final report

Project code: B.NBP.0554

Prepared by: Dr Raj Kurup, Dr Anne Barnes, Dr Halina Kobryn and Prof Nick Costa

Environmental Engineers International
Murdoch University

Date published: November 2011

ISBN: 9781741917079

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Review of the effects of water quality on ruminant health and productivity

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Water quality can affect a number of physiological states such as growth rate, lactation and reproduction of ruminant livestock. Typical factors that affect water quality include odour and taste, physical and chemical properties, presence of toxic compounds and concentrations of macro- and micro-mineral elements. This study reviewed the literature on water quality and its impact on the water intake, health and productivity of ruminants; identified water tests suitable for use on-property and laboratory options for north Australian beef producers; produced maps showing different aspects of groundwater quality for northern Australia and made recommendations on measures to treat or prevent water quality problems.

Data and information from peer reviewed journal papers, conference proceedings, publications of various state departments of agriculture, manufacturers' brochures and standards including ANZECC Guidelines, and USEPA, and of Government of Canada were used as resource material. Groundwater sampling, storage, handling procedure and testing – both on property and at external laboratories were investigated and approximate unit costs, of various options for groundwater treatment for northern beef producers was provided. It was recommended MLA develop an interactive CD or internet link for producers, which would provide maps of northern Australia, with time series data of groundwater quality embedded at the sampling locations.

Executive summary

Meat and Livestock Australia (MLA) has identified water quality and its effect on ruminant livestock as an area of concern to producers and other livestock industry stakeholders. Availability of sufficient quantity of good quality drinking water is important for the health and productivity of ruminants. Poor water quality can affect a number of physiological states such as growth rate, lactation and reproduction of ruminant livestock.

The aim of this report is to have a readily available reference material for producers to have easy access to information on groundwater quality, the impact of water quality on the productivity of their livestock and to identify options of potential solutions to address water quality issues. The objectives of this study were to:

- carry out a literature review on water quality and its impact on the water intake, health and productivity of ruminants;
- provide available case studies and examples of the losses in productivity that had been recorded in beef cattle
- identify water tests suitable for use on-property and laboratory options for north Australian beef producers;
- produce maps showing different aspects of groundwater quality for northern Australia; and
- to make recommendations where possible on measures to treat or prevent water quality problems.

The project was a desktop study. The report primarily focused on analysis of groundwater quality of the northern beef belt, from latitude 13.03 S; longitude 117.58 E to latitude 24 S; Longitude 152 E. This includes the northern Western Australia (WA), the Northern Territory (NT) and northern Queensland.

The report was prepared using data and information from:

- ➢ peer reviewed journal papers, conference proceedings and reports of university extension centres;
- ➢ publications of Departments of Agriculture of WA, South Australia, NT and Queensland;
- ➢ standards including ANZECC Guidelines, and USEPA, and CCME - Canadian Water Quality Guidelines;
- ➢ manufacturers' brochures, technical reports on water treatment systems.

The geo-referenced data of groundwater quality were collected from the following sources:

- Western Australia: Water Information Branch, Department of Water, Government of Western Australia
- Northern Territory: Manager, Spatial Data and Mapping, Department of Natural Resources, Environment, The Arts, and Sport, Northern Territory Government.
- Queensland: Water Systems, Water Accounting and Management, Department of Environment and Resource Management, Queensland Government.

A summary of the water contaminant guidelines for Australia and overseas and the recommended levels from various studies along with the percentage of groundwater samples of the study area that exceeded the safe limit are provided as follows:-

Summary of water quality guidelines and % of samples exceeded the limit

Water Contaminant (mg/L)	ANZECC	CCME	US-EPA	Recommended safe limit	% of samples exceeded the limit		
					WA	**NT**	**QLD**
pH (<5.5)	NA	NA	NA	5.5 - 8.5	1.2	6.7	4.1
pH (>8.5)	NA	NA	NA	5.5 – 8.5	8.7	1.3	3.1
TDS	4000	3000		4000	16	6.27	14.2
Aluminium	5	NA	NA	5	3.3	ND	0.4
Boron	5	NA	NA	5	0.4	ND	0.5
Calcium	1000	NA		1000	0.41	0.16	2.32
Fluoride	2	1 to 2	0.5	1 to 2	0	12.7	4
Iron	NA	NA	2	2	0	0	2.3
Magnesium	NA	NA	NA	5000	0	0.2	0.14
Manganese	NA	NA	NA	10	0	0	1.4
Nitrate + Nitrite	NA	100	NA	500	0	0.1	0.1
Sodium	NA	None	NA	1000	4.7	4.6	13.4
Sulphate	1000	1000	NA	1000	6.3	7.2	12.7

NA-recommendation not available; ND – No data available

The concentrations of other contaminants such as arsenic, cadmium cobalt, copper, lead, molybdenum, nickel, selenium, and zinc were found to be below the ANZECC permissible limits for WA and QLD. The database for NT did not have concentrations of the above contaminants except for selenium and zinc, but both were within the limits. No data was available for mercury, nitrite, uranium and vanadium in the water quality database of the three states.

The recommended on-site tests for groundwater quality are pH, alkalinity, turbidity, electrical conductivity, nitrite, nitrate, arsenic, iron and sulphate. These parameters include both the listed ones in the water quality guidelines as critical to animal health and the ones that might affect the palatability, colour and odour of the water.

A number of water quality field testing kits are available for accurate level analysis of groundwater.

A number of technologies, individually or in combination can decrease considerably or completely eliminate the water quality issues subject to the capital and operating costs and complexity of operations.

Contents

1. Background

Meat and Livestock Australia (MLA) has identified water quality and its effect on ruminant livestock as an important area of concern to producers and other livestock industry stakeholders. It is important to note that water is an essential nutrient, second only to oxygen in importance to sustain life and health of ruminants. However, unlike the careful and continuous attention paid to other nutrients in the ration; oftentimes the quality and provision of drinking water does not receive the attention necessary to ensure optimal nutrition and ruminant livestock performance. The quality of both groundwater and surface water is important for the health and productivity of ruminants. Poor water quality can affect a number of physiological states such as growth rate, lactation and reproduction of ruminant livestock (Lardy et al, 2008).

This report primarily focused on the groundwater quality of the northern Australia, starting from northern Western Australia through to the Northern Territory and northern Queensland. Beef cattle production is the dominant in pastoral industry in these regions and the cattle estimates are shown in Figure 1. Within the arid and semi-arid regions of these areas, water availability and quality are major limitations on production. For instance, salinity is a major water quality issue for most of the regions in Australia, but particularly for arid and semi-arid regions.

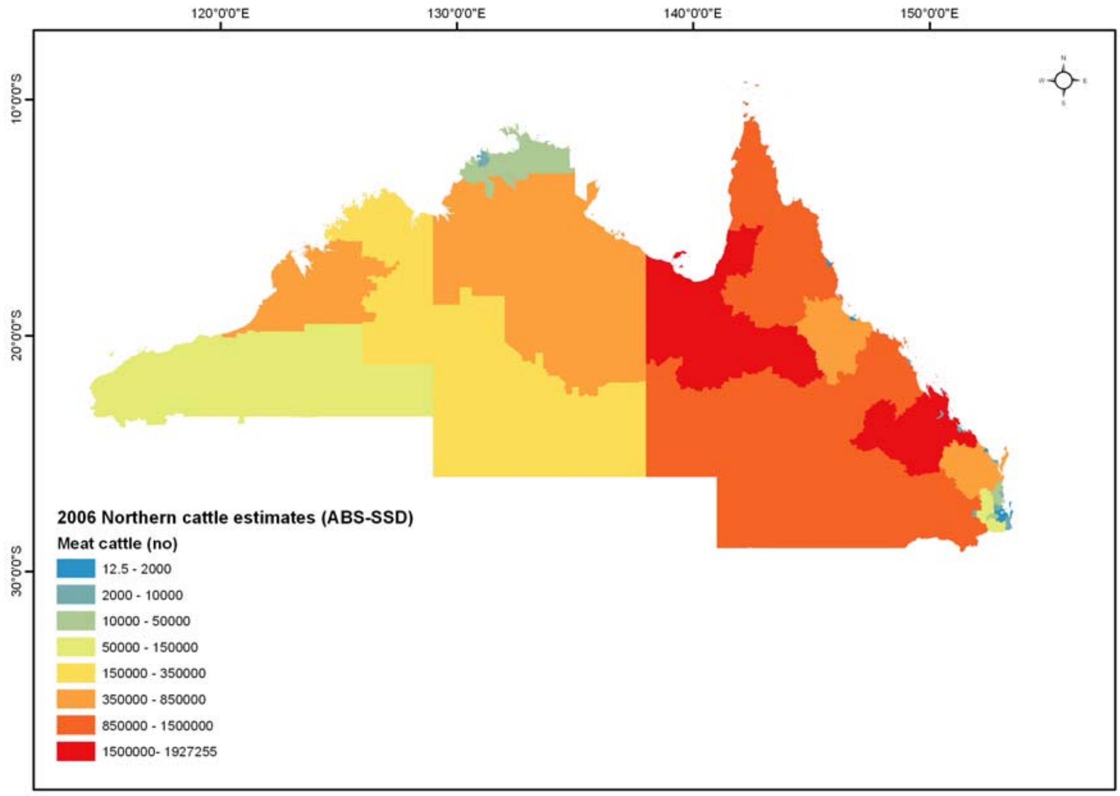


Figure 1: Northern Australian cattle (Australian Bureau of Statistics, 2006)

Typical factors that affect water quality include odour and taste (organoleptic properties), physical and chemical properties, presence of toxic compounds, concentrations of macro- and micro-mineral elements, and microbial contamination (Patience, 1994). Excess levels of some of these factors may have direct effects on the acceptability (palatability) of drinking water; whereas others may affect the animal’s digestive and physiological functions, once consumed and absorbed (Patience, 1994).

A number of impurities can affect the quality of underground water supplies. For example, hydrogen sulphide, because of its rotten egg smell, can affect the water intake (Chemistry Centre, 2007). Similarly, iron in excess of 0.3 mg/L can cause iron toxicity and reduced feed intake, decreased growth, and impaired milk yield for lactating animals (Beede, 2005).

MLA has identified the need for producers to have easy access to information on the impact of water quality on the productivity of their livestock and engaged the project team to prepare this report.

The scope of the report, as approved by MLA, includes a desktop literature review on the relevant aspects of water quality and its impact on the water intake, health, productivity and grazing behaviour of ruminants; a list of water tests suitable for use on property and laboratory options for north Australian beef producers; maps showing different aspects of underground water quality for northern Australia and recommendations where possible on measures to treat water quality problems.

2. Project objectives

The detailed project objectives were to:

1. Complete a literature review on all aspects of water quality and its impact on the water intake, health, productivity and grazing behaviour of ruminants including examples of the losses in productivity that had been recorded in beef cattle.

2. Identify water tests suitable for use on-property and laboratory options for north Australian beef producers.

3. Produce maps showing different aspects of underground water quality for northern Australia, and highlight those regions where water quality would likely to impact on water intake, health and productivity.

4. Make recommendations where possible on measures to treat or prevent water quality problems.

5. Provide case studies and examples of the losses in productivity that had been recorded in beef cattle

3. Methodology

The project was a desktop study. The report was prepared using data and information from peer reviewed journal papers, conference proceedings, books and publications of Departments of Agriculture of WA, South Australia, NT and Queensland, standards andmanufacturers' brochures. The peer reviewed journal papers and conference papers were obtained from scientific databases. The standards used include ANZECC Guidelines, and USEPA, and water quality standards of the government of Canada.

Details of equipment for on – property testing of water and the level of accuracy of this equipment were collected from the respective equipment providers. Approximate cost of the equipment as well as the costs for analyses was also obtained from the equipment providers.

The geo-referenced data of groundwater quality of bore water were provided by the following sources:

- **Western Australia**: Water Information Branch, Department of Water, Government of Western Australia. Phone: 08 6364 7468, Email: waterinfo@water.wa.gov.au
- **Northern Territory**: Manager, Spatial Data and Mapping, Department of Natural Resources, Environment, The Arts, and Sport, Northern Territory Government. Phone: 08 8999 3411, Email: datarequests.nretas@nt.gov.au
- **Queensland**: Water Systems, Water Accounting and Management, Department of Environment and Resource Management, Queensland Government. Phone: 07 4688 1021, Email: Productdelivery@derm.qld.gov.au.

The groundwater data sets collected and managed by the above agencies have been used in this report. The geographical boundaries for the dataset for each of the State are given in Table 1.

Table 1: Geographical boundaries of groundwater quality data set

State	North – West		South East		No of observations
	Longitude	Latitude	Longitude	Latitude	
WA	117.58	-13.03	149.66	-23..33	740
NT	128.4	-9.6	138.1	-21.8	59838
Queensland	138	-9	152	-24	42729

There is a large variation in the amount of data from each state. In the case of WA, the data provided were collected from 1/1/2005 to 1/4/2010. Although there are 11,480 bores within the mapped geographical area in WA, most have a single level and total dissolved solids sample at time of drilling and many of these do not have a known date so this has greatly reduced the data from bores fitting the requirements down to 584. In the case of NT, the historical data was provided. Though the total data provided for water quality was over 42,000 for Queensland, for some parameters there were only limited data available. The data were plotted as provided except for conversion to a common unit (e.g. microgram per litre to milligram per litre).

The report has provided maps in smaller size along with the text for referencing to the map, but full sized maps with higher resolution are provided in the appendix.

4. Results and discussion

4.1 Introduction

Water is the single most important and essential nutrient for livestock. Animals, as well as humans, can live for long periods of time without food. Without water, however, death can occur in a matter of days. Water is involved either directly or indirectly in virtually every physiological process. Water is a medium for transporting nutrients, waste material, hormones and other chemical messengers, as well as food along the gastrointestinal tract. It also plays an important role in regulating body temperature, acts as a lubricant for skeletal joints and is a component of many basic chemical reactions and processes such as blood circulation, food digestion, temperature control and production. A calf's body contains 75 to 80% water at birth and about 55 to 65% water at maturity (Raisbeck et al 2008).

The water intake of livestock varies greatly between species and between animals of the same species, depending on their environment, age, type of feed and production environment. Water intake occurs through eating and drinking.

