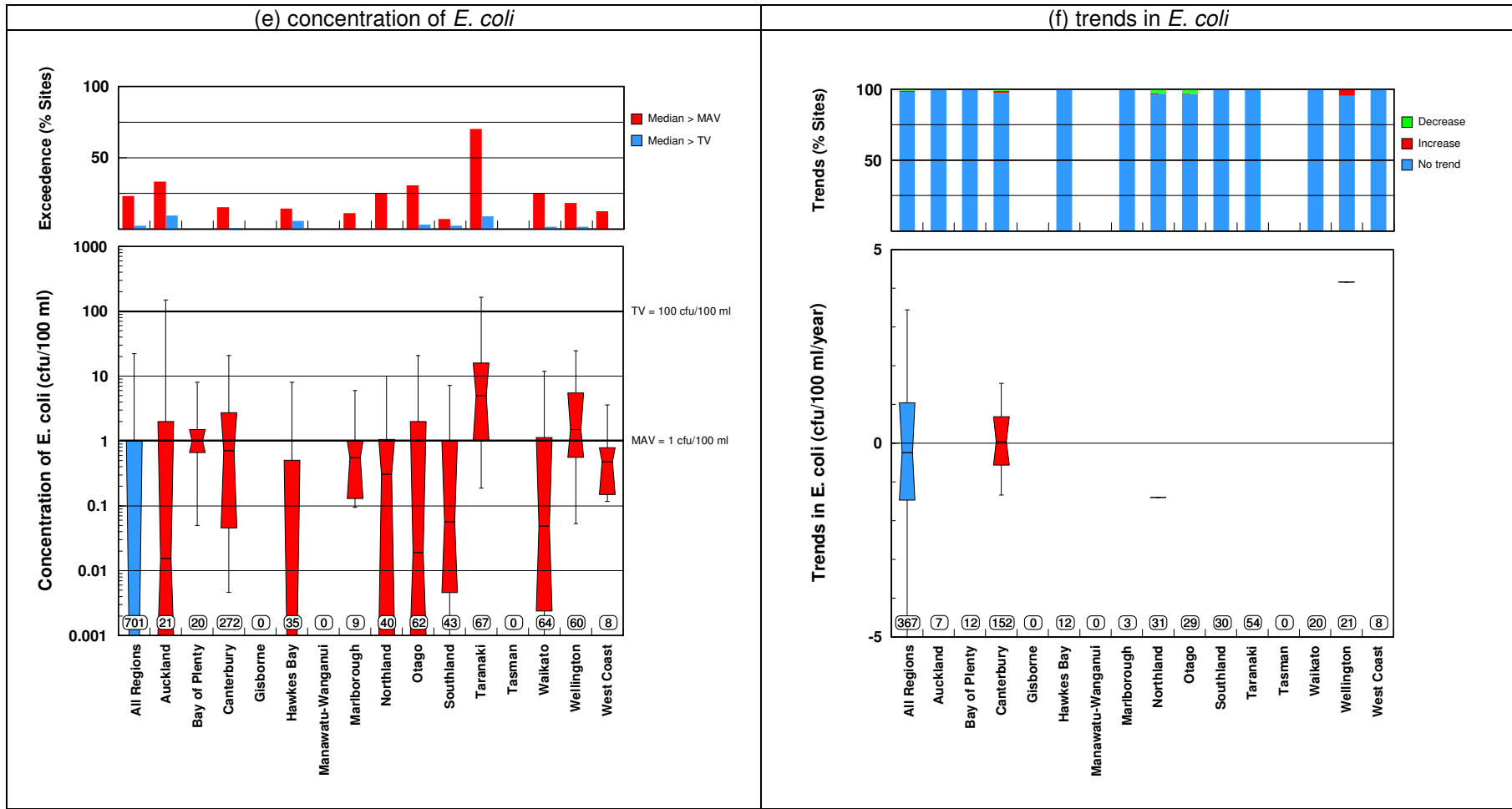


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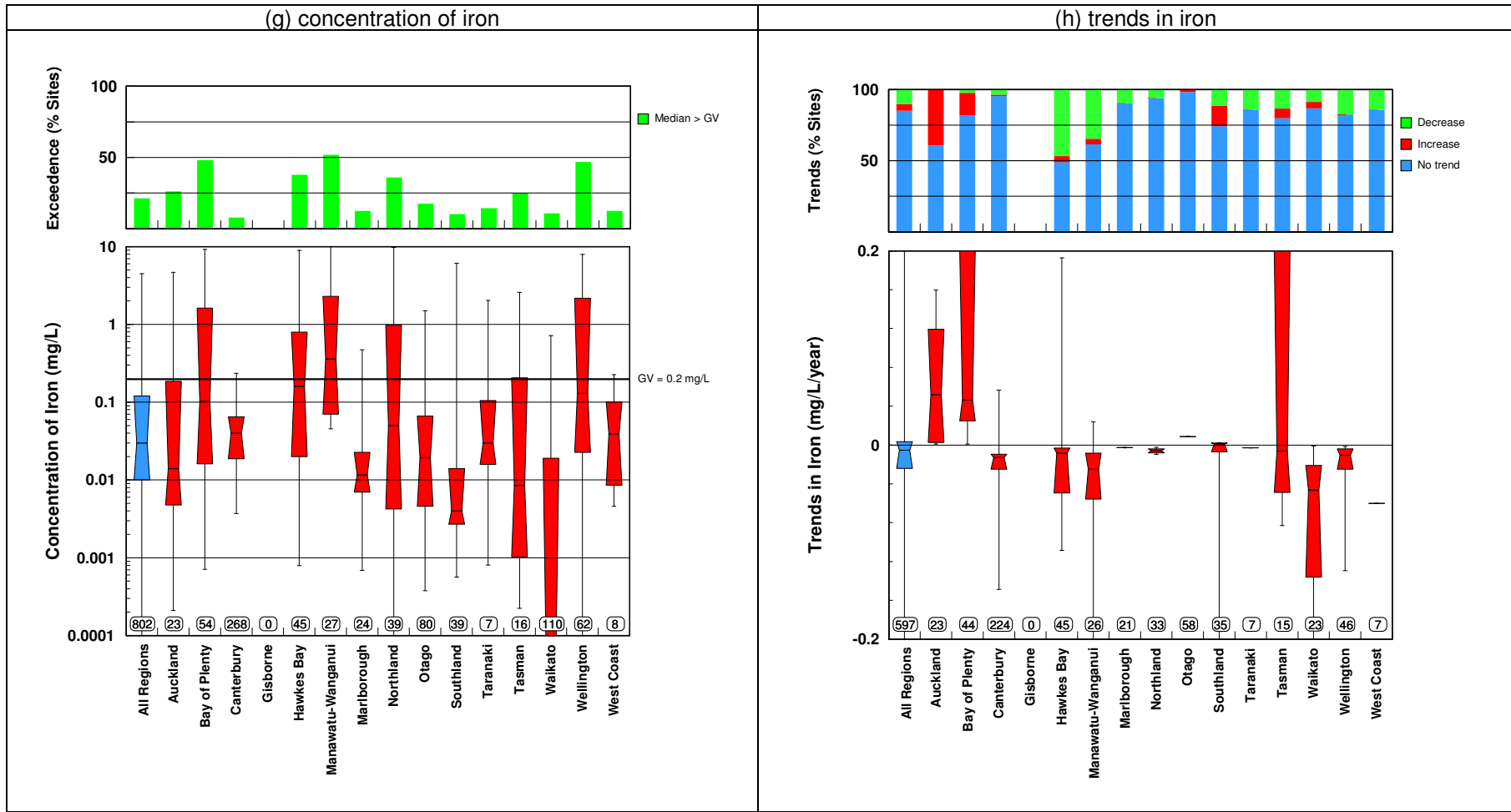


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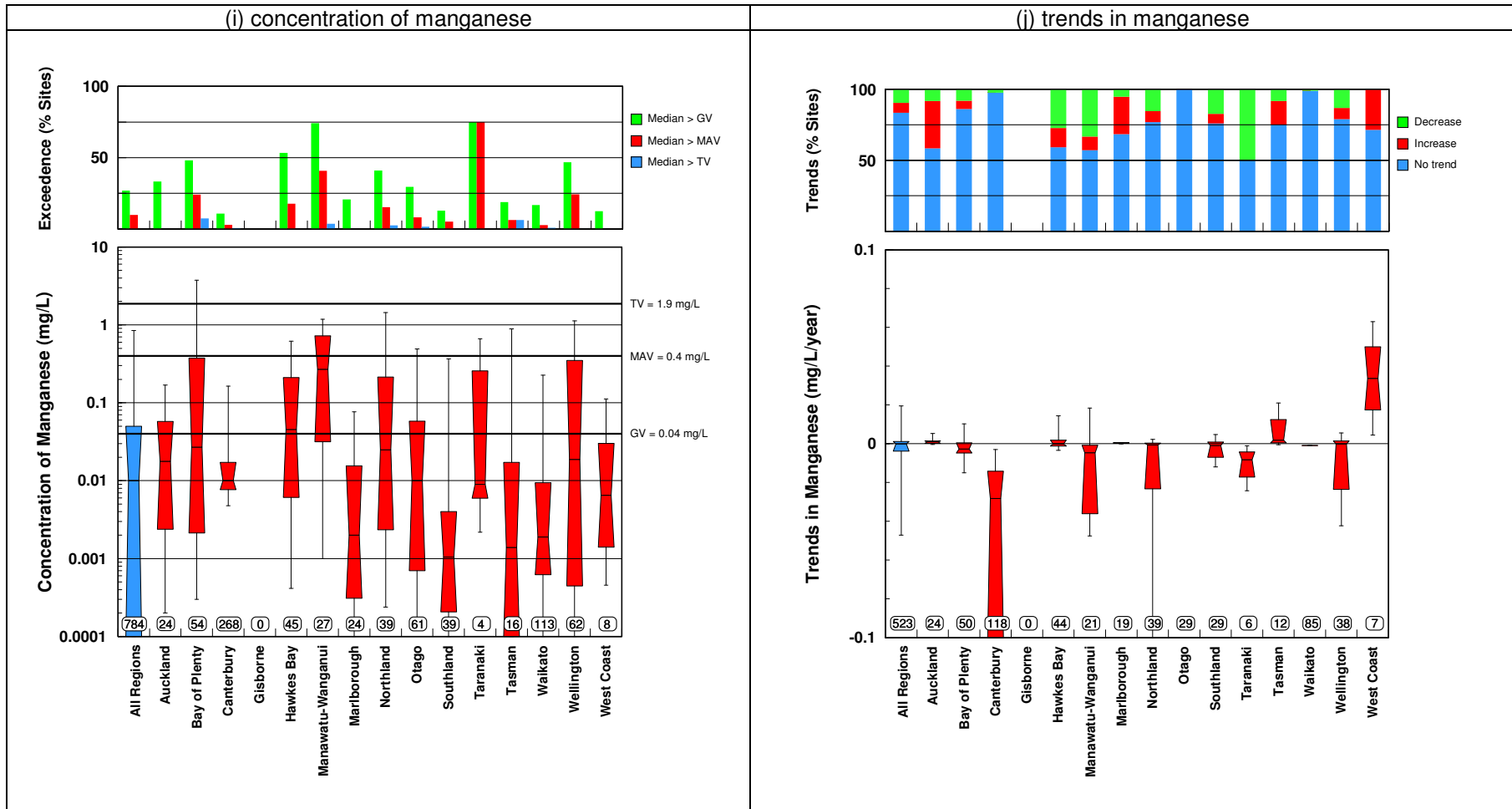
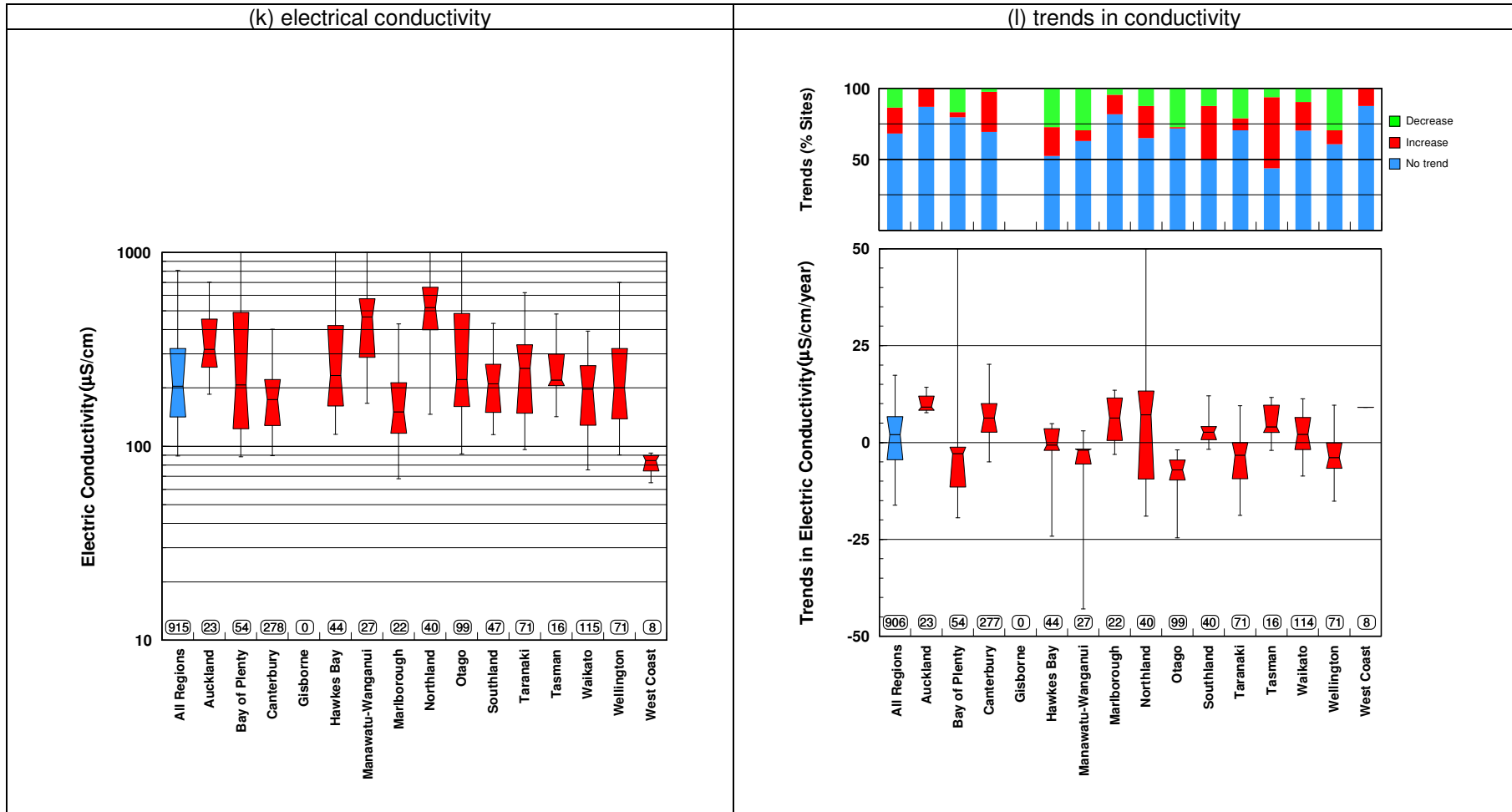
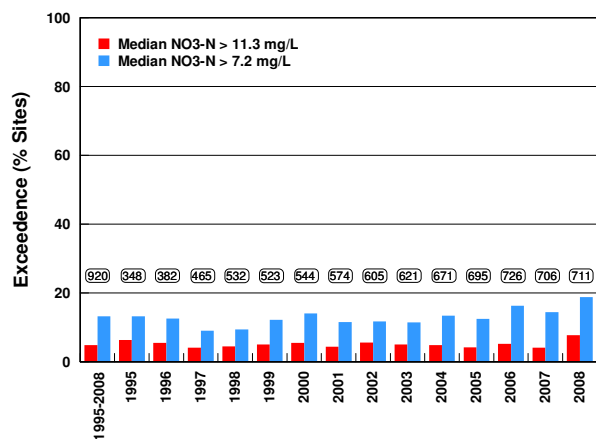


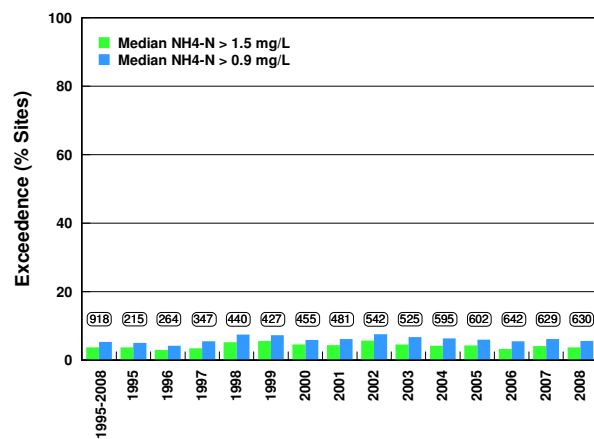
Figure 1. Continued



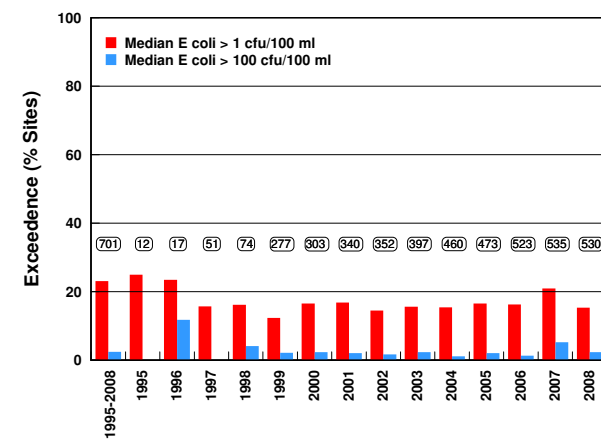
(a) nitrate-nitrogen



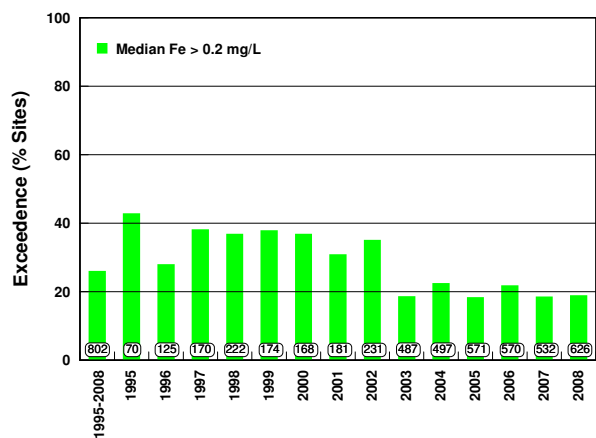
(b) ammoniacal-nitrogen



(c) E.coli



(d) iron



(e) manganese

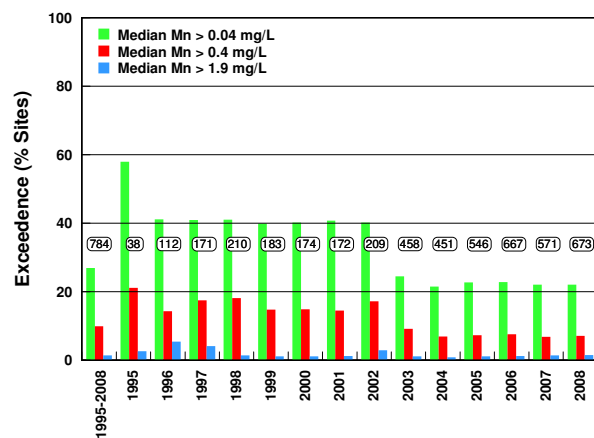


Figure 2. Year-by-year change in percentage of New Zealand monitoring sites exceeding standards or guidelines for human consumption and ecosystem protection specified in the DWSNZ and ANZECC, respectively. Numbers above X axes show the number of sites at which state and trend statistics could be calculated for the parameter in question for the region of interest.

Figure 3. Year-by-year changes in regional percentiles for **nitrate-nitrogen (NO₃-N)** in groundwater based on site-specific median values. Y axis scales in mg/L. Numbers above X axes show the number of sites at which median values could be calculated for the region and calendar year of interest. Horizontal lines on each graph represent the health-related Maximum Acceptable Value (11.3 mg/L) specified in the DWSNZ and the Trigger Value for ecosystem protection (7.2 mg/L) defined in the ANZECC guidelines.