Livestock production in Australia relies on both surface water and groundwater supplies. Surface water, that includes water in streams and dams, is influenced by catchment geology, topography, soil type and climate (ANZECC, 2000)

In this report, groundwater is defined as water that has accumulated in the ground, completely filling and saturating all pores and spaces in rock or soil. Groundwater is free to move more or less readily, it is the reservoir for springs and wells, and is replenished by infiltration of surface water (Wright, 2004). Groundwater, which is used as a source of drinking water for livestock over a large area of Australia (ANZECC, 2000), may contain large quantities of dissolved salts, depending on the soil and parent rock of the surrounding area and many other factors including rainfall, evaporation, vegetation and topography (ANZECC, 2000).

The quality of both groundwaters (depending on the depth of the aquifer) and surface waters may be affected by catchment land use practices, including agriculture, mining and other industries, with the potential for increased concentrations of salt, nutrients and other contaminants, such as pesticide residues and heavy metals (ANZECC, 2000).

Good water quality is essential for successful livestock production. Poor-quality water can reduce animal production, impair fertility and lactation and, in extreme cases, cause animal losses as stock drink less than they need, become clinically ill or stop drinking all together (Beede, 2005). Salinity, acidity, algal growth, pollution and toxic elements all affect the suitability of water for stock (Olkowski, 2009). Unfortunately, the quality of the water provided to livestock for consumption is often overlooked.

Evaluating the quality of water is very important. The factors that are usually considered in these analyses include organoleptic properties such as odour and taste, physiochemical properties, presence of minerals, toxins and micro-organisms (Beede, 2005). These factors can either affect the consumption of water or biological functions (Luke, 1987).

Cattle require large amounts of water every day. They meet this requirement via three sources: drinking or free water intake (FWI), ingestion of water contained in feed, and water produced by the body's metabolism of nutrients (NRC, 2001). Water consumption of cattle is influenced by a variety of factors including body size and physiological status, feed intake and water content of the feed and climate. Several equations have been developed to predict water intake of cattle (e.g. Winchester and Morris 1956; Murphy 1992), which attempt to take into account the increase in water intake that accompanies factors such as greater amounts of dry feed in the diet, increased water requirements for young, growing, pregnant or lactating animals, and higher evaporative water losses in hotter environments. Cattle and sheep may consume 10-20% of their body weight as free water, so it is important that they have adequate access to drinking water of suitable quantity. Under hotter conditions, water intakes can at least double (Beede and Collier 1986). Equations for predicting water consumption for cattle (lactating and dry cows) have been presented in NRC (2001). A summary of range daily water consumption of different types of cattle is provided in Table 2.

Table 2: Summary of daily water consumption of cattle

Cattle Type	**Daily Consumption (Litres a day)**
Weaners	25-50
Dry stock	35-80
Lactating cow - grass land	40-100
Lactating cow - saltbush	70-140
Dairy cattle	70–250

Adapted from (Dennis, 2008)

The daily water consumption presented in Table 2 is indicative only because when considering the quantity of water needed to supply to livestock, it is advised to make a very liberal allowance, above the peak needs of an animal, to allow for dry periods and infrastructure failure (e.g. busted pipe/tank) (Dennis, 2008). Other factors to consider are the number of animals likely to be watered on the system and the number of watering points to be used at the same time. This is important, as no matter how big the water storage is, the water distribution network (pipes and troughs) must allow sufficient flow to meet animals' needs (Dennis, 2008).

The provision of adequately spaced water points in grazing areas will allow animals to access sufficient water to maintain feed intake, and will also result in wider use of pasture (Dennis, 2008). Rouda et al (1990) reported that Santa Gertrudis x Hereford cattle walked about 8 km daily, while Fensham and Fairfax (2008) showed little cattle activity more than 5 km away from water, and suggested that water should be provided every 5 km for cattle, and every 3 km for sheep. Squires (1976) found marked differences in the amount and frequency of drinking between early and mid summer, and on saltbush versus grassland; sheep drank more, and more frequently when it was hotter and when they were grazed on saltbush, and travelled further when they were drinking twice daily or when the available feed had decreased. There are concerns that providing water to increase use of plants grazed may have negative impacts on the survival of the plants (Fensham and Fairfax 2008).

The presentation of the water source may influence the drinking events. Veira (2007) reviews work that gave cattle a choice of drinking from a creek or river, or from a trough, and found that most animals preferred to drink from the trough. However, there was no stated difference in total dissolved solids between trough and creek/river water. Placement of the trough in the paddock is important in determining its use. Veira (2007) included data from an unpublished experiment where one trough was well used and another was not – the author made no judgement about why one was used more than the other, simply that there can be an influence of site of trough. The author mentioned that possibly using attractants such as salt, molasses block etc might increase it use, but had no data to support this idea.

4.2 Water Quality Parameters

4.2.1 Palatability

Cattle are apparently sensitive to the taste and odour of water (reviewed by Wright, 2005), and water intake may be reduced if there is contamination with faeces or other organic matter. Cattle drinking clean water have been reported to gain more weight than those with access only to untreated water, presumably because the cattle drink more of the higher palatability water and therefore also increase feed intake (Lardner et al 2005; Willms et al 2002).

Lardner at al (2005) compared untreated dugout water that waspumped to a trough, aerated, coagulated with aluminium sulphate and powdered activated carbon. Apparently there were no significant differences in water chemistry and biological constituents among treatments. Willms et al (2002) used "clean" water from a well, spring or river trucked in and supplied in a trough, versus pond water pumped to a trough, versus direct access to the pond. The concentrations of the various solutes are reported in that paper, and varied between sites or experiments as well as among treatments. At one site the "clean" water had higher SO_4 than the pond water, while at another site, the pond water had very high SO_4. Pond water tended to have higher coliform counts than clean water. These authors suggested that the mechanism for increased cow productivity on "clean" water related to effects on feed intake, both in terms of spending more time grazing, and (in pen trials) eating more.

Dairy cows have been shown to drink more desalinated water than saline-brackish well water (Solomon et al 1995) with resultant higher milk production. The saline water had 3.4 times more total dissolved solids (TDS) than desalinated water as presented in Table 3.

Table 3: Minerals composition of the salty water (SW) and the desalinated water (DW) (mg/L)

Mineral	**SW**		**DW**	
	X	Standard Error	X	Standard Error
Na	287	15	75.6	23.1
Ca	239	7	48.5	8.9
Mg	101	2	23.3	7.4
K	16.9	1.7	4.66	1.31
Cl	580	24	249	12
S	256	14	40.6	16.4
Total TDS	**1479.9**		**441.66**	

(Solomon et al (1995).

Valtorta et al (2008) reported that cows drank more water with the high amount of total dissolved solids (TDS, 10,000 mg/L compared to 1,000 and 5,000 mg/L). This citation isn't a recommendation, merely referencing what was reported. As the review states, factors other than water TDS – such as diet, and what the actual composition of the water– may influence water consumption. Valtorta et al (2008) concluded that "consideration of TDS alone is insufficient to characterize drinking water quality".

The composition of the water and diet varied between these studies, showing that factors other than water composition may influence intake. Cattle under confined conditions in climate controlled rooms, supplied only with electrolyte supplemented water while exposed to high temperature and humidity drank 1.3 times as much as the animals supplied with tap water (Beatty 2005).

There is little published information about water consumption under Australian pastoral conditions, where the water may be of varying salinity.

4.2.2 Water temperature

Generally, cattle prefer water at 10-20°C; provision of cool water to cattle under hot conditions may decrease water intake (Milam et al 1986) and provide some short relief from the heat as the consumed water absorbs heat in the body (Lanham et al 2008; Stermer et al 1986; Purwanto et al 1996).

Under severe environmental conditions (range 12-48°C, mean maximum 38, mean minimum 21°C) cooling the drinking water of Hereford cattle from about 32 to 18°C increased growth rate and decreased water intake, while Brahman cattle supplied with warm water (32.2°C) grew at the same rate as Herefords with cool water (18.3°C) (Ittner et al 1951), and similar findings were reported by Lofgreen et al (1975), that Brahman-British bred cattle performed as well with warm water (32.2°C) as British cattle receiving cooled water (18.3°C). The amount of water drunk will also influence the intake of water-borne minerals, contaminants and toxins.

Note: *The mean of maximum and minimum temperature is a normal way to express environmental temperatures. Under most conditions, the temperature in a day changes, so that there is a hottest time (maximum) and coolest time (minimum). The range in temperature could be expressed as the coolest it ever got during a period of study – in this case 12°C, to the hottest it every got – in this case 48°C. By taking every day's maximum temperature and calculating the mean of those you could get a mean maximum (in this case 38°C), and you could do the same for the minimum temperatures and get a mean minimum (in this case 21°C). This means it was generally pretty hot at this place, but you can also see there were extremes.*

4.2.3 pH

The hydrogen ion concentration in water determines the pH level. A pH value of 7 indicates "neutral" water. Values less than 7 are increasingly acidic and values greater than 7 are increasingly alkaline. The EPA (1997) recommendation for the pH of human drinking water is between 6.5 and 8.5. No information was found in the scientific literature as to what effects the pH of water has on water intake, animal health, animal production, or the microbial environment in the rumen (NRC, 2001).

The definition of "normal" water pH varies between authorities, but it is usually described as somewhere between 5.5-6.5 and 8-9 (Raisbeck et al, 2008). If the pH is lower than 5.5, acidosis and reduced feed intake may occur in cattle (Raisbeck et al, 2008).

Alkaline water with pH greater than 8.5 may result in higher risk of metabolic alkalosis. Alkaline water may cause digestive upsets, laxative action, poor feed conversion, reduced water and/or feed intake. For dairy cattle, these conditions have been associated with reduced milk yield and milk fat, low daily gains, increased susceptibility to infectious, metabolic disorders, and reduced fertility (Lardy et al, 2008).

Raisbeck et al (2008) carried out a literature review on effect of pH on animal health, and reported that they were unable to find any reports detailing acute toxicity as a result of drinking extremely acidic or alkaline water. However, one of the co-authors of the report investigated field cases in which cattle drank extremely basic solutions (pH 12-14) resulting in erosions and hemorrhage in the mouth and esophagus (Raisbeck et al 2008). The review concluded that the commonly touted acceptable ranges for drinking water pH (a low of 5.5-6.5 and a high of 7.5-9.0) were excessively conservative from a strictly animal health standpoint, at least on the acid side, but there were not sufficient experimental and/or clinical data to offer a specific alternative (Raisbeck et al 2008).

From the database of water quality of groundwater of northern WA, NT and northern QLD provided for this by the respective state government agencies (details given in the methodology), the pH values that were found to be below 5.5 and above 8.5 have been mapped and presented in the appendix. Figure 2 to Figure 4 show the reduced reference maps for discussion in this section. It is noted that overall data density varies between the states. The high pH groundwater in WA is mostly present in the top north part of WA.

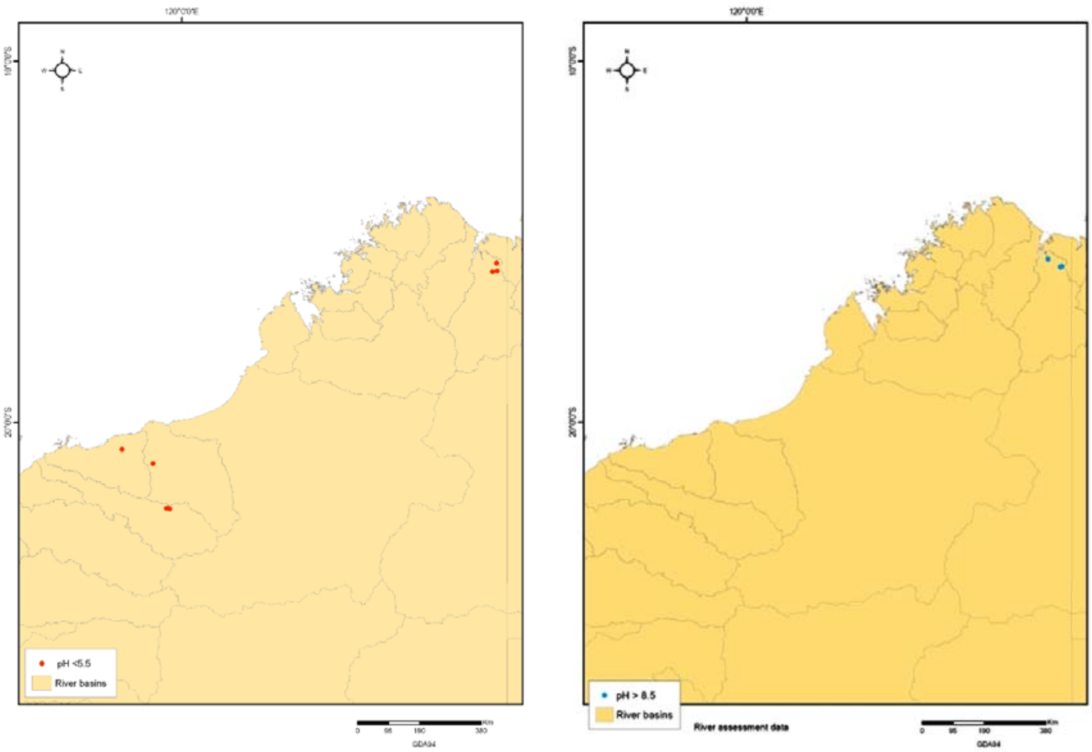


Figure 2 Extreme values of pH of northern WA. (Left side - pH < 5.5 and the right side pH>8.5)

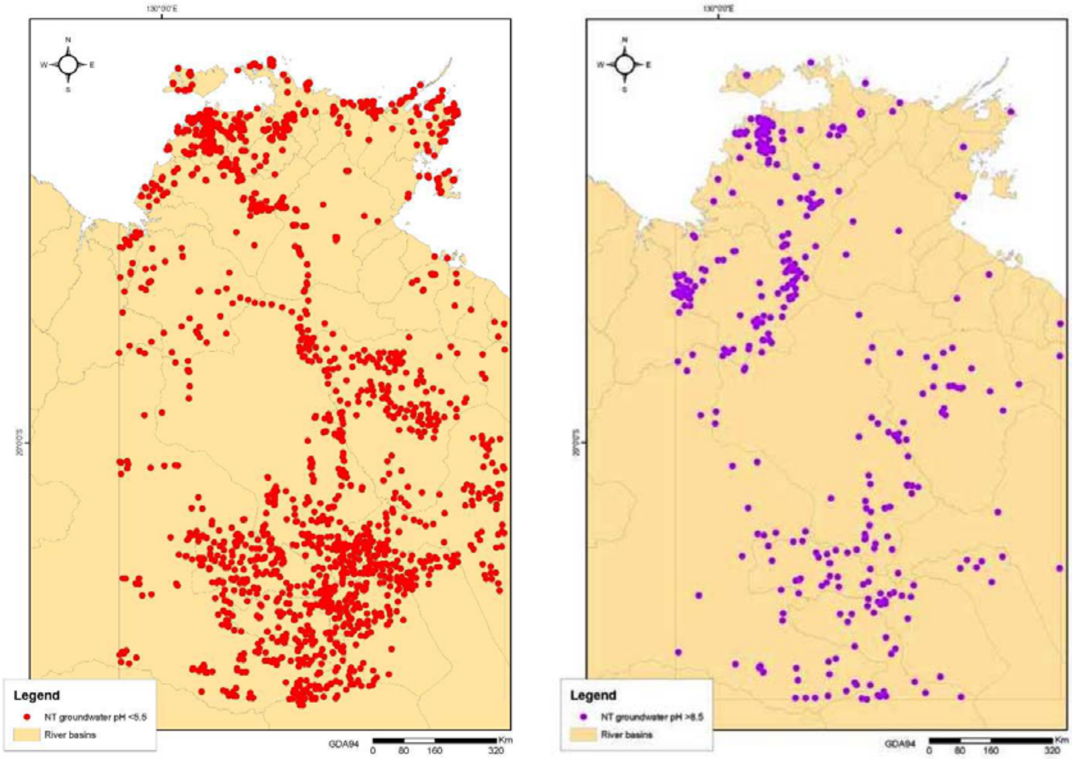


Figure 3: Extreme values of pH of NT. (Left side - pH < 5.5 and the right side pH>8.5)

Table 4: Statistical analysis of pH data of groundwater samples

	WA	NT	QLD
Total No of samples	660	41500	6481
Minimum pH	4.2	2	3.3
Maximum pH	9.9	12.2	11.6
Average pH	7.81	7.16	7.15
STD	0.73	0.96	0.82
No of samples pH<5.5	8	2780	268
No of samples pH>8.5	58	548	201

The statistical analysis of the pH data is presented in Table 4. In WA, the pH of the groundwater outside of the 5.5 to 8.5 range was more towards the alkaline side, but for both NT and QLD, this was in the acidic side. However, the average pH of groundwater of all the states was between 7 and 8. It can be seen that only a marginal number of (i.e. < 5% average) samples showed pH values in the extreme range. For locations with extreme pH values, further testing of groundwater samples may be beneficial. The review of groundwater quality data indicates that for most part of the northern Australia, the pH value of the groundwater is within the acceptable range for cattle.

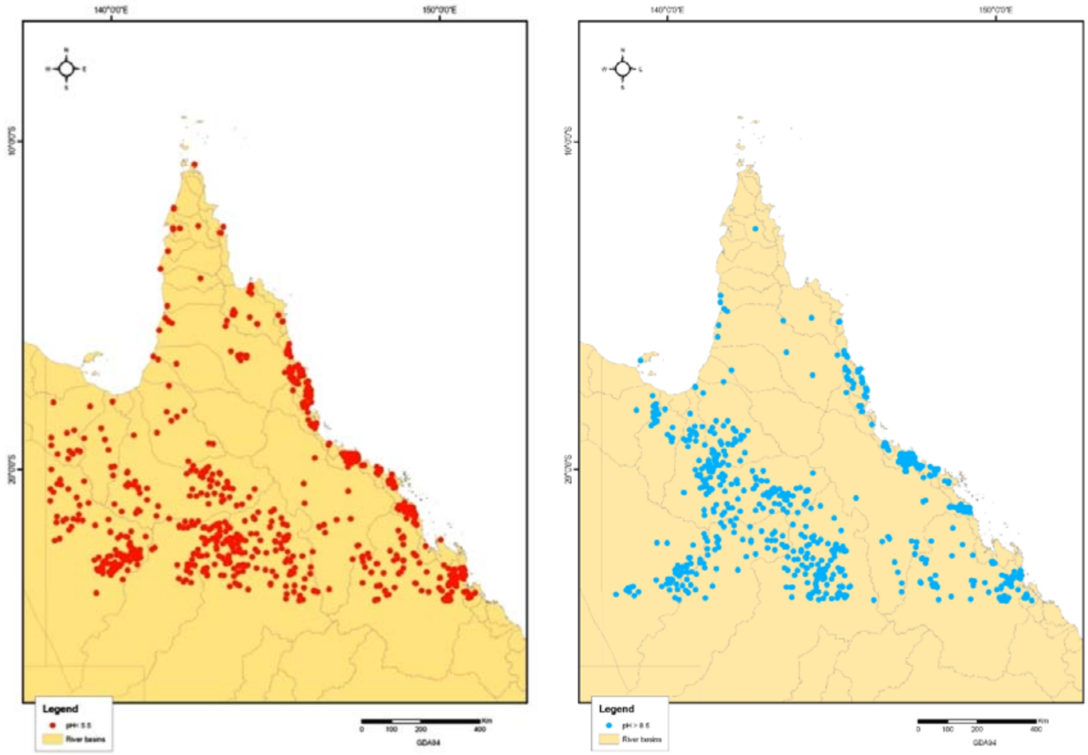


Figure 4: Extreme values of pH of northern QLD. (Left side - pH < 5.5 and the right side pH>8.5

4.2.4 Microorganisms - Blue-green algae

Algal blooms are more likely to occur in surface water with high concentrations of organic material, such as faecal material, and nitrogenous and phosphorus wastes from run-off from fertilised pasture, and blooms are also more likely during periods of sunny weather with temperatures of between 15-30°C, and in water of pH greater than or equal to 6 (reviewed in Wright 2005). Some cyanobacteria produce toxins that are released when the algal cells die. The prevalence of toxic cyanobacteria in Australian water supplies is unknown, but the risks will be higher for animals in warm weather drinking from stationary water sources. The algal growth can be killed with copper sulphate but animals should be restricted from drinking the water for a certain number of days after such treatment, because the death of the algal cells will cause a rapid and extensive release of their toxins. Further details are provided in section 4.3 of this report, where all cases reported through the Animal Health Surveillance Quarterly are summarized.

As the scope of this review is limited to groundwater quality and the database of the groundwater quality did not consist of data of cyanobacteria or algal biomass, no maps of these items could be prepared. For cases where groundwater will be stored in surface dams, there is a possibility of algal growth, which needs to be monitored.

4.2.5 Other microorganisms

Leptospira spp can be water borne, passing in infected urine into the surface water and then infecting other animals. Preventing animals from standing in the water may limit the contamination of the water source (Wright, 2005).

Coliform bacteria can contaminate surface water sources from faecal matter and run off, and contamination increases if the animals are able to stand in the water, and if there is effluent discharge close to the water source. Troughs should be cleaned regularly to limit contamination and microbial proliferation. Faecal bacteria of particular concern include E. coli and Salmonella, while protozoa such as Cryptosporidium and Giardia can also be transmitted in contaminated water (Hubbard et al., 2004). No data on these microorganisms were available for groundwater and hence no maps have been prepared.

4.2.6 Total dissolved solids

The total dissolved solids (TDS) in the water is the sum of all ions present, and includes sodium chloride, bicarbonate, sulphate, calcium, magnesium, silica, iron, potassium, fluoride, phosphorus and other elements, as well as the organic ions such as pollutants, herbicides and pollutants (Raisbeck et al 2008). Much research has investigated cut-off or trigger values for the different components for water to be considered safe, and while it is apparent that the rumen can buffer quite high concentrations of most salts, there are critical values, and some salts and minerals are more critical than others. As mentioned in section 4.2.1, very saline water may be unpalatable to animals, and therefore they will not drink well, and may decrease feed intake (Solomon et al., 1995). They can adapt over time to the taste and physiological effects of water with higher salt content, with increased renal excretion of excess salt (Raisbeck et al, 2008).

Research varies in how the TDS content of water is reported and therefore the effects vary. Most ruminant work regarding the effects of salinity on water intake and production have concentrated on dairy cows, with the detrimental effects of high TDS in water easier to measure when there were associated decreases in milk production (e.g. Challis et al 1987; Solomon et al 1995). There will be an effect of diet on how much salt can be tolerated in the water, for instance with animals grazing saltbush or receiving high salt diets having a lower tolerance for salts in the drinking water (Lardy et al, 2008).

Other references list limiting figures which differ slightly. The National Research Council guidelines reviewed in Wright (2005) suggested that water containing less than 1,000 mg TDS /L should be safe for any class of beef cattle; up to 4,999 mg/L may cause temporary and mild diarrhoea but should be satisfactory for all classes of beef cattle; over 5,000 mg/L should not be used for pregnant or lactating cattle; 7,000-10,000 should be avoided except in older cattle in a low-stress environment; and that water over 10,000 mg/L should not be used at all for cattle. It may be noted that TDS is a measure of all inorganic and organic substances dissolved in water. These individual solutes range in toxicity from relatively non-toxic substances, such as Ca^{2+}, to extremely toxic (Hg^{2+}, Se^{+4}), but tests of TDS do not differentiate between them. It is the specific ions rather than the total concentration in the water which may determine whether the water is safe or toxic (Raisbeck et al, 2008). According to ANZECC (2000), if water has purgative or toxic effects, especially if the TDS concentration is above 2,400 mg/L, the water should be analysed to determine the concentrations of specific ions.

Table 5: Tolerances of livestock to total dissolved solids (salinity) in drinking water (mg/L)

Stock	**Desirable maximum concentration for healthy growth**	**Maximum concentration without loss of production**	**Maximum concentration that may be safe for limited periods**
Sheep	5,000	5,000-10,000	10,000-13,000
Beef cattle	4,000	4,000-5,000	5,000-10,000
Dairy cattle	2,500	2,500-4,000	4,000-7,000

Markwick (2007) from the NSW DPI adapted the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) values of tolerances of livestock for TDS, which are presented in Table 5. At maximum concentration of TDS without loss of production, livestock may have initial reluctance to drink or there may be some scouring. But stock should adapt to this concentration without loss of production. In the case of maximum concentration of TDS that may be safe for limited periods, loss of production and a decline in animal condition and health would be expected. Stock may tolerate these levels of TDS for short periods if introduced gradually (ANZECC, 2000).

Wright (2005) cites work by Embry et al from 1959 where heifers provided with water containing 10,000 mg added sodium sulphate per litre were reported to have a severe reduction in water intake, diarrhoea, and weight loss, while water containing 4,000 or 7,000 mg added sodium sulphate per litre resulted in greater water intake, reduced free-choice mineral intake, and no change in animal performance, compared with animals on control water. Those researchers found that adding 7,000 or 10,000 mg/L sodium chloride alone versus a mixture of salts (NaCl, Magnesium sulphate and sodium sulphate at 7,000 or 10,000 mg/L) increased water intake compared to control water or the mixture of salts. Heifers offered tap water (100 mg TDS/L) drank less than those offered tap water mixed with 10,000 mg additional NaCl/L, with similar growth performance. Adding 20,000 mg NaCl/L resulted in severe anorexia, weight loss, lethargy, anhydremia and collapse. This confirms the conclusions made by Raisbeck et al (2008) – “that it is the actual ions rather than the total concentration in the water which may determine whether the water is safe or toxic.” It can be concluded that animals appear to tolerate high concentrations of sodium chloride in water, but are less tolerant of the mixtures of ions.

Also of concern in regards to TDS and salinity, is the increase in salinity over time during hot weather particularly, because of evaporation of water from dams, soaks and tanks (Chemistry Centre 2007). There will also be changes in salinity due to storm water run-off; after the first rain of the season the dry land and creek beds will be flushed of salt so that the water is initially more saline, then as flow increases the salinity drops due to continued flow of fresh water.

Table 6: Statistical analysis of TDS data of groundwater samples

	WA	NT	QLD[1]
Total No of samples	50	35619	40597
Minimum (mg/L)	70	3	4
Maximum (mg/L)	8740	79500	147400
Average (mg/L)	1806	1260	33242
STD (mg/L)	2065	2740	8284
No of samples TDS>2,500 mg/L	9	4087	9000
No of samples TDS>4,000 mg/L	8	2203	5785
No of samples TDS>10,000 mg/L	0	388	2744

[1]Data as conductivity, TDS has been estimated by multiplying 0.67

A summary of the statistical analysis of TDS data of groundwater of northern WA, NT and northern QLD is provided in Table 6. The groundwater quality data for northern Queensland reported electrical conductivity in place of TDS. For conversion of electrical conductivity to TDS, a factor 0.67 has been used following McNeil and Cox, (2000). In northern QLD, 6.8% of the samples showed a TDS over 10,000 mg/L whereas for NT, only 1% of the total samples exceeded this value. For northern WA, there was no sample which had TDS value over 10,000 mg/L, however, the total number of samples were only 50. Similarly, 14.2% of the samples of northern QLD were over the safe limit of 4,000 mg/L of TDS for beef cattle. In the case of NT, 6.2% of samples were above 4,000 mg/L of TDS and for WA, 16% of the samples had a TDS value above 4,000 mg/L, but all samples were below 9,000 mg/L.

Figure 5 and Figure 6 show the low resolution maps of TDS data of groundwater of northern WA and NT respectively whereas Figure 7 shows the conductivity of groundwater of northern Qld. High resolution versions of these maps are presented in the appendix. It is interesting to note that the high TDS groundwater were observed in the northernmost part of WA, whereas in the case of NT, the high TDS water mostly located below the mid southern part of the state. For northern Qld, the high TDS groundwater was mostly on the south east part as shown in Figure 7.

It is advised to carry out detailed analysis of the groundwater on these locations where the maps indicate high TDS value (in excess of 4,000 mg/L) for implementation of an effective water treatment and / or management system for provision of potable water for cattle and other rumen livestock.