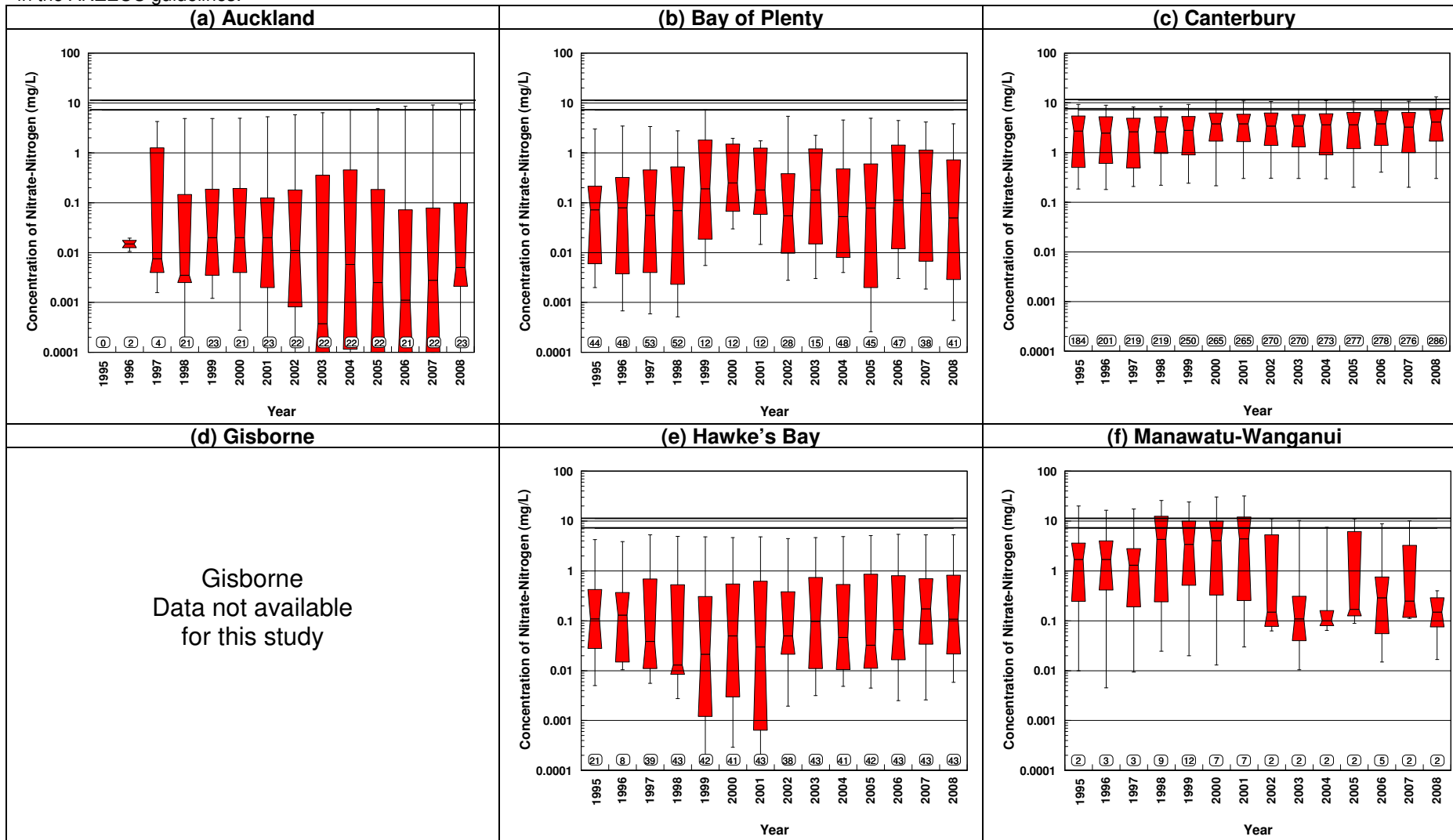


Figure 3. Continued

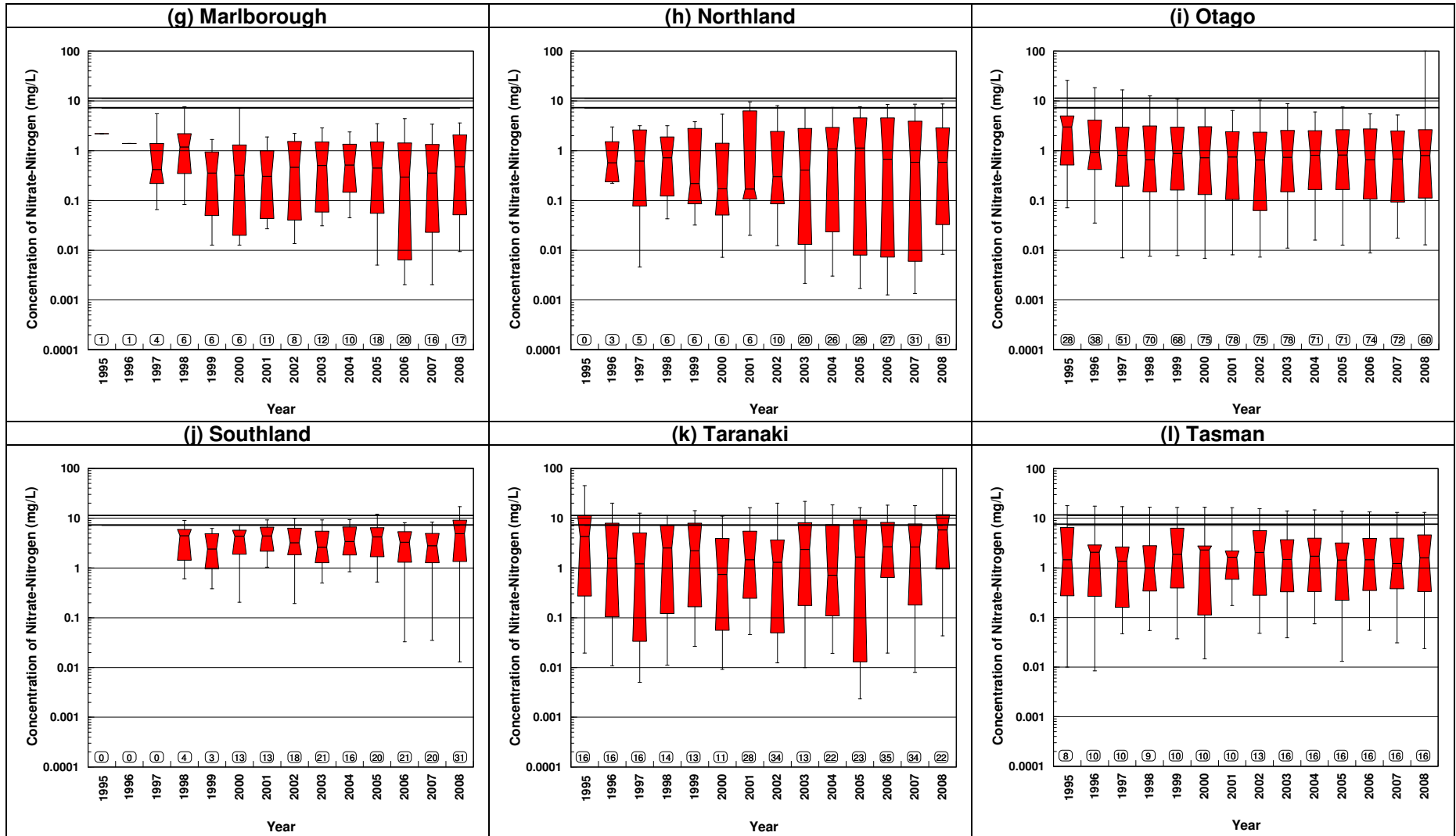


Figure 3. Continued

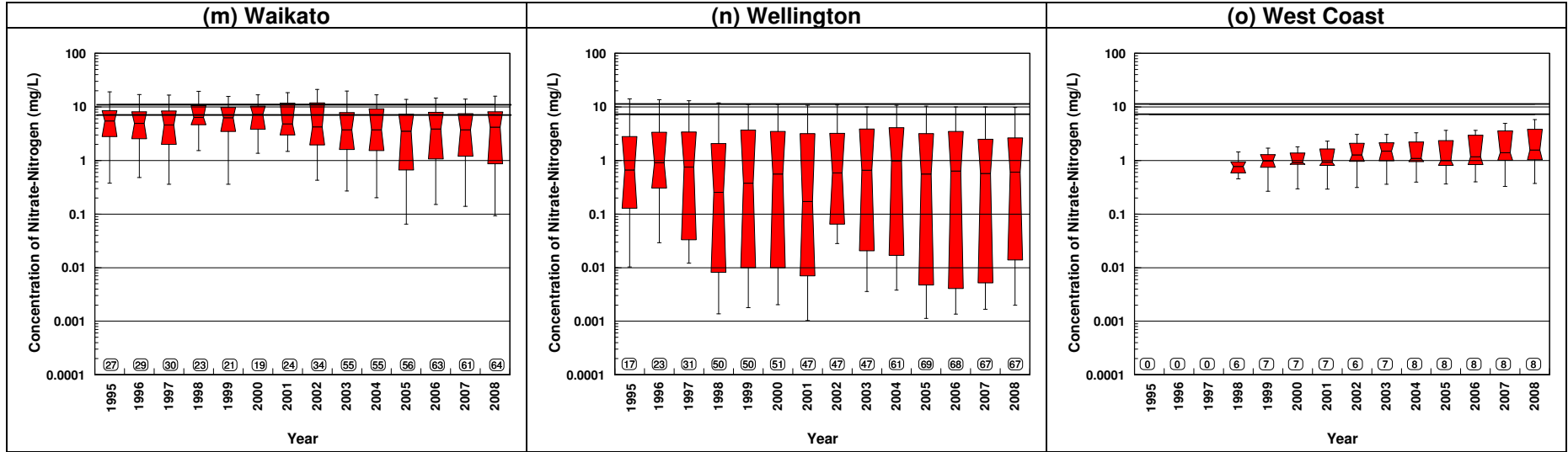


Figure 4. Year-by-year changes in regional percentiles for **ammoniacal-nitrogen (NH₄-N)** in groundwater, based on site-specific median values. All Y axis scales in mg/L. Numbers above X axes show the number of sites at which median values could be calculated for the region and calendar year of interest. Horizontal lines on each graph represent the aesthetic Guideline Value (1.5 mg/L) specified in the DWSNZ and the Trigger Value for ecosystem protection (0.9 mg/L) defined in the ANZECC guidelines.

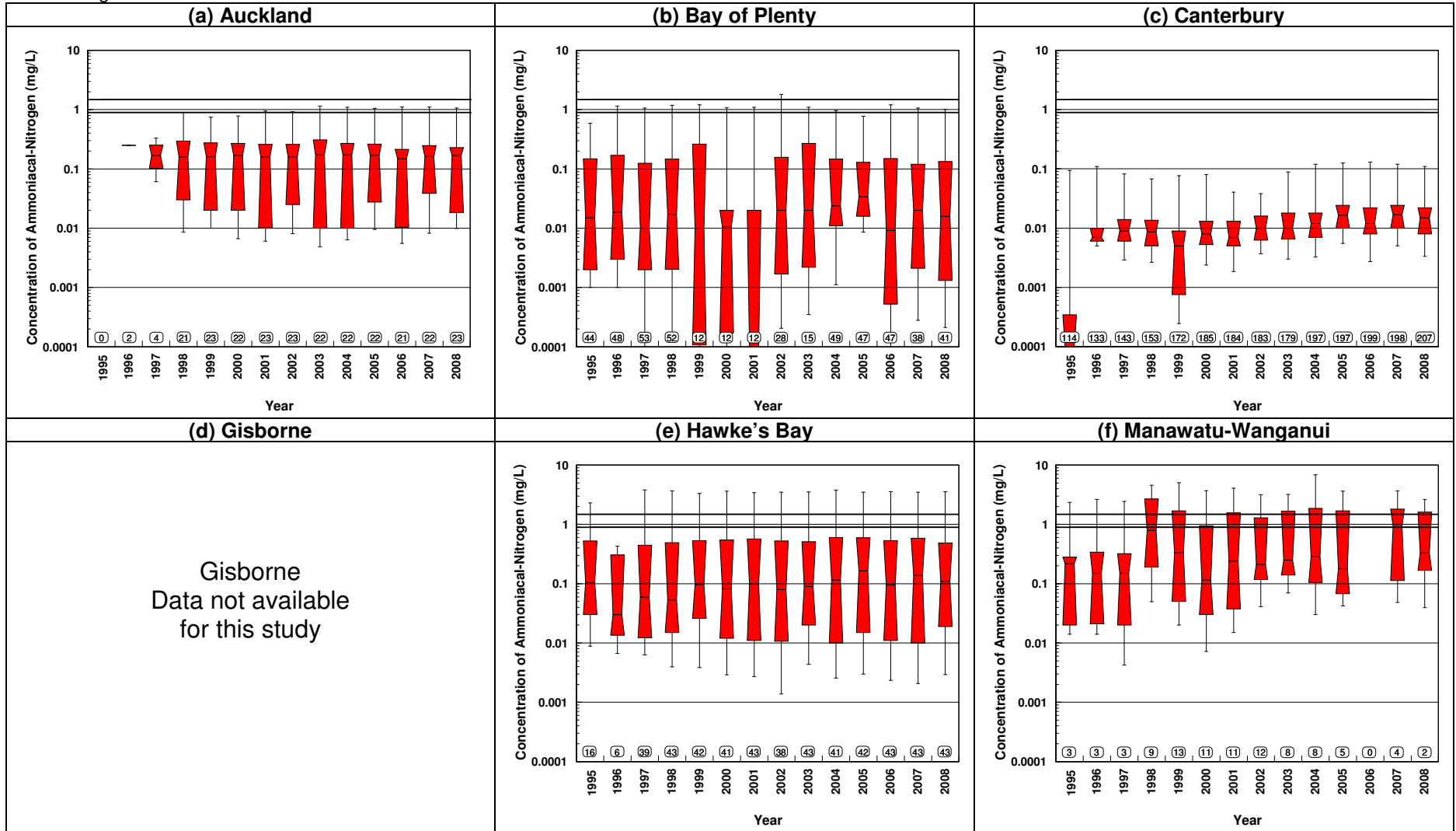


Figure 4. Continued

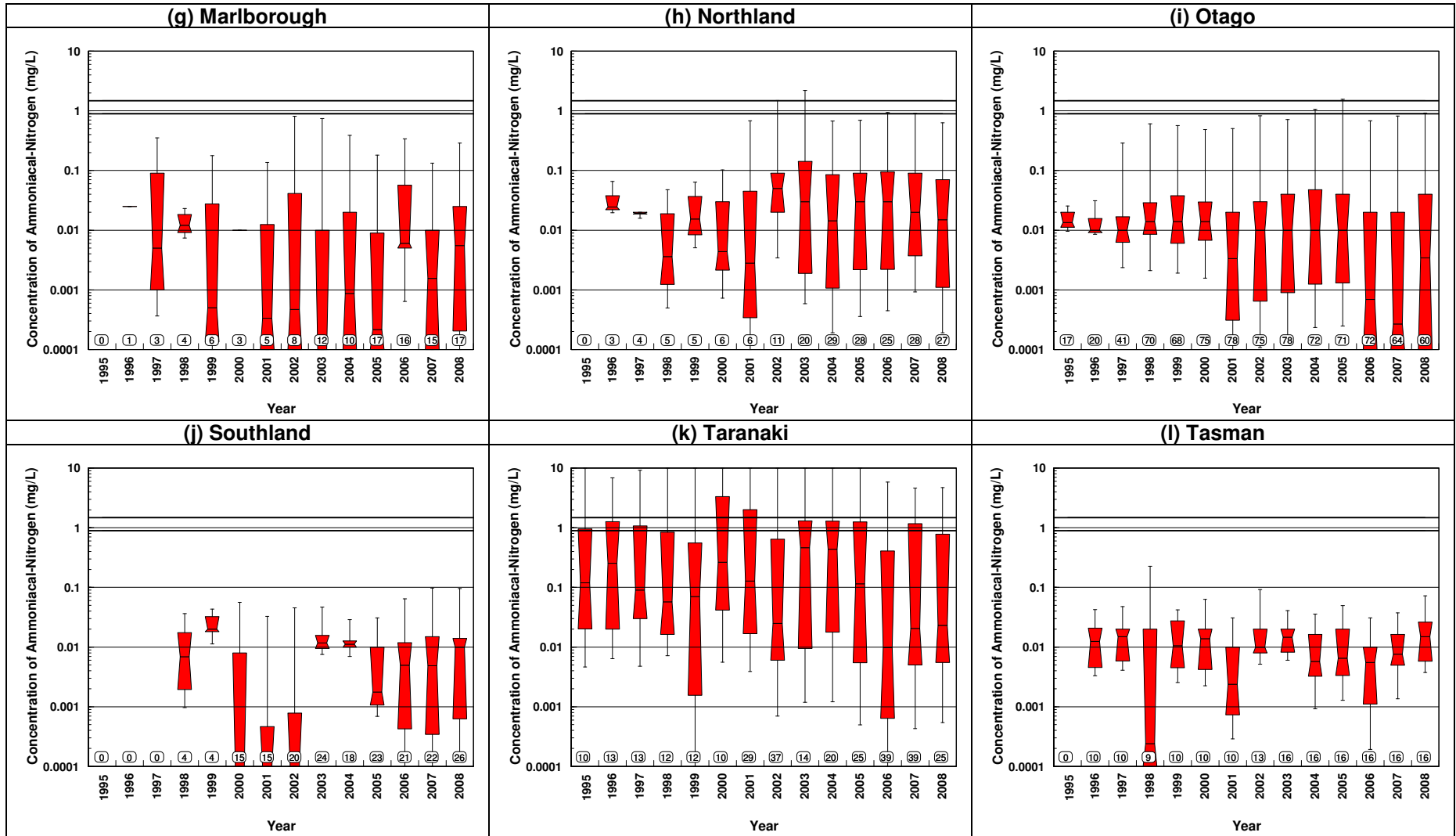


Figure 4. Continued

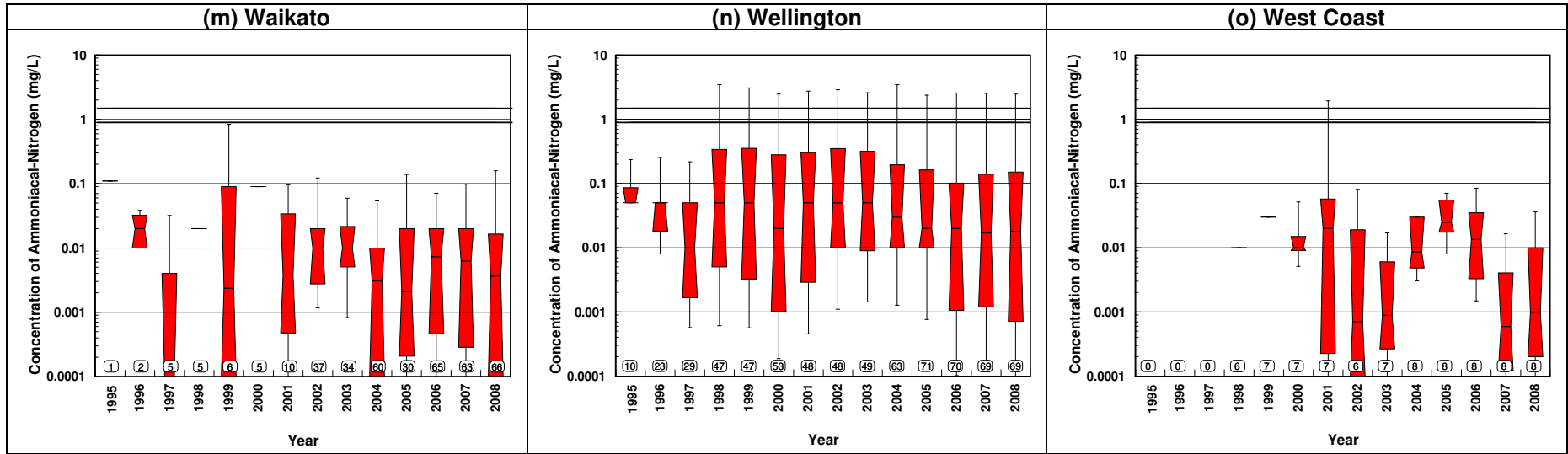


Figure 5. Year-by-year changes in regional percentiles for *E. coli* in groundwater, based on site-specific median values. Faecal coliform concentrations (blue) or total coliform concentrations (green) used where *E. coli* data were not available. All Y axis scales in cfu/100 ml. Numbers above X axes show the number of sites at which median values could be calculated for the region and calendar year of interest. Horizontal lines on each graph represent the health-related Maximum Acceptable Value (1 cfu/100 ml) specified in the DWSNZ and the Trigger Value for livestock consumption (100 cfu/100 ml) defined in the ANZECC guidelines.