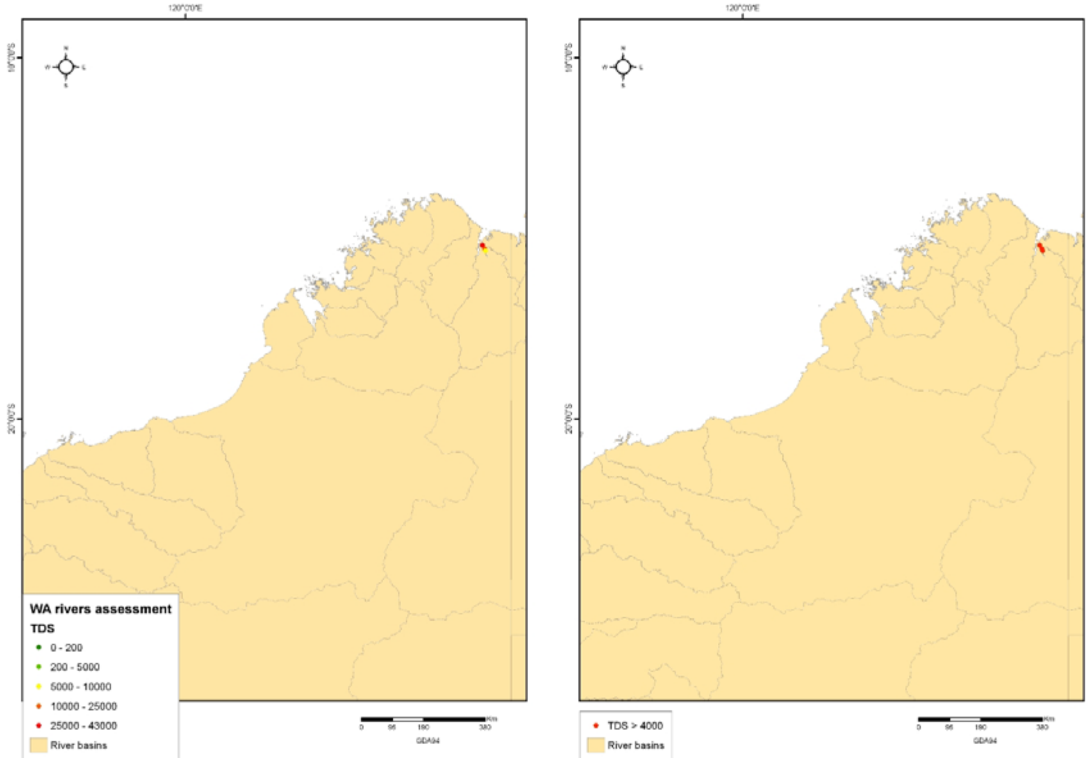


Figure 5: TDS of groundwater of WA (left – all data, right - TDS >4,000 mg/L)

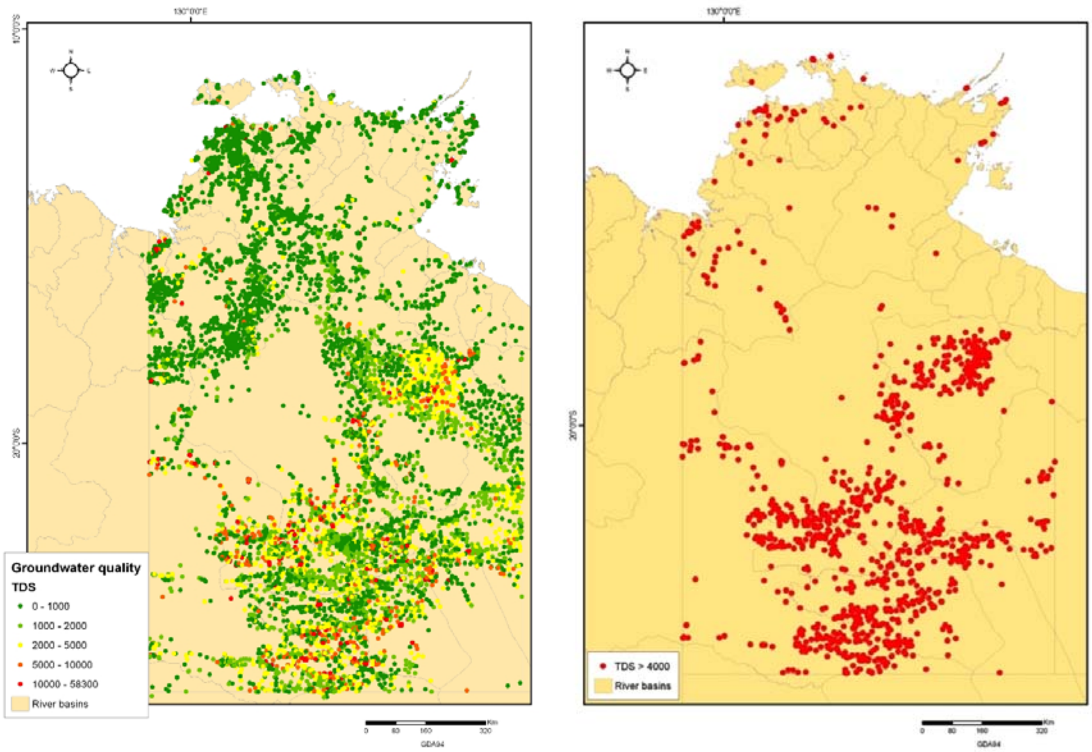


Figure 6: TDS of groundwater NT (left – all data, right - TDS >4,000 mg/L)

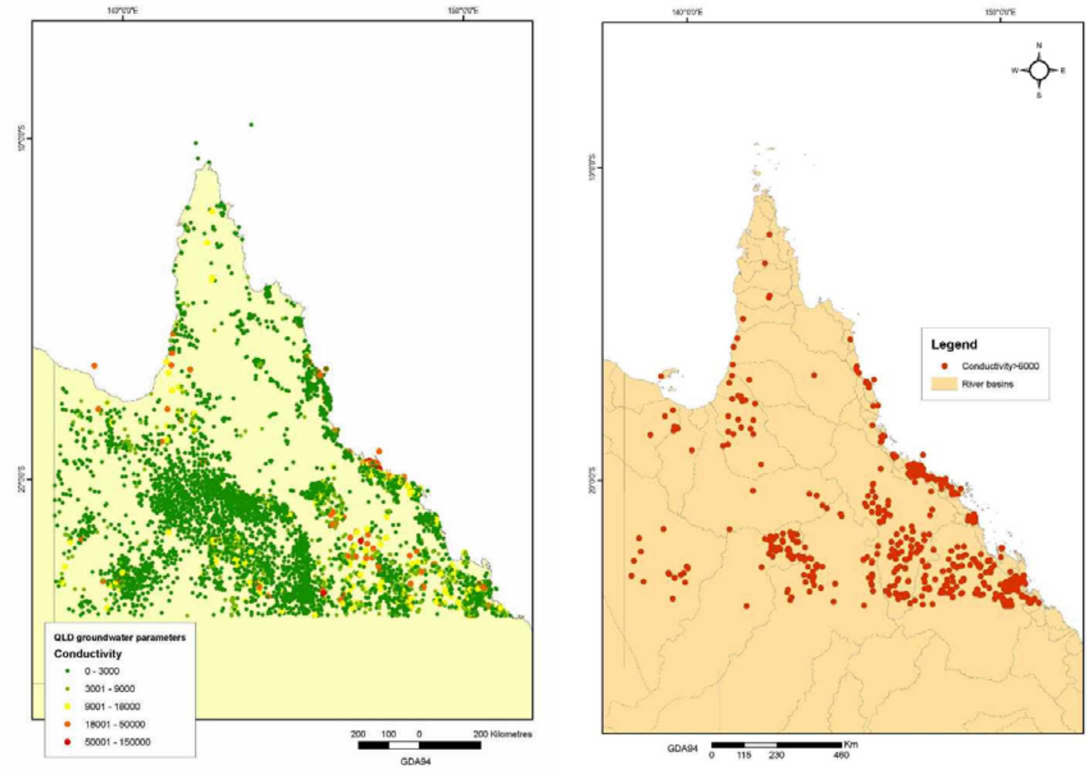


Figure 7: Conductivity of groundwater northern QLD (left – all data, right - Conductivity >6,000 uS/cm)

4.2.7 Sodium

There is no specific trigger value for sodium in the water quality guidelines (ANZECC, 2000) for livestock, but the levels of sodium in the northern Western Australia was found to be well below 5,000 mg/L.

Sodium toxicity is related to the availability of water, because sodium has the osmotic effect of attracting water to it. If animals have adequate access to water, then they can increase excretion of sodium; however, if sufficient good quality water is not available then acute sodium toxicity can occur, with dehydration and neurological signs such as blindness, incoordination, convulsions, recumbency and death (reviewed in Raisbeck et al 2008). Chronic oversupply of sodium can result in a metabolic cost for elimination of that sodium, with associated reductions in growth and production. The normal response to an increase in dietary sodium is to drink more, but if the water itself contains high concentrations of sodium, then there is increased risk of a toxic dose. Acute intoxication has resulted when cattle have consumed water containing around or over 5,000 mg sodium/L, and chronic toxicity with increased intake of the saline water, diarrhoea, reductions in feed intake, decreased milk production have occurred when cattle have consumed water containing 2500 mg sodium/L (Jaster et al 1978, cited by Raisbeck et al 2008). Sheep appear more tolerant to salt than cattle, and water containing 15,000 mg sodium/L was associated with reduced feed intake, decreased body weight, and increased water intake of sheep (Peirce 1957; Wilson 1966 as cited in Raisbeck et al 2008). The “safe” level for salt depends on availability of low salinity water, feed intake of salt, metabolic state of the animal. Raisbeck et al (2008) recommended keeping drinking water sodium concentrations at less than

1,000 mg/L, but noted that short term exposure to high concentrations, up to 4000 mg/L, should be well tolerated.

Table 7: Statistical analysis of sodium in groundwater samples

	WA	NT	QLD
Total No of samples	83	37585	40827
Minimum (mg/L)	10	1	0
Maximum (mg/L)	5,100	26,200	91,000
Average (mg/L)	311	228	897
STD (mg/L)	682	625	2830
No of samples with Na>1,000 mg/L	4	1738	5463
No of samples with Na>2,500 mg/L	1	312	2809
No of samples with Na>5,000 mg/L	1	94	1723

The average concentration of sodium in the groundwater samples collected from northern Australia is below 1000 mg/L. Table 7 presents the statistical analysis of groundwater samples of northern WA and QLD and NT. In the case of QLD, the three data out of a large database of 40,827 (i.e. 0.007%) were above 50,000 mg/L. The sodium concentration in the groundwater exceeded 1,000 mg/L by 4.71% of WA, 4.62% of NT and 13.4% for QLD. Only limited number of samples (0.25%) of groundwater of NT exceeded 5,000 mg/L of sodium, and for WA only one sample exceeded this concentration. But for QLD, 4.2% of the groundwater samples had sodium concentrations above 5,000 mg/L.

The GIS maps of concentration sodium in the groundwater collected from various bores are provided in the Appendix. Low resolution maps are presented in this section for easy reference. Figure 8 presents the map showing the concentration of sodium in the groundwater of northern WA and the Figure 9 shows the groundwater map of both NT and northern Queensland. All data are in mg/L. The northern most locations of WA show higher sodium concentration, whereas in the case of NT, the southern part of NT has groundwater with sodium concentration of 5,000 mg/L or above. The south-east part of northern QLD also has bores with groundwater with sodium concentration in excess of 5,000 mg/L. For these locations, detailed investigation may be carried out for sodium concentration of the groundwater and remedial measures may be required if the groundwater is to be provided as the sole drinking water source for cattle.

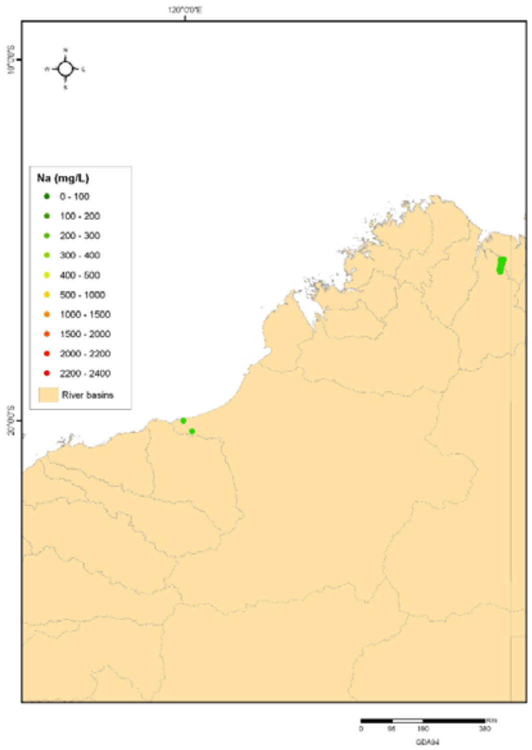


Figure 8 Sodium concentration of groundwater mg/L- WA

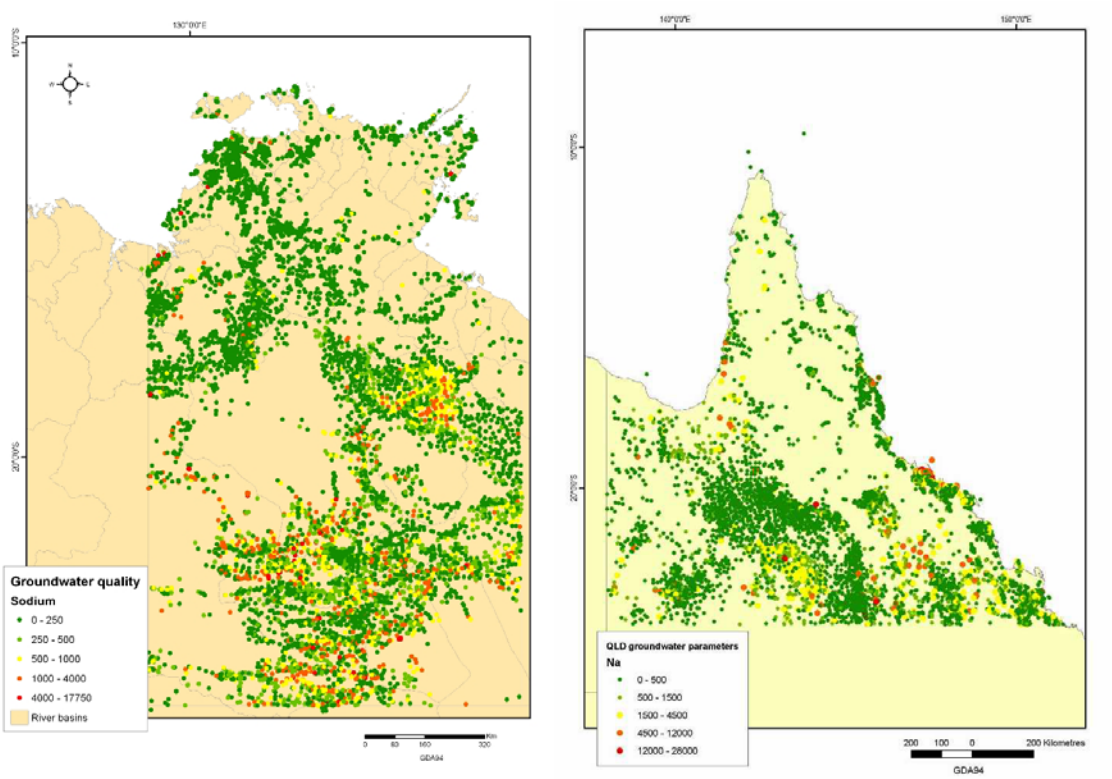


Figure 9: Sodium concentration of groundwater mg/L (left- NT; right- QLD)

4.2.8 Sulphate

One of the most critical and commonly found salts in water is the sulphate ion. Other forms of sulphur such as sulphides may also be found in some ground water. Once exposed to the atmosphere, the sulphides may become aerobically converted to sulphates, and can contribute to overall poor quality of the water and health problems.