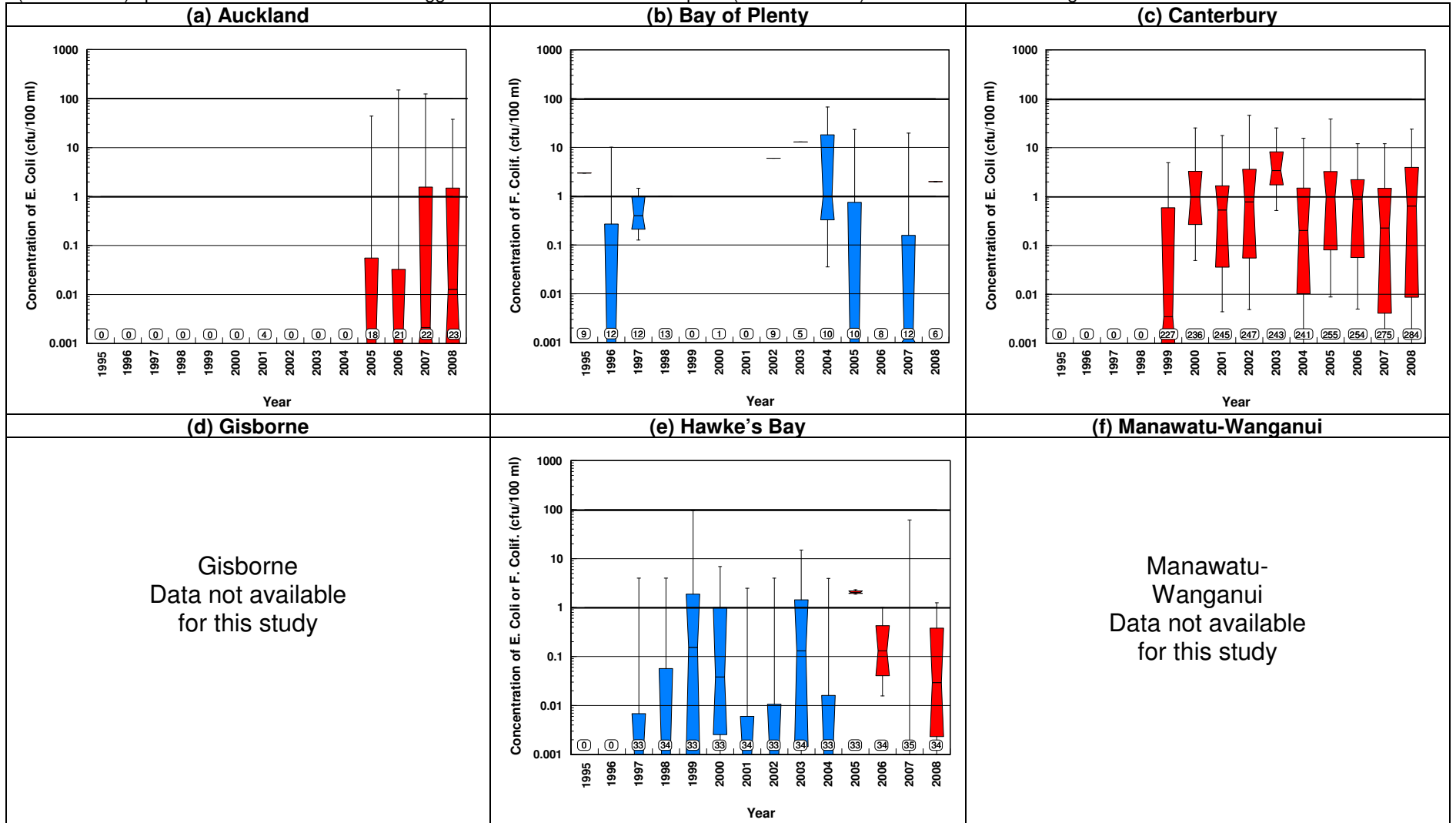


Figure 5. Continued

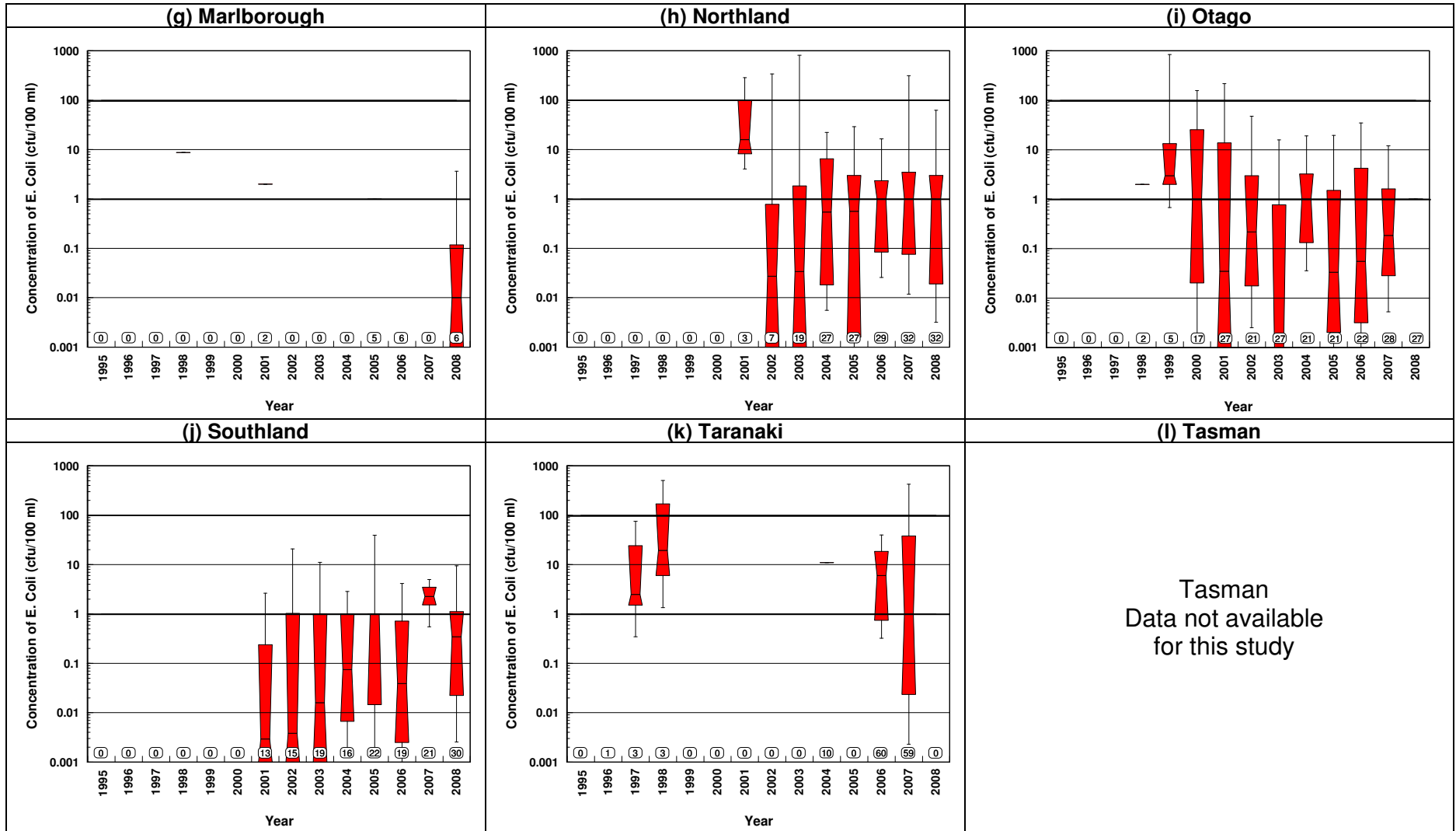


Figure 5. Continued

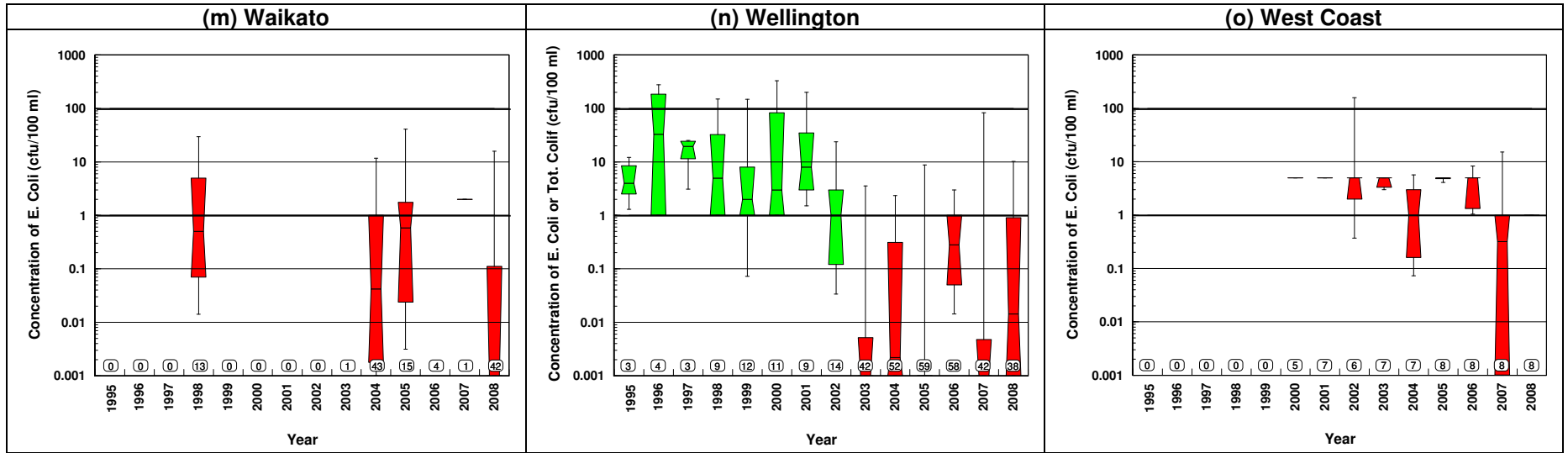


Figure 6. Year-by-year changes in regional percentiles for **dissolved iron** (Fe) in groundwater. Total Fe concentrations (blue) used where dissolved Fe data were not available. All Y axis scales in mg/L. Numbers above X axes show the number of sites at which median values could be calculated for the region and calendar year of interest. Horizontal line on each graph represents the aesthetic Guideline Value (0.2 mg/L) specified in the DWSNZ.

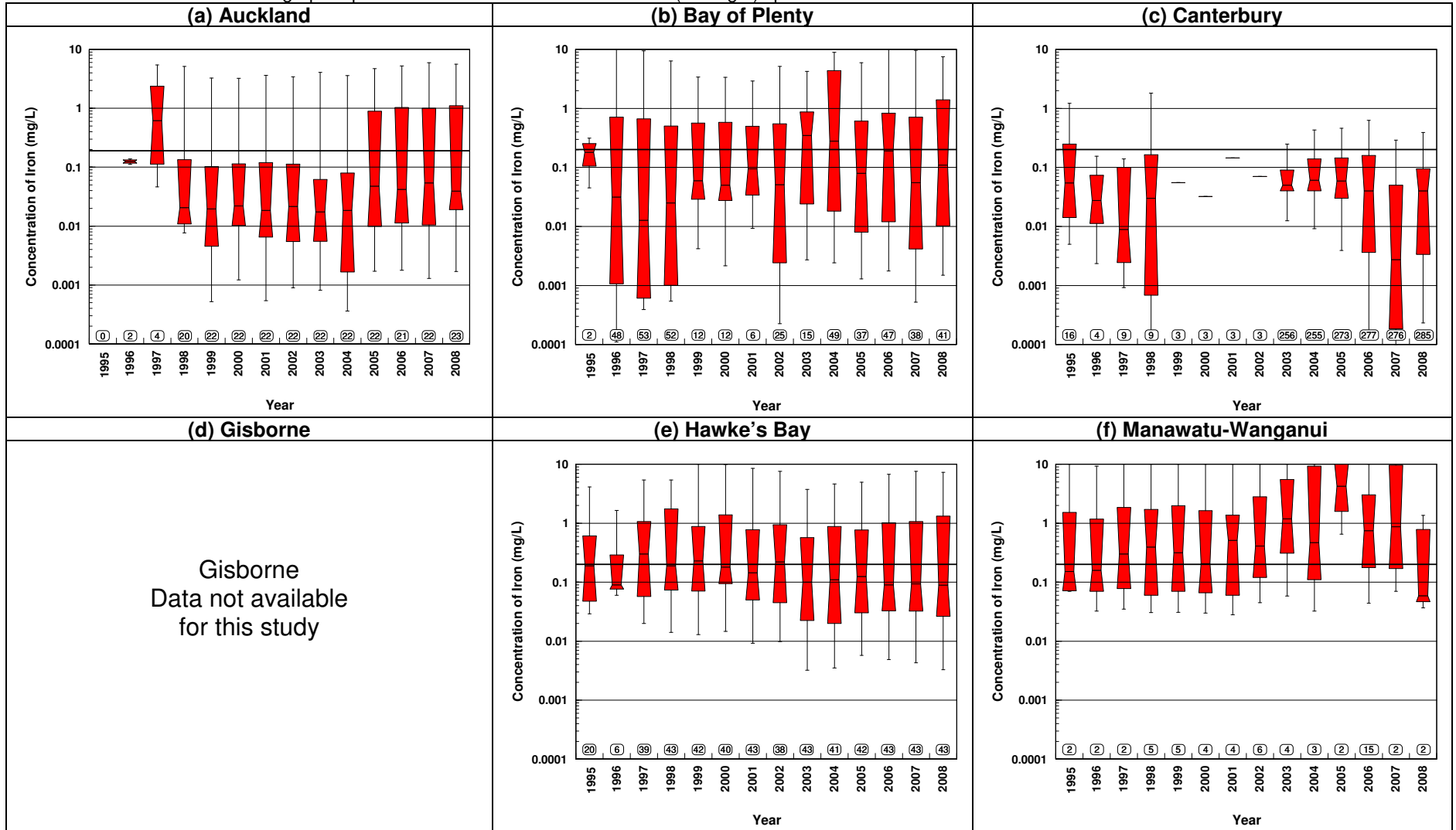


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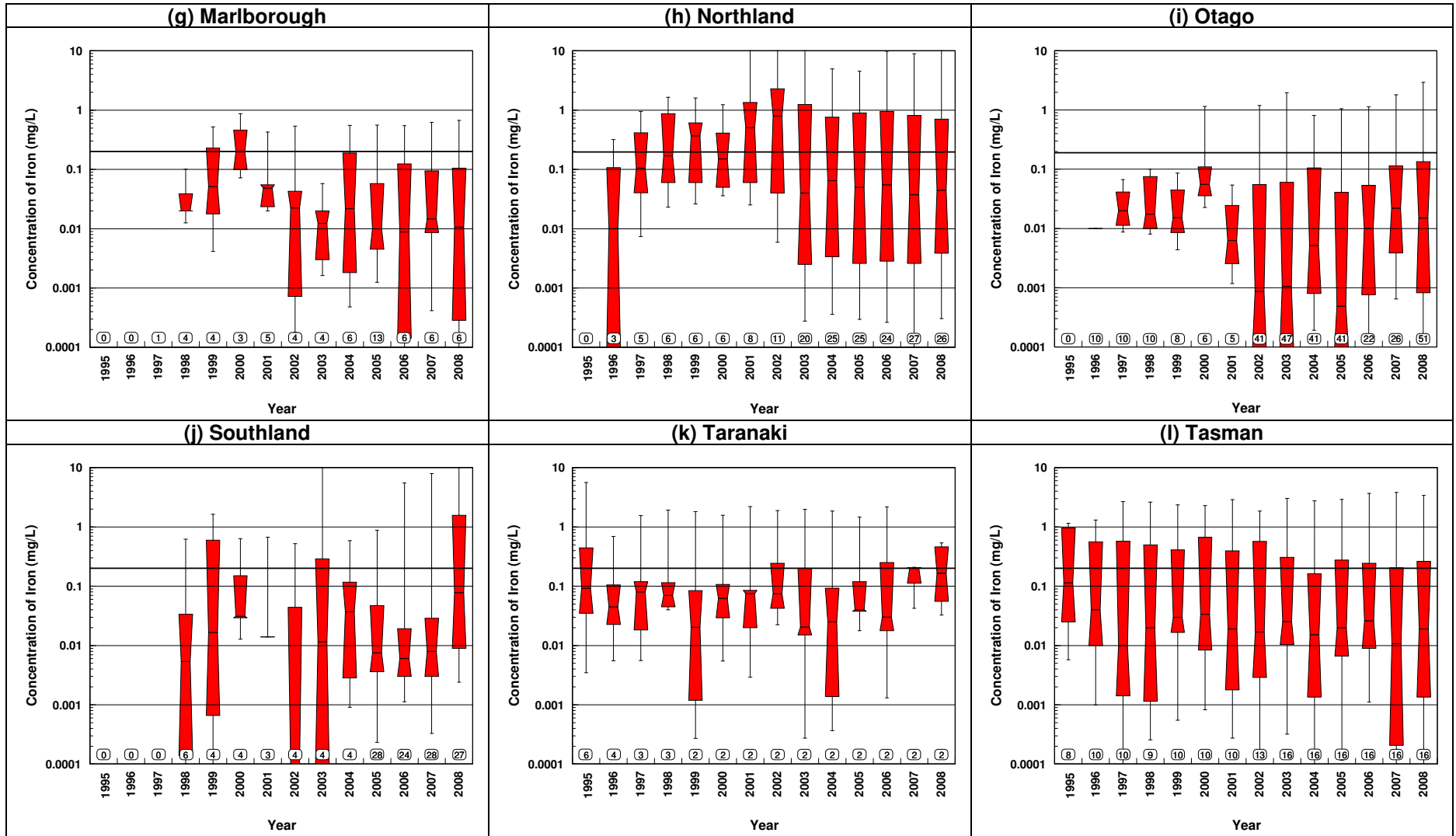


Figure 6. Continued

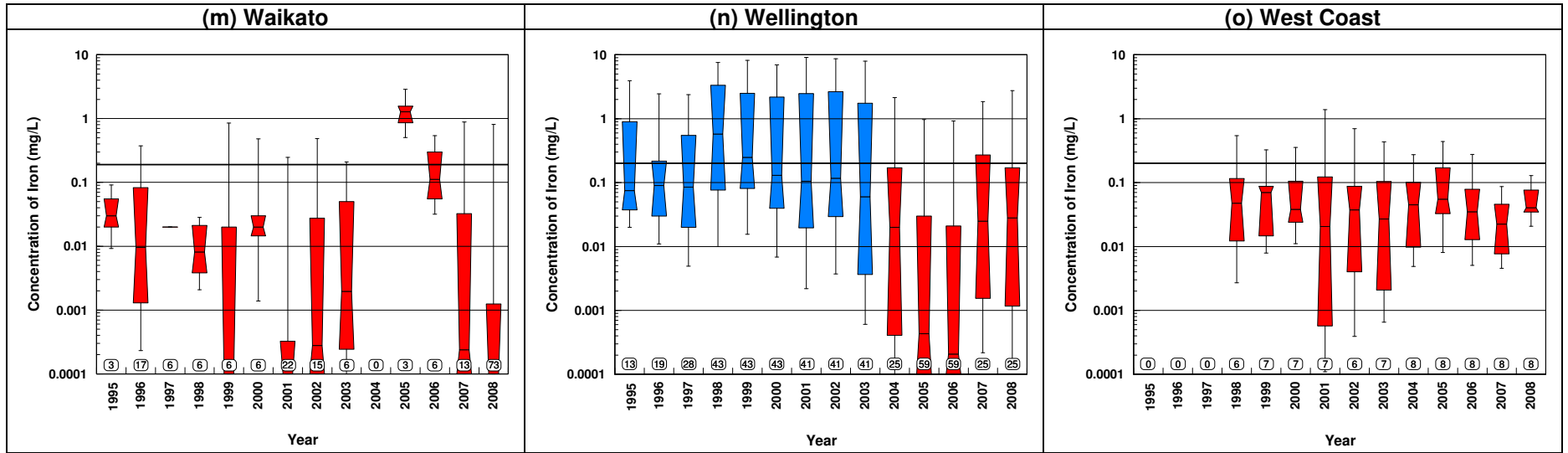


Figure 7. Year-by-year changes in regional percentiles for **manganese** (Mn) in groundwater. Total Mn concentrations (blue) used where dissolved Mn data were not available. All Y axis scales in mg/L. Numbers above X axes show the number of sites at which median values could be calculated for the region and calendar year of interest. Horizontal lines on each graph represent the aesthetic Guideline Value (0.04 mg/L) and the health-related Maximum Acceptable Value (0.4 mg/L) specified in the DWSNZ and the Trigger Value for ecosystem protection (1.9 mg/L) defined in the ANZECC guidelines.