Sulphate can reduce the palatability of water; Weeth and Capps (1972) reported discrimination by cattle against water containing 1,450 mg sulphate/L and rejection at 2,150 mg sulphate/L, while Grout et al (2006) showed that the cation associated with the sulphate was important, and magnesium sulphate was less acceptable to heifers than sodium sulphate.

While sulphur is required for health and in the rumen can be used in the synthesis for sulphur containing amino acids by the rumen microbes, the hydrogen sulphide intermediary produced can cause toxicity and sudden death if produced in excessive quantities. As reviewed by Wright (2005), production of H_2S from sulphate ions can be rapid, and overwhelm the usual routes of disposal, such as oxidation by oxyhaemoglobin in the blood and the sulphide oxidase system in the liver. Eructated rumen hydrogen sulphide can be reabsorbed after inhalation, and bypass the liver to exert toxic effects on the respiratory, circulatory and nervous systems. The neurotoxic effects associated with high sulphate water appear to manifest as a form of polioencephalomalacia, which results in clinical signs of seizures, blindness, ataxia and recumbency. There are many reports of Polioencephalomalacia (PEM) and death in animals receiving excessive amounts of sulphate, and indicated water as a source of sulphate (reviewed by Gould 1998 and Gould 2000; Cammack et al 2010).

Raisbeck et al (2008) reviewed the literature regarding effects of excessive sulphur on other minerals. Dietary sulphur can also interfere with copper metabolism; sulphide produced by rumen bacteria can reduce copper absorption, by producing complexes with molybdenum and copper which cannot be absorbed, and which therefore decrease bioavailability of copper. Sulphur also inhibits the uptake of zinc, and of dietary selenium.

There is much literature reporting that higher concentrations of sulphur can reduce water and feed intake, and result in decreased average daily gain and feed efficiency of cattle and sheep, reviewed by Raisbeck et al (2008). Their review stated: *"Toxic S concentrations have been shown to reduce the feed intake, water intake, growth, and performance of animals. Cattle given water containing 1,219 mg* SO_4^{2-}*/L in conjunction with a diet containing 0.16% S (0.29% total S intake), exhibited depressed dry matter intake (DMI). Adding 0.72%* SO_4 *(0.24% dietary S) to cattle diets reduced weight gains by 50% after the first two weeks. Concentrations of 0.35% or more dietary S resulted in diminished DMI in lactating dairy cows. Water containing 5,000 mg sodium sulfate (*Na_2SO_4*)/L and grass hay containing "0.75%* SO_4*" reduced water intake by 35% and feed intake by 30% in cattle. Decreases in average daily gain (ADG), feed efficiency, and dietary net energy were seen when heifers were fed 0.25% S as ammonium sulfate (*$(NH_4)_2SO_4$*). Supplying heifers with water containing 2,814 mg* SO_4*/L and hay containing "0.55%* SO_4*" reduced hay intake by 12.4% during the summer months. Water containing 3,087 mg* SO_4*/L reduced ADG by 27%, DMI by 6.2%, and water intake by 6.1 L in steers, and it increased the incidence of polioencephalomalacia (PEM). Cattle on a low plane of nutrition decreased their water intake when consuming water with 1,000 mg* SO_4*/L, and cattle on a high plane of nutrition had a slight decrease in feed intake when consuming 2,000 mg* SO_4*/L* (Raisbeck et al. 2008)

The critical concentration of sulphates in water may depend on the sulphur in the feed. Loneragan et al (2001) reported reduced feedlot performance of cattle consuming water containing 583 mg sulphate/L while others suggest that water concentrations of less than 1,000 mg/L should be acceptable and safe for animals on normal feed (ANZECC 2000; CCME 2005), and that keeping water sulphate concentrations below 1,800 mg/L should minimise the possibility of acute death of cattle (Raisbeck et al 2008).

The mean SO_4 of the groundwater samples collected from northern WA, QLD and NT is below 500 mg/L as presented in Table 8. However, 6.3% of WA, 7.2% of NT and 12.7% of QLD samples showed SO_4 concentration above 1,000 mg/L and less than 5% of the samples showed SO_4 above 1,800 mg/L.

The concentration of sulphate in groundwater in the northern WA, QLD and NT is presented in maps in the appendix. Figure 10 to Figure 12 show the low resolution maps of sulphate concentration of groundwater samples of these states. Similar to the previously discussed constituents, the elevated concentration of sulphate (>1,000 mg/L) in WA is up north (near Wyndham and Ord River reserve areas) as shown in Figure 10. In the case of NT (see Figure 11) the sulphate concentration of groundwater is higher in the central and the south regions. Similarly the Figure 12 shows that for QLD, higher levels of sulphate are found in the groundwater samples in the central areas and some part of the eastern coastal boundary. Where the elevated levels of sulphate (>1,000 mg/L) are found, detailed groundwater analysis is advised to be carried out to accurately determine the sulphate levels and if required, appropriate water treatment solutions need to be implemented.

Table 8: Statistical analysis of sulphate in groundwater samples

	WA	NT	QLD
Total No of samples	55	38,506	39,712
Minimum (mg/L)	5	0	0
Maximum (mg/L)	6500	57,000	9999.9
Average (mg/L)	450	395	265
STD (mg/L)	1224	1822	790
No of samples with SO_4>1,000 mg/L	7	2770	2484
No of samples with SO_4>1,800 mg/L	2	1361	1730

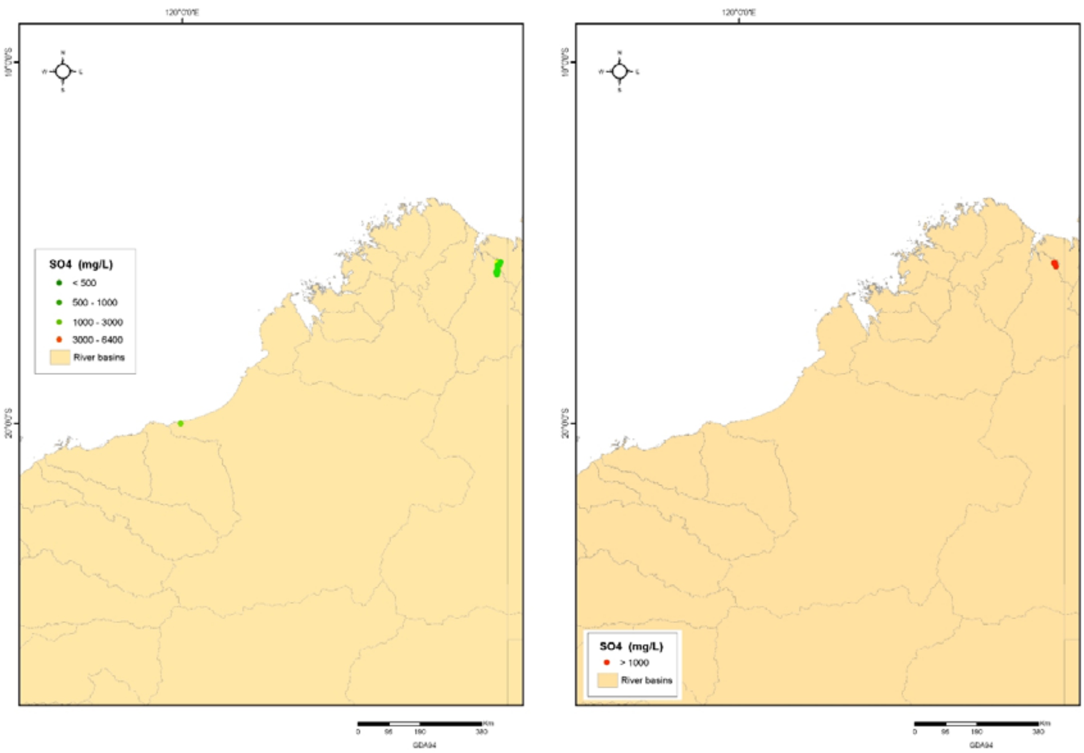


Figure 10 Sulphate concentration of groundwater in WA (left - all; right - > 1,000 mg/L)

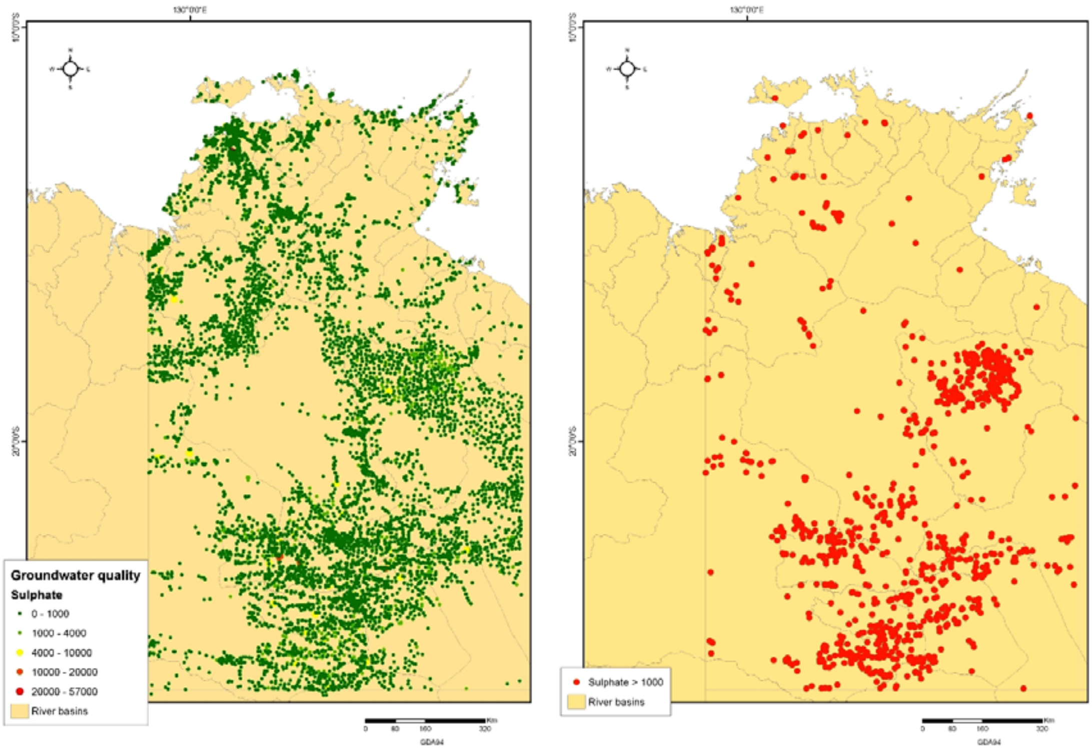


Figure 11 – Sulphate concentration of groundwater – NT (left- all; right - > 1,000 mg/L)

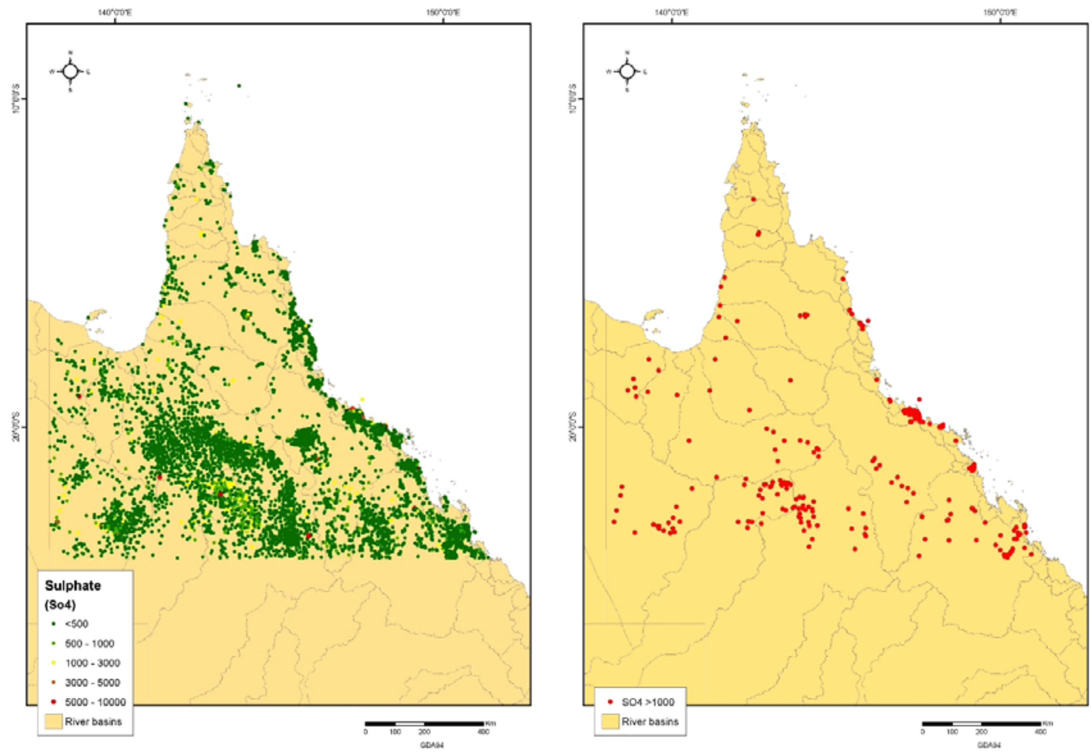


Figure 12 - Sulphate concentration of groundwater - QLD (left- all; right - >1,000 mg/L)

4.2.9 Nitrates

High nitrate concentrations in drinking water can result from run-off from agricultural areas such as paddocks heavily fertilised with chemical fertilisers or manure. The high toxicity of nitrates for ruminants is due to the conversion within the rumen of nitrate to nitrite, which can then be absorbed to bind to the haemoglobin in the red blood cells, drastically reducing the oxygen carrying capacity, so that the animal cannot supply sufficient oxygen to the tissues. Clinical signs include signs of hypoxia/anoxia such as gasping, high heart rate, muscle weakness, neurological deficits, collapse, and death. Ruminants are considered to be perhaps 10 times more sensitive to nitrate than are monogastrics (Raisbeck et al 2008). It is more common for nitrate/nitrate toxicity to occur due to feed containing excessive concentrations, but there are reports of deaths following consumption of contaminated water, e.g. with fertiliser (1,000-6,000 mg nitrate/L, reviewed by Raisbeck et al 2008). The National Research Council recommends a maximum safe concentration of 100 mg nitrate nitrogen/L water for livestock (cited by Wright 2005), while Raisbeck et al (2008) state that a water concentration of 500 mg nitrate/L or 100 mg nitrite/L in the absence of forage nitrate, should provide an adequate safety margin. These values differ slightly from the trigger values of 400 mg nitrate/L and 30 mg nitrite/L reported by the ANZECC and ARMCANZ (2000).

Table 9: Statistical analysis of nitrate in groundwater samples

	WA	NT	QLD
Total No of samples	57	7644	33946
Minimum (mg/L)	0.01	0	0
Maximum (mg/L)	50	880	701
Average (mg/L)	3.6	14	6.9
STD (mg/L)	8	42	21.5
No of samples with NO_3>500 mg/L	0	9	7
No of samples with NO_3>1,000 mg/L	0	0	0

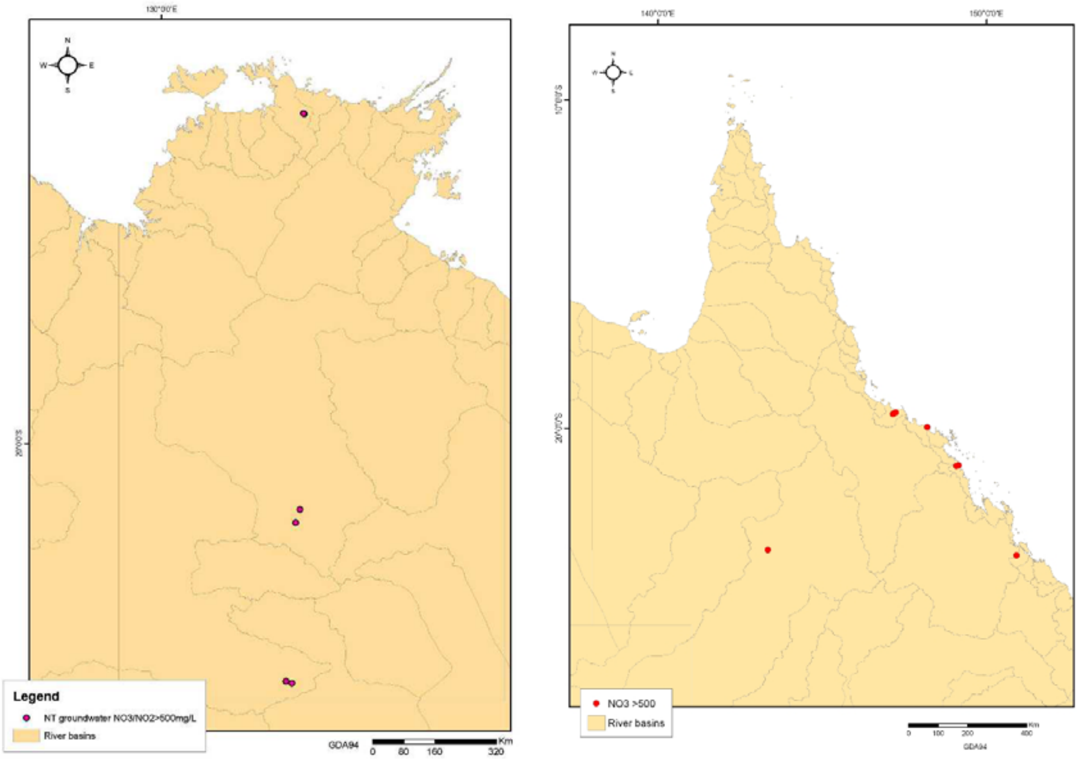


Figure 13: Nitrate concentration (> 500 mg/L) of groundwater: NT (left) and QLD (right)

The concentration of nitrate in the groundwater samples of all northern WA, QLD and NT is within the 1000 mg/L limit, though less than 0.1% of the samples in NT and QLD showed above 500 mg/L limit. As presented in Table 9, the average nitrate concentration of groundwater samples across the three states was below 14 mg/L. No samples were above 1,000 mg/L.

Figure 13 shows the map of location of groundwater samples with greater than 500 mg/L of nitrate concentration for NT and northern QLD. As the nitrate concentration of groundwater is below 50 mg/L for northern WA, the nitrate concentration of WA nitrogen for WA is not plotted. The elevated nitrate concentration of nitrate (>500 mg/L) is mostly located in the mid south region of NT and on the mid-eastern coastal areas of northern QLD. As the groundwater samples did not show significantly elevated levels of nitrate i.e. >500 mg/L except for a few locations, it can be considered that the nitrate concentration is not a significant concern. The treatment solutions for elevated levels of nitrate are relatively simple as mentioned in the later section. However, if the groundwater with higher levels of nitrate is stored in open dams, and the phosphorus is also abundant in the water, there is a significant chance for algal growth in the stored water.

4.2.10 Calcium

The trigger value of Ca specified in most of the water quality guidelines for cattle is 1,000 mg/L (ANECC, 2000, CCME 2005). In most cases, livestock should tolerate concentrations of calcium in water beyond this value, if calcium is the dominant cation and dietary phosphorus levels are adequate. However, in the presence of high concentrations of magnesium and sodium, or if calcium is added to feed as a dietary supplement, the level of calcium tolerable in drinking water may be less. Therefore, the potential adverse effects associated with high levels of Ca in the water must be considered together with the overall dietary Ca. Though the risk of calcium toxicity may be relatively low, adverse effects of high levels of calcium in the water must be considered in the context of its complex interactions with other nutrients such as phosphorus, zinc, but it may also affect magnesium, iron, iodine, manganese, and copper. This can lead to secondary deficiency of these elements, particularly when the dietary level of these elements is already low or only marginally adequate (Olkowski, 2009). Ca levels above 1,000 mg/L may cause phosphorus deficiency by interfering with phosphorus absorption in the gastrointestinal tract (N T Government, 2010).

When cattle are on high-concentrate diets, it is important to add mineral supplements high in Ca to maintain the appropriate Ca: P ratio (Greg and Lardy 2005). For high producing herds, a balanced intake of Ca and P is important. A ratio of between 1 to 2 parts of calcium to 1 of phosphorus is desirable. However, the actual amount of each in the diet is more important (Mayberry, 2005).

Although not very common, the most possible health effects due to excess Ca are associated with skeletal disorders. Prolonged intake of excessive levels of Ca - 1,000 mg/L - may cause osteoporosis, vertebral ankylosis and degenerative osteoarthritis. However, under some circumstances, calcium can be deposited in skeletal muscles as well as in the heart muscle. Cardiac function can be compromised, or in more extreme and advanced cases, heart failure can be a result (Olkowski, 2009)

Table 10: Statistical analysis of calcium in groundwater samples

	WA	NT	QLD
Total No of samples	1709	39001	40786
Minimum (mg/L)	0.31	0	0
Maximum (mg/L)	2660	32940	6200
Average (mg/L)	60.28	75	129.3
STD (mg/L)	137.9	250	331
No of samples with Ca >1,000 mg/L	7	64	946

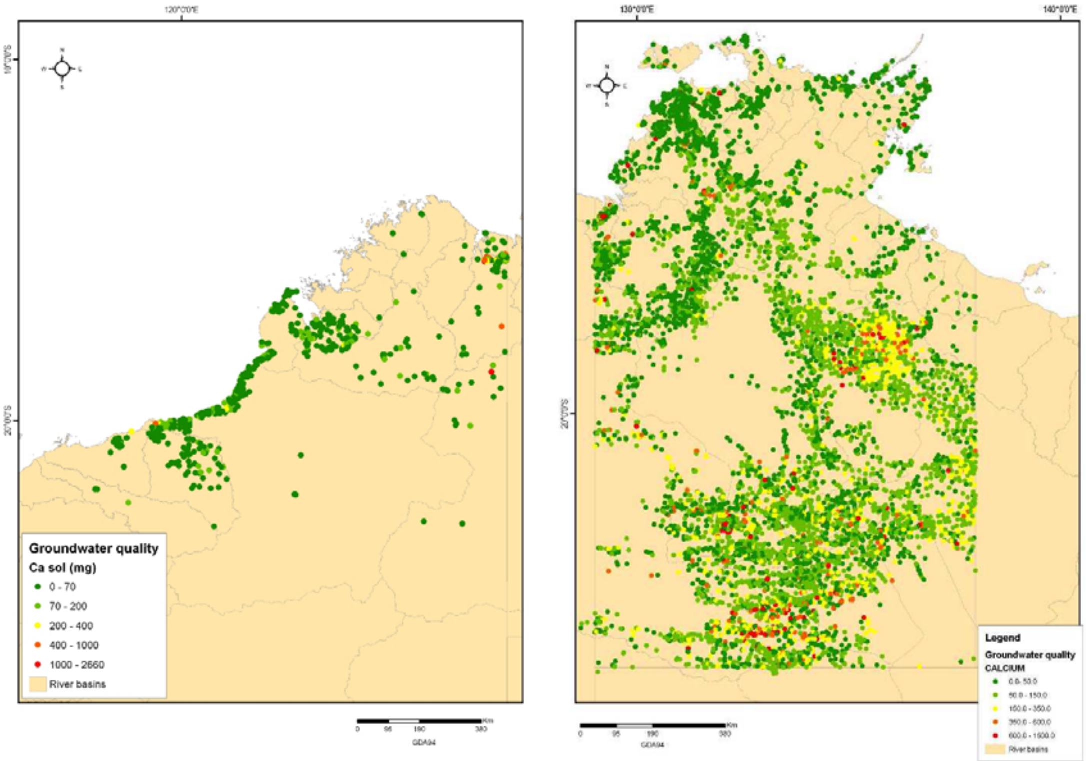


Figure 14: Calcium concentration (mg/L) of groundwater: WA (left) and NT (right)

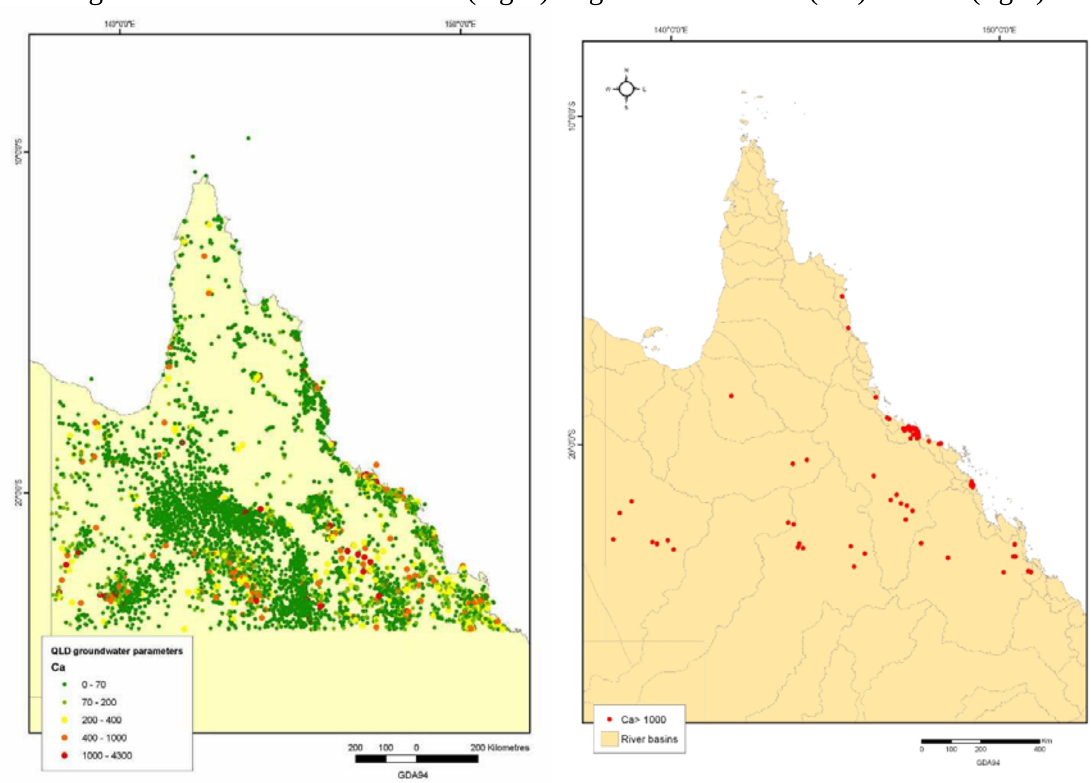


Figure 15: Calcium concentration (mg/L) of groundwater: QLD – all (left) and QLD >1000 mg/L (right)

The average and maximum concentrations of calcium in the groundwater in WA and NT and QLD are presented in Table 10. WA has the lowest average concentration of calcium amongst the three states with a value of 60.28 mg/L. Only 0.16% of the total samples of 39,000 of NT exceeded the upper limit of 1,000 mg/L of Ca in the groundwater. Similarly, only 0.41% of WA samples were above 1,000 mg/L of Ca. In comparison, 2.32% of a relatively larger sample size of 40, 780 were above the upper limit for QLD. As both WA and NT samples exceeded the upper ranges marginally (<0.5%), no separate reference maps of Ca concentration in excess of 1,000 mg/L have been presented for these states.