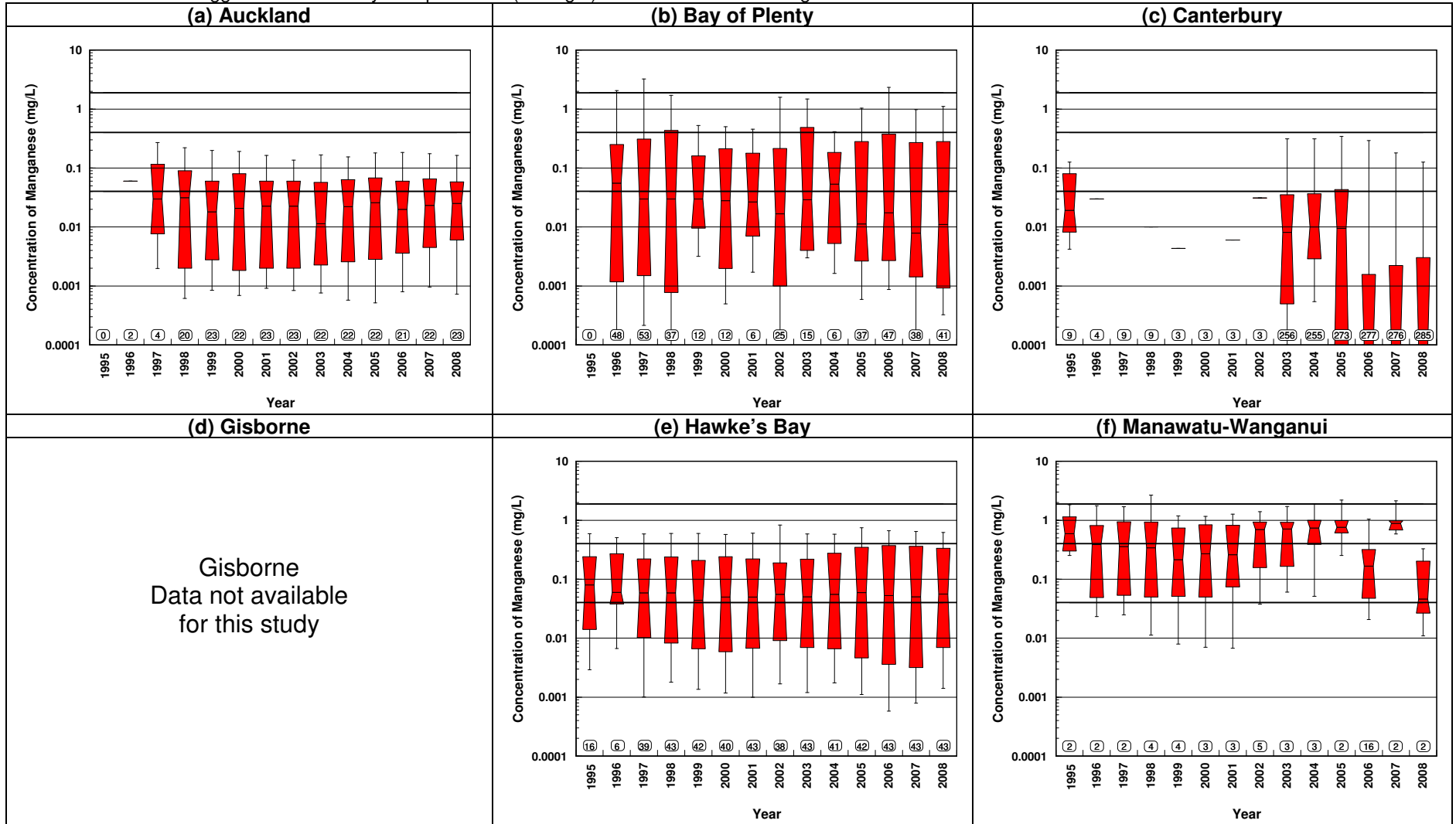


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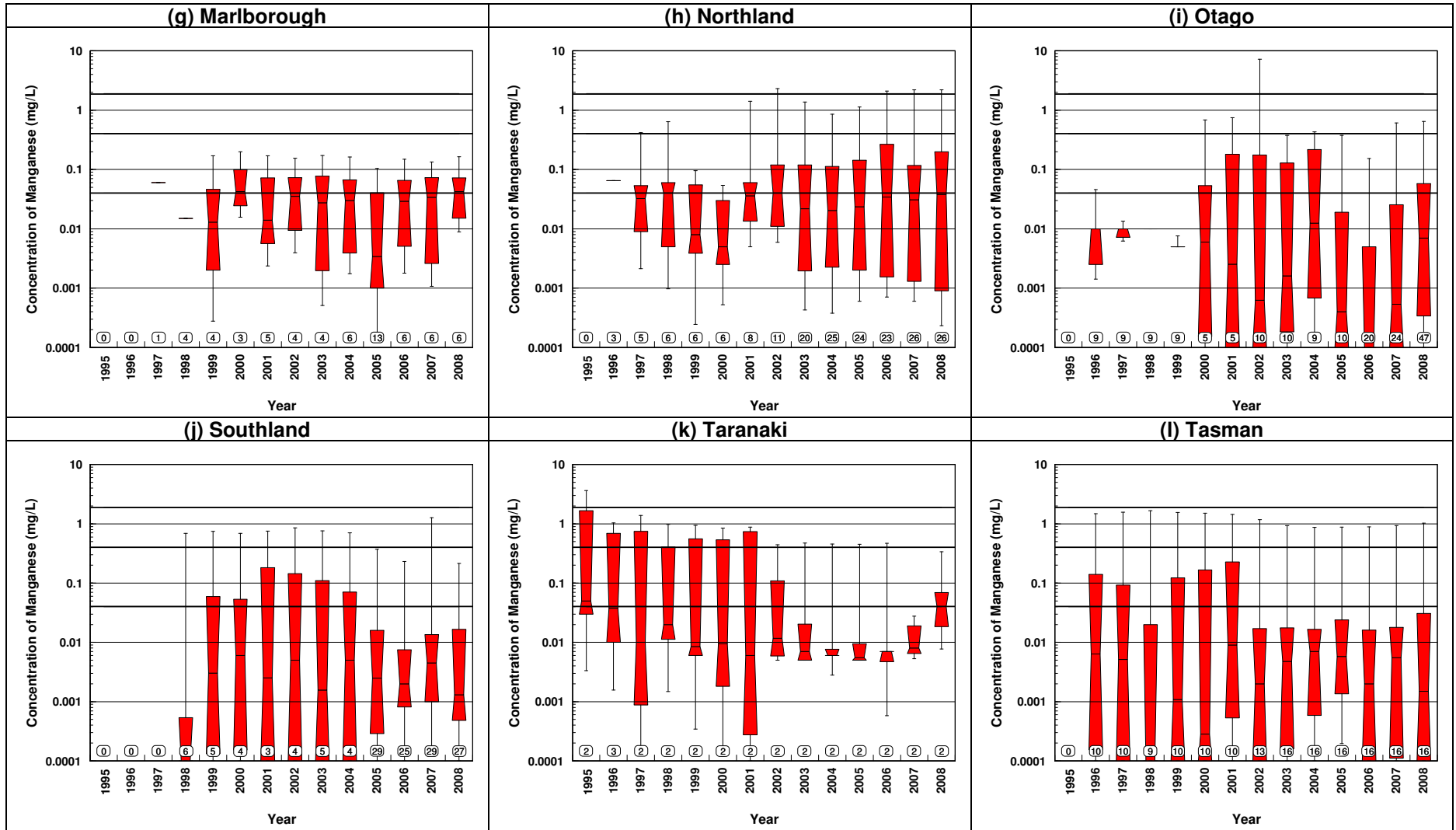


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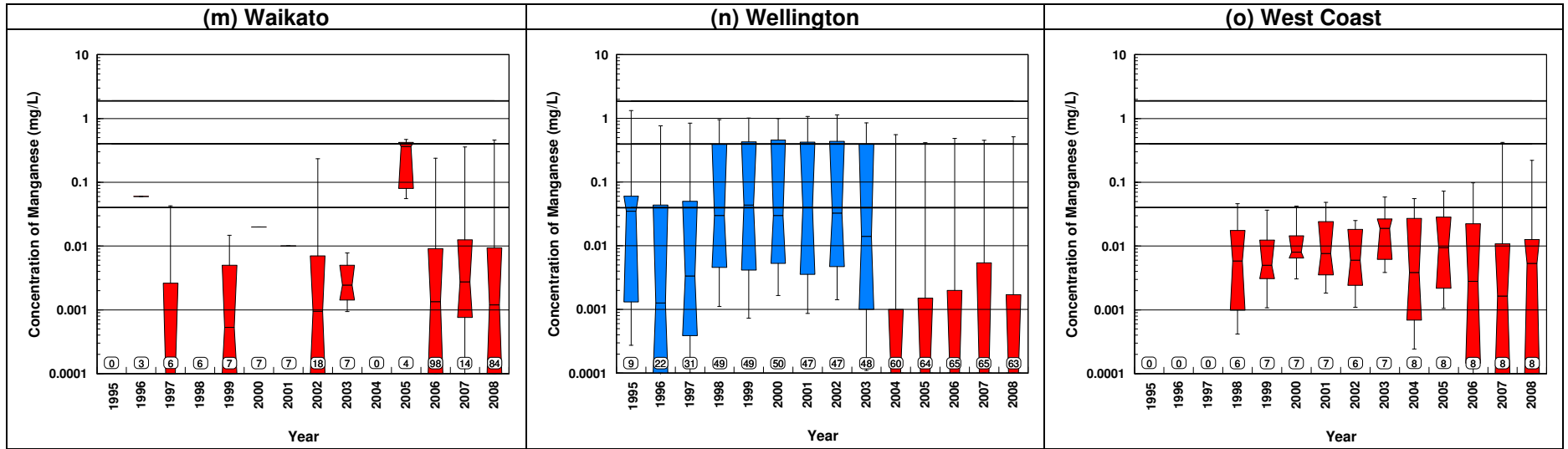


Figure 8. Year-by-year changes in regional percentiles for **electrical conductivity** in groundwater. All Y axis scales in $\mu\text{S/cm}$. Numbers above X axes show the number of sites at which median values could be calculated for the region and calendar year of interest.