Figure 14 presents the geographical distribution of Ca concentration in the groundwater of WA and NT. The concentration of Ca in the groundwater of northern QLD for all samples and for the samples that exceeded 1,000 mg/L is shown in Figure 15. The higher values of Ca are mostly located at bores in the mid-central and mid - south part of NT, and for QLD, the higher values bores are located at the middle of eastern coastal boundary.

4.2.11 Phosphorus

Phosphorus has an extremely important biochemical and physiological role in livestock diet. Deficiency of P in diet has resulted in reduced growth rate, depraved appetite, and reduced milk production in cattle. High P uptake can result in bone re-absorption, urinary calculi, elevated plasma phosphorus levels (NRC, 1980). However, there are no reports in the literature of problems associated with excessive amounts of phosphorus in water on the health of cattle.

The maximum and average concentrations TP of groundwater samples in the northern WA (total number = 70) were found to be 1.4 and 0.26 mg/L. However, for northern QLD, the average concentration of TP (total phosphorus, calculated from the phosphate values in the data) in the groundwater was 0.3 mg/L (STD = 5.25 g/L) and the maximum was found to be 156 mg/L, out of a sample size of 2950. The NT groundwater quality data did not have TP values. The ANZECC, (2000) and other EPA regulations do not specify any upper value of TP or phosphate in groundwater for suitability to feed cattle.

As the TP values of groundwater samples of northern QLD showed a higher variability, the phosphorus values as phosphate have been plotted and presented in Figure 16. The mid-section of east coast of northern QLD showed higher phosphate values.

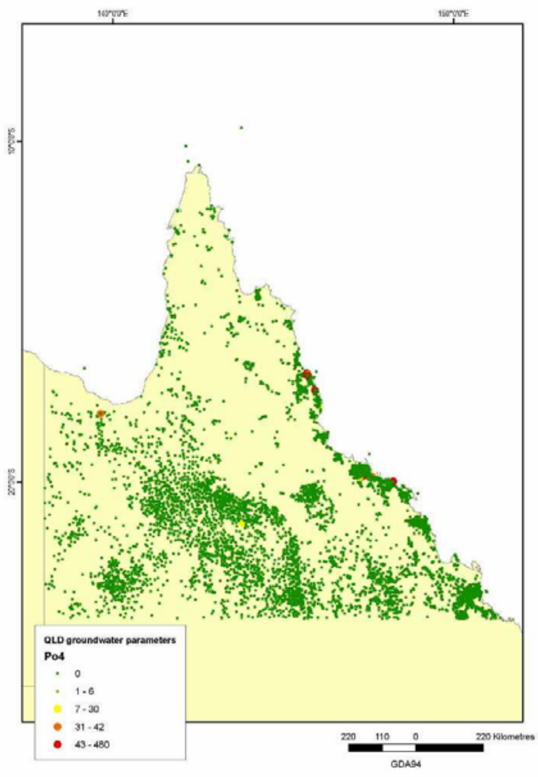


Figure 16: Phosphate concentration (mg/L) of groundwater: QLD

4.2.12 Magnesium

Magnesium may be of concern in water in certain areas. High magnesium such as 5,000 mg/L has been associated with diarrhoea, (Chemistry Centre 2007), lethargy, lameness, decreased feed intake and decreased performance (ANZECC, 2000) while concentrations up to 2,000 mg/L have been observed to have no ill effects on cattle (Northern Territory Fact Sheet; ANZECC, 2000). In South Africa, an upper limit of 1,000 mg Mg/L is proposed, with some adverse effects possible at lower concentrations; the effects may depend on the presence of other salt (DWAF 1996).

Table 11: Statistical analysis of magnesium in groundwater samples

	WA	NT	QLD
Total No of samples	83	39,035	40627
Minimum (mg/L)	2	0	0
Maximum (mg/L)	1,900	69,000	5900
Average (mg/L)	91.8	101.6	147.8
STD (mg/L)	279	694.4	434.9
No of samples with Mg >1,000 mg/L	2	582	1,372
No of samples with Mg >2,000 mg/L	0	261	626
No of samples with Mg >5,000 mg/L	0	82	37

The magnesium concentration in the groundwater of northern WA is relatively low, with an average value of 91.8 mg/L. Except for two samples, the highest value was found to be 370 mg/L, and the two higher values were found to be below 2,000 mg/L as presented Table 11. However, 1.5 % of NT and 3.4% of samples exceeded 1,000 mg/L of Mg in the groundwater. As the samples of WA showed low values of Mg, a map of Mg in the groundwater of northern WA has not been made.

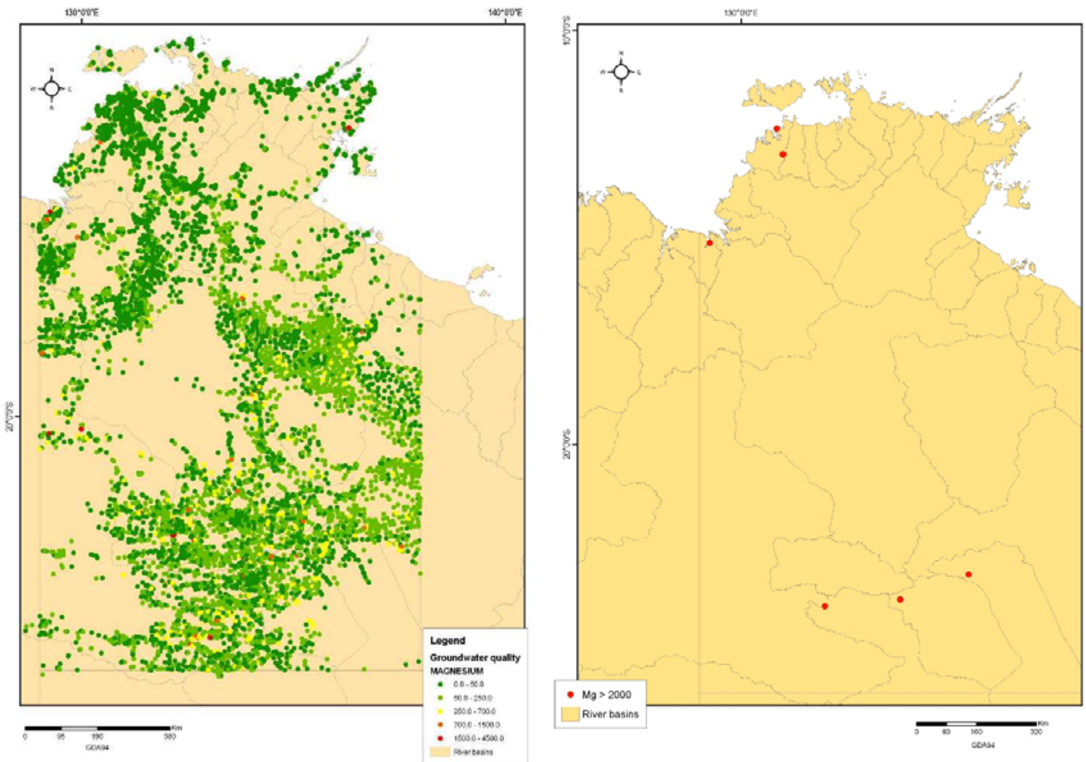


Figure 17: Magnesium concentration (mg/L) of groundwater- NT (left- all; right >2,000 mg/L)

Figure 17 shows the distribution of groundwater samples with concentration for Mg in NT and Figure 18 presents the same for northern QLD. In the case of NT, samples in the mid North and mid South showed higher concentration of over 2,000 mg/L of Mg in the groundwater (Figure 17). In the case of northern QLD, the higher concentration of Mg (excess of 2,000 mg/L) was found in samples from the mid-East, on the coastal area as shown in Figure 18. Detailed investigations may be carried out for locations with higher than 2,000 mg/L of Mg to identify the appropriate solutions if the groundwater is to be provided to cattle.

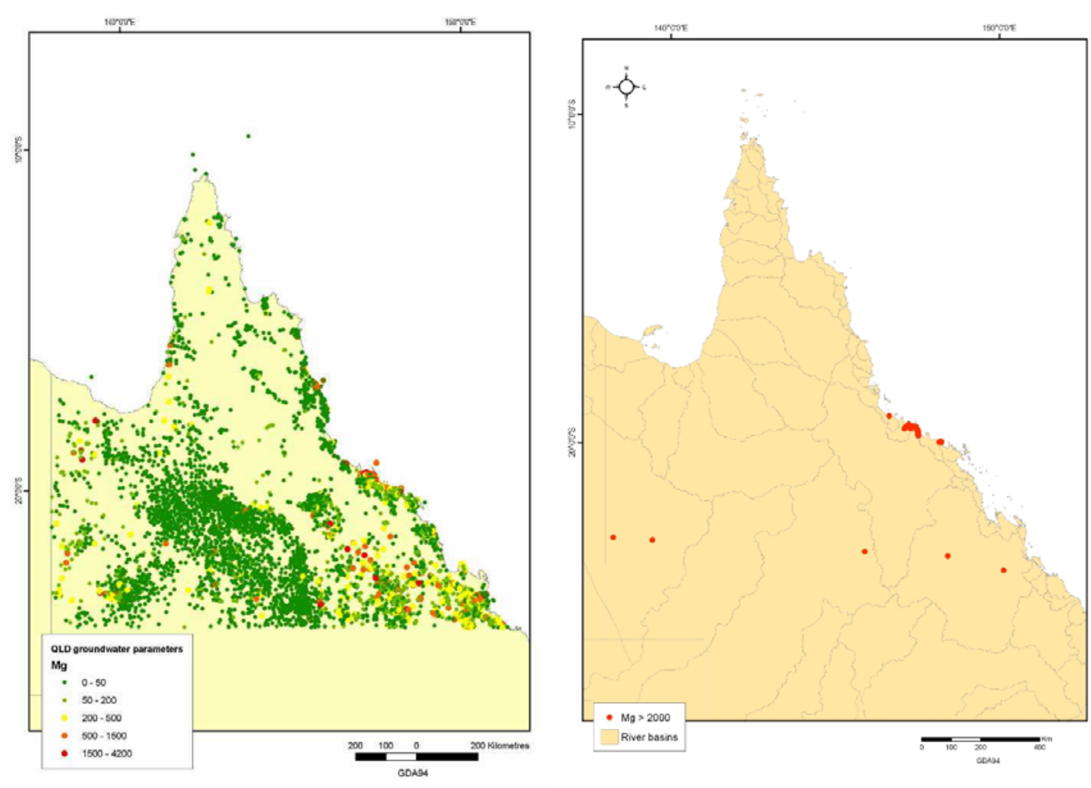


Figure 18: Magnesium concentration (mg/L) of groundwater- QLD (left- all; right >2,000 mg/L)

4.2.13 Manganese

Manganese (Mn) has not been included in the ANZECC (2000) guidelines for livestock water quality. Manganese is an essential element for animal nutrition, but only about 3% of ingested manganese is absorbed. Generally, the contribution of water manganese to the total dietary manganese appears to be negligible. South African guidelines (DWAF 1996) recommend an upper limit of 10 mg Mn/L in livestock drinking water.

The maximum concentration of Mn in the groundwater samples of QLD 66 mg/L, and the average value of 24,462 samples was found to be 0.54 mg/L with a standard deviation of 3.3 mg/L. Only 1.4% of the samples showed Mn concentration above 10 mg/L in the groundwater of northern QLD. Figure 19 illustrates the concentration of Mn in groundwater in northern QLD. The elevated concentration (>15 mg/L) of Mn is mostly located in the middle of eastern coastal area and mid south border.

No data was available for manganese in the groundwater for WA and NT.

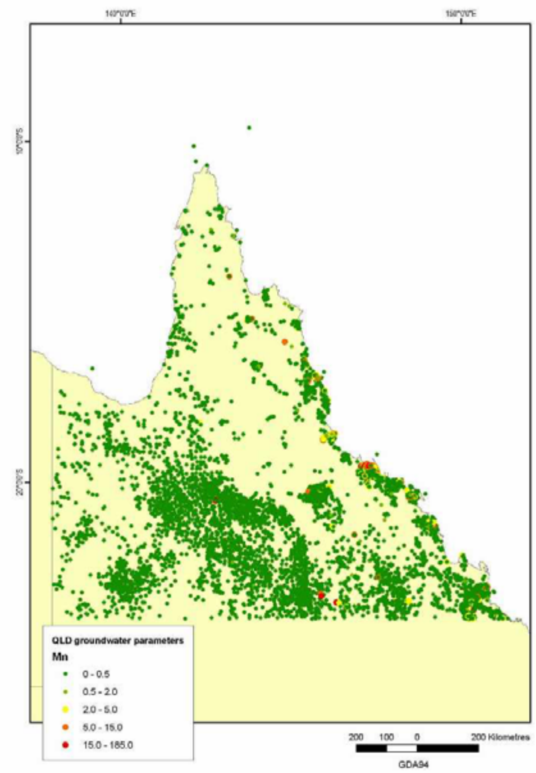


Figure 19: Manganese concentration (mg/L) of groundwater- QLD

4.2.14 Aluminium

ANZECC (2000) guidelines specify that where aluminium concentrations in water exceed 5 mg/L, stock intake of phosphorus in the diet should be investigated. Animals, particularly ruminants, may tolerate much higher levels of aluminium as long as there is sufficient phosphorus in the diet to compensate for the effects of aluminium.