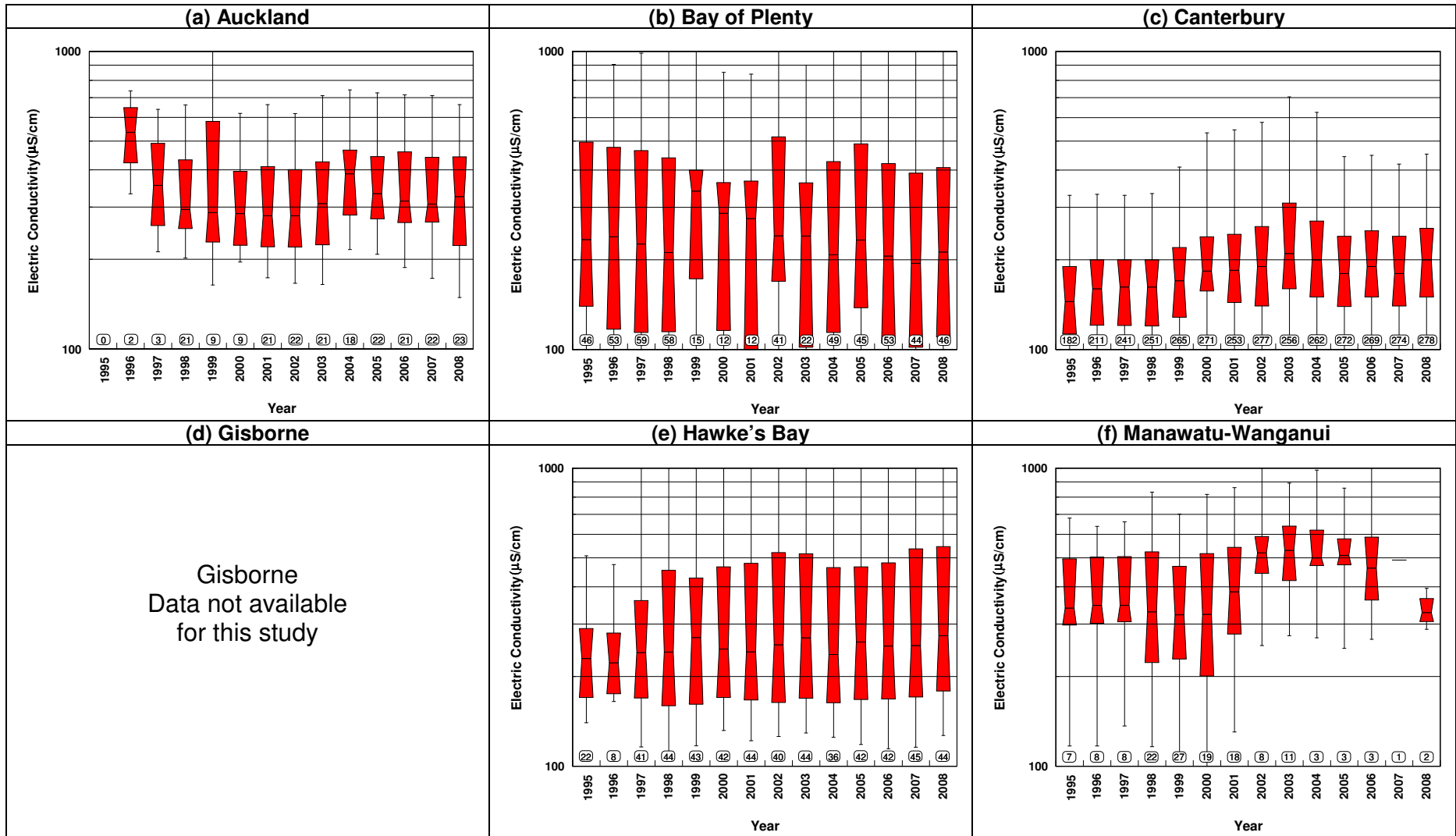


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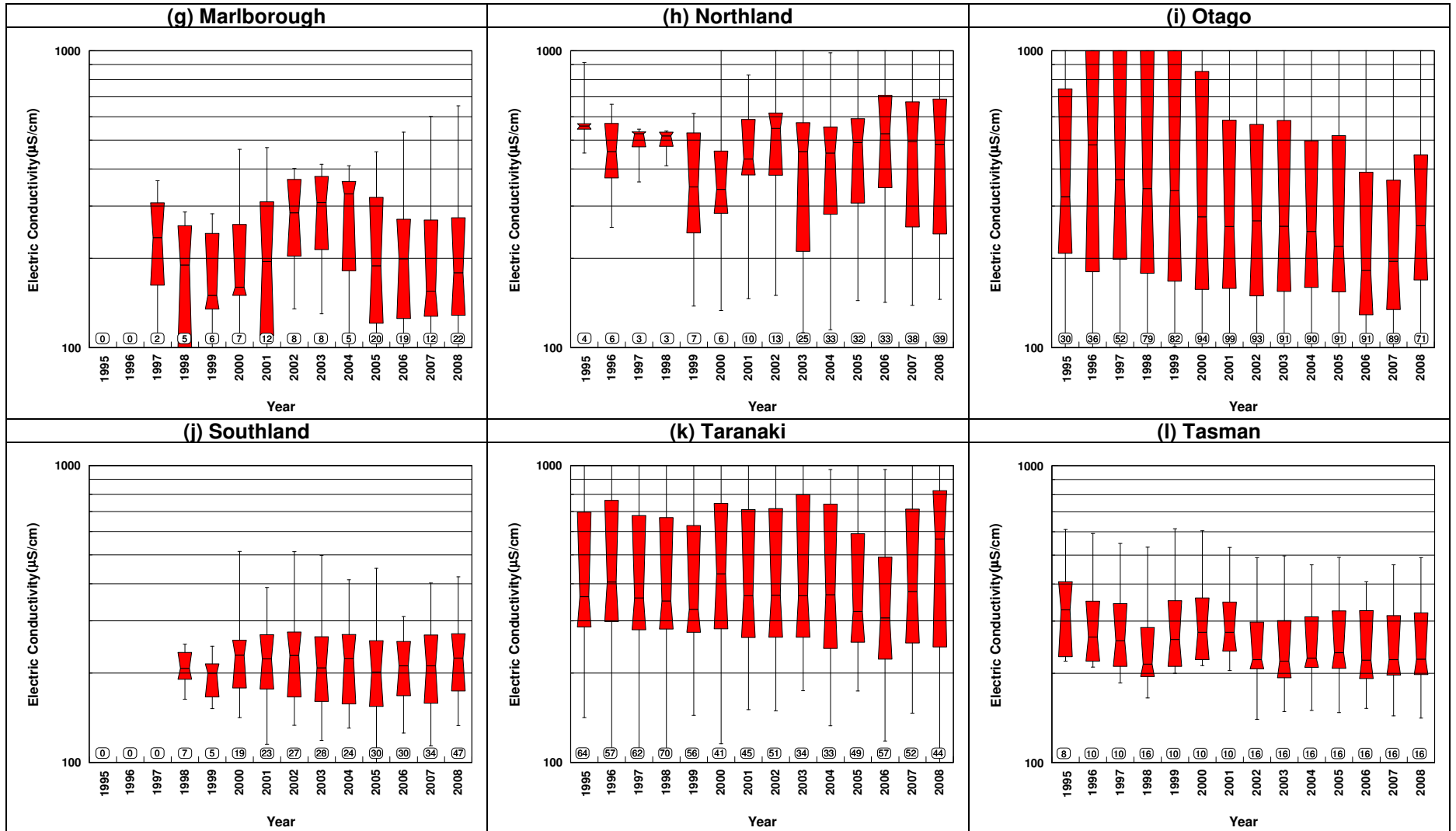
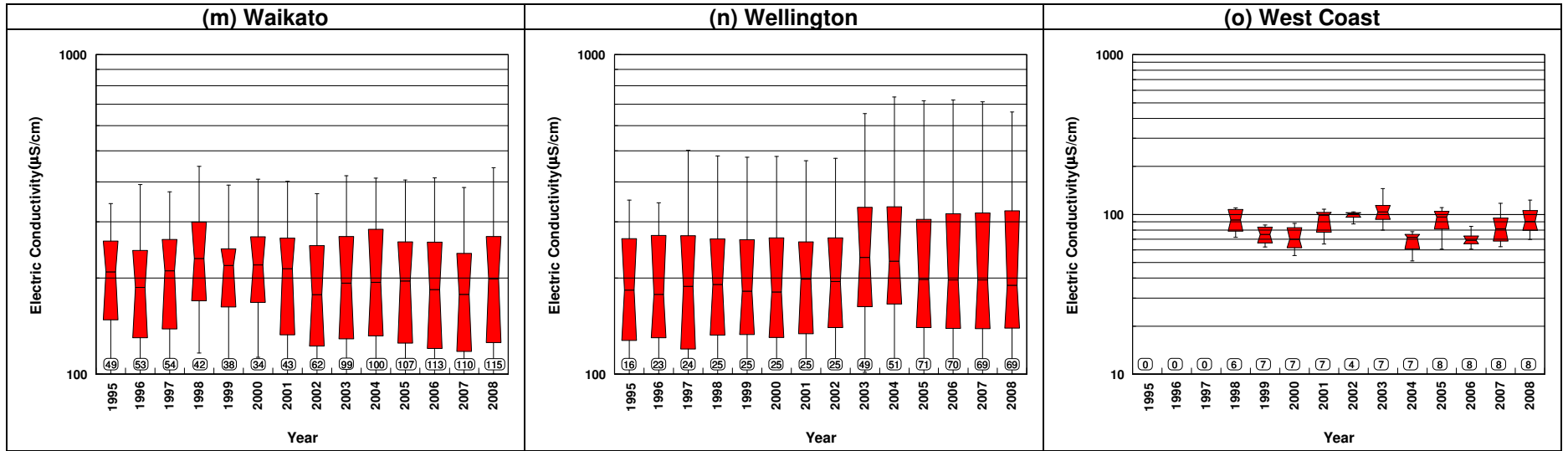


Figure 8. Continued



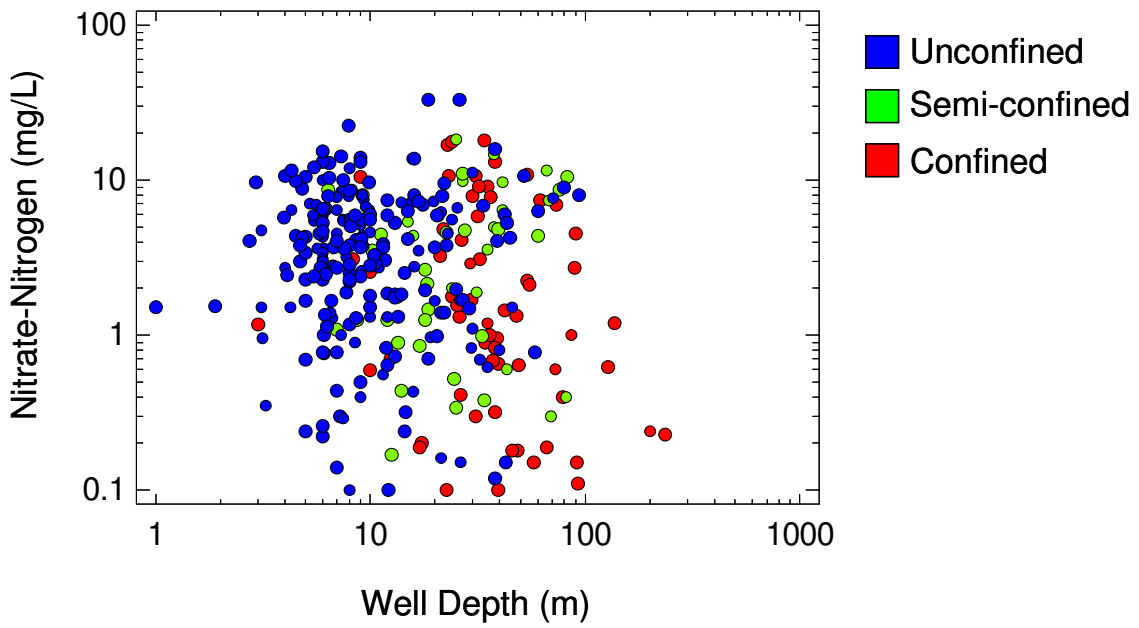


Figure 9. Relationships between site-specific median NO₃-N concentration, well depth and aquifer confinement.

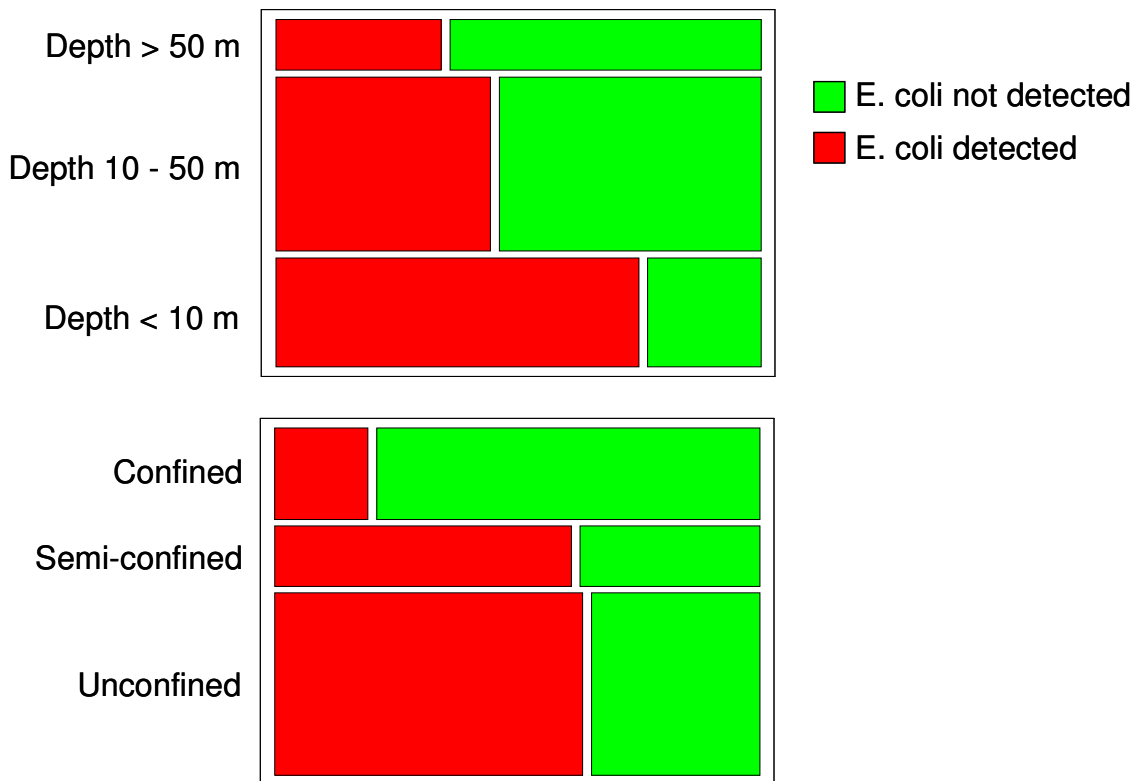


Figure 10. Relationships between detection of *E. coli* and well depth and aquifer confinement.

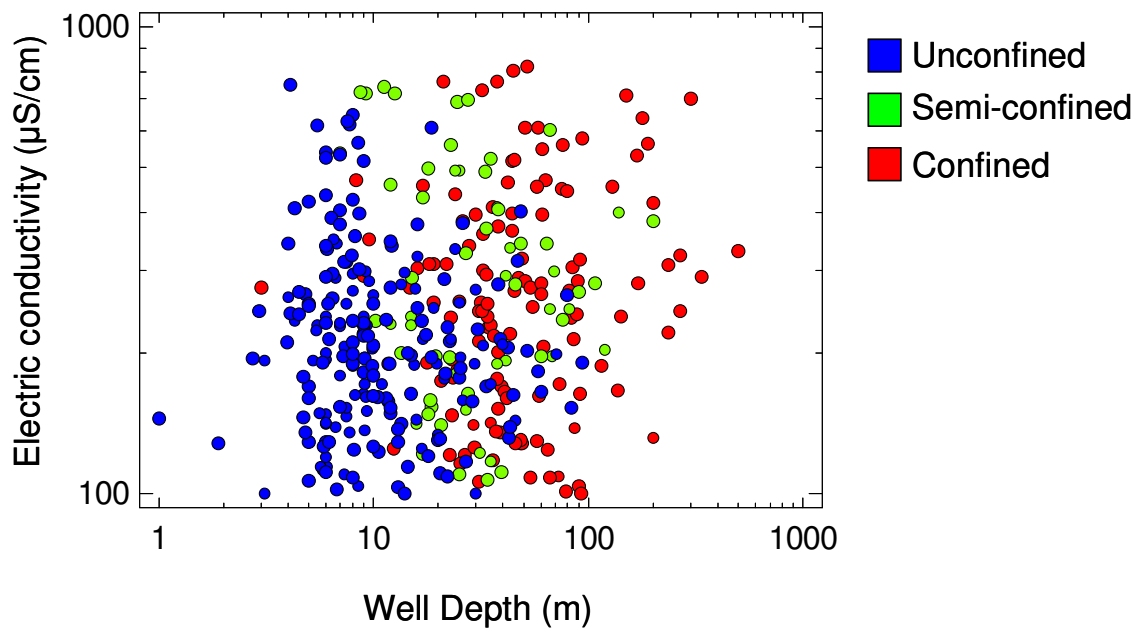


Figure 11. Relationships between the median electrical conductivity, well depth and aquifer confinement.