High levels of aluminium react with phosphorus in the intestine of animals to form a nonabsorbable complex, thus affecting phosphorus absorption and metabolism and resulting in symptoms of phosphorus deficiency (NRC 1980, cited by ANZECC 2000). Symptoms include reduced growth and disturbances in carbohydrate metabolism. Ruminants may be less susceptible than monogastrics, since organic anions in the rumen may complex the aluminium and prevent it precipitating with phosphate (ANZECC 2000).

Table 12: Statistical analysis of aluminium in groundwater samples

	WA	QLD
Total No of samples	574	8329
Minimum (mg/L)	0.006	0
Maximum (mg/L)	99.99	16.53
Average (mg/L)	0.91	0.04
STD (mg/L)	4.98	0.28
No of samples with Al >5 mg/L	19	3

The average value of Al in the groundwater of northern WA is <1 mg/L and for northern QLD it is 0.04 mg/L as presented in Table 12. In the case of QLD, only 0.04% of the samples showed >5 mg/L of Al in the groundwater. However, for WA, 3.3% of groundwater samples showed Al concentration above 5 mg/L, these samples were located at north (towards the eastern side) of

WA as shown in Figure 20. In the case of QLD, the concentration of Al was even throughout the northern part as shown in Figure 21. No data was available for Al in the NT groundwater quality database, hence not plotted.

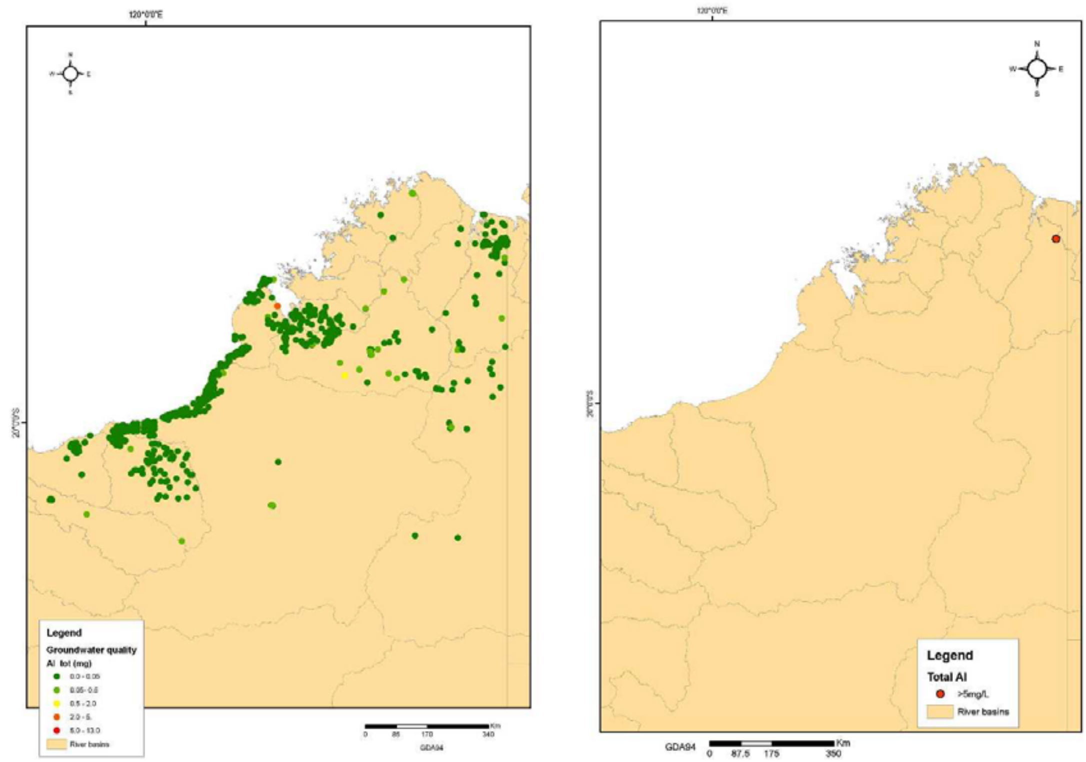


Figure 20: Aluminium concentration (mg/L) of groundwater- WA (left- all; right >5 mg/L)

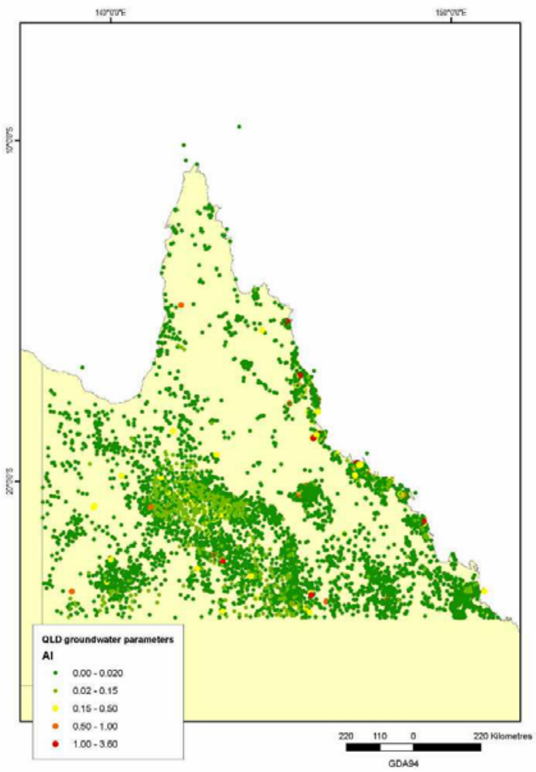


Figure 21: Aluminium concentration (mg/L) of groundwater- QLD

4.2.15 Arsenic

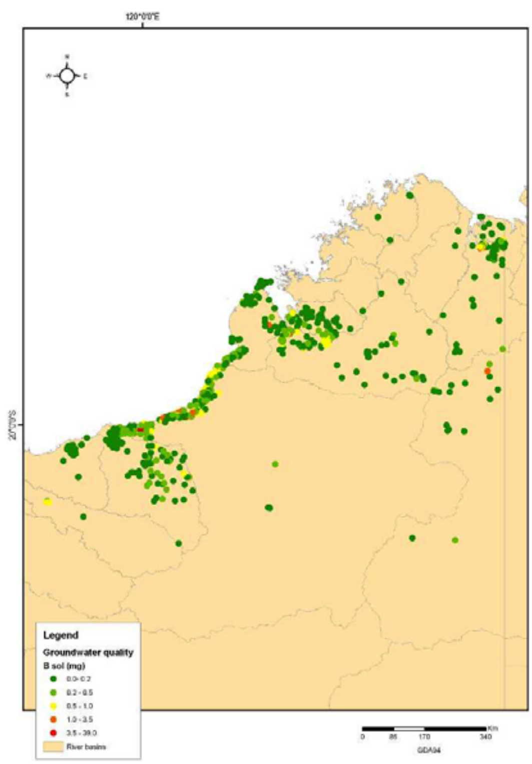
Arsenic (As) has been found in the Australian environment, mostly associated with mining, and also with other industry such as agriculture; there are contaminated sites where there was previous use of arsenic based chemicals for eradicating cattle ticks (Smith et al 2003). The trigger value considered for water, in the absence of any arsenic in the diet, is 0.5 mg/L (ANZECC, 200); however, Raisbeck et al (2008) recommended an upper value of 1.0 mg arsenic/L for livestock drinking water. Previous studies reported As in Australia to range between 1 and 5,000 µg/L (Hinwood et al. 2004; Smith et al., 2003). The less toxic pentavalent forms of As are more likely to occur in surface waters (Roth and Reddy, 2007; Langner et al., 2001). Generally, it is concluded that ruminant animals are less susceptible to As than monogastrics (NRC, 2005).

As concentration has not been plotted as the concentration of As in the groundwater WA and QLD is below 0.03 mg/L, much below the trigger value of 0.5 mg/L and no data was available for As for NT. Based on the As concentration in groundwater for QLD and WA, it can be assumed that that natural background concentrations seldom exceed a few ppm, except in areas contaminated by anthropogenic activities.

4.2.16 Boron

According to ANZECC (2000) guidelines for water quality for livestock, if the concentration of boron (B) in water exceeds 5 mg/L, the total boron content of the livestock diet should be investigated. Higher concentrations in water may be tolerated for short periods of time.

Boron dissolved in water or contained in food is rapidly absorbed from the gastrointestinal tract in animals and excreted via the urine. Boron concentrations of 150 mg/L in drinking water for cattle resulted in reduced hay consumption and a loss of weight (Green and Weeth 1977) cited in ANZECC (2000).



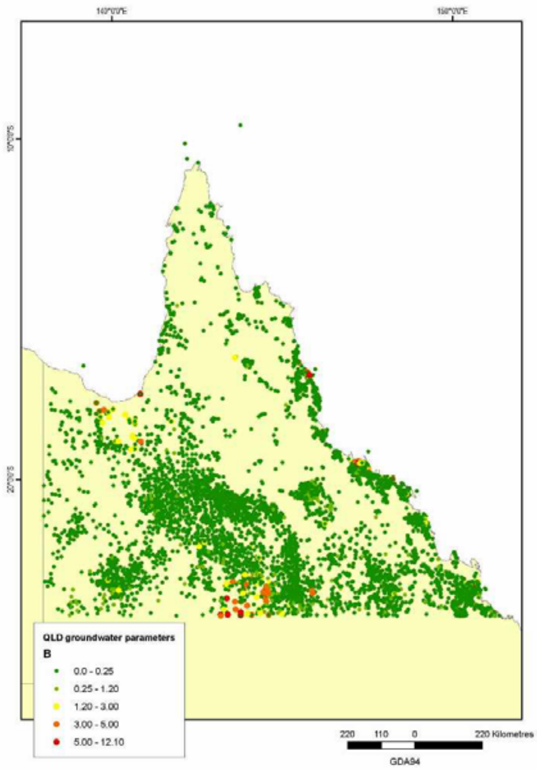


Figure 22: Boron concentration (mg/L) of groundwater- WA (left); QLD (right)

Table 13: Statistical analysis of boron in groundwater samples

	WA	QLD
Total No of samples	564	8391
Minimum (mg/L)	0	0
Maximum (mg/L)	39	13.2
Average (mg/L)	0.41	0.21
STD (mg/L)	1.8	0.67
No of samples with B >5 mg/L	2	40

The concentration of B in the groundwater of WA exceeded 5 mg/L only for two samples (0.4%) and for QLD for 40 samples (0.5%) as shown in Table 13. The average concentration of B in the groundwater was 0.41 mg/L for WA and 0.21 mg/L for QLD, both are significantly lower than the ANZECC (2000) limit of 5 mg/L. The groundwater samples from the middle of south end of northern QLD showed higher concentration of B (> 5 mg/L) as shown in Figure 22. No data for Boron for NT was available and hence not plotted.

4.2.17 Cadmium

Usually only a small amount of the total cadmium intake by livestock comes from drinking water, with most coming from food. Nevertheless, cadmium concentrations in drinking water for livestock should be restricted because of its toxic and possibly teratogenic, mutagenic and carcinogenic effects (ANZECC (2000, CCME 2005).

A number of studies have reported that only a small part of the ingested cadmium in ruminants was absorbed, with most absorbed cadmium going to the kidney and liver. Anaemia, abortions, stillbirth and reduced growth were observed in animals given cadmium in doses of 1–160 mg/kg bodyweight as reported in ANZECC (2000). A concentration of total cadmium greater than 0.01 mg/L in drinking water for livestock may be hazardous to animal health as per ANZECC (2000).

Cadmium concentration has not been plotted as the concentration of Cd in the groundwater of WA and Queensland was found to be below 0.002 mg/L, much below the trigger value of 0.01 mg/L and no data was available for Cd for NT.

4.2.18 Chromium

The livestock water quality guidelines of Australia and New Zealand, Canada and South Africa specify that the levels of total chromium exceeding 1 mg/L in the drinking water of livestock may be hazardous to animal health (ANZECC, 2000; CCME, 2005).

Trivalent chromium is an essential element in the diet of mammals, being required for carbohydrate and lipid metabolism. Salts of chromium (III) are poorly absorbed by the gastrointestinal tract, whereas the absorption rate of chromium (VI) is much higher. Chromium (VI) is much more toxic to animals than chromium (III) CCME, 2005).

The concentrations of chromium in the groundwater of WA and Queensland have been found to be much lower (<0.002 mg/L) and hence not plotted in this report. No data of chromium concentration in NT was available.

4.2.19 Cobalt

Levels of total cobalt in drinking water for livestock exceeding 1 mg/L may be hazardous to animal health, particularly if cobalt supplements are being used (ANZECC, 2000).

Cobalt is an essential element in the diet of animals, and is important in several enzyme systems, particularly as a component of vitamin B12. Generally cobalt has a low toxicity to animals and in ruminants, cobalt deficiency, in practice, is more likely to occur (NRC 2005).

Reduced appetite and some weight loss when cobalt was administered daily at concentrations of 1.1 mg/kg bodyweight to the diet of calves. According to CCME (2005), drinking water for calves would have to contain at least 10 mg/L cobalt before the above symptoms would be evident. Cattle may tolerate cobalt at concentrations of 10 mg/kg in their diet, which is about 100 times normal requirements (NRC 2005).Cobalt has been found to be of very low concentration in both WA and Queensland (<0.002 mg/L) and hence not been plotted in the report. No data for Cobalt was available for NT.

4.2.20 Copper

Copper is an essential element in the animal diet. Copper nutrition in animals is influenced by the dietary intake of molybdenum, iron and sulphur. Excessive intake of copper can lead to copper toxicosis in livestock, which generally would be expected to relate to a high intake from feed rather than from water. Initially, copper accumulates in the liver of animals and may cause some reduction in growth. Chronic and acute effects such as liver damage and haemolytic jaundice can occur with extended exposure to high levels of copper.

Concentrations of total copper in drinking water for livestock exceeding 0.5 mg/L may be hazardous to the health of sheep whereas for cattle, the limit is above 1 mg/L copper (ANZECC, 2000). Concentrations of copper in WA and Queensland groundwater were within 0.4 mg/L, and hence not plotted. No data for copper for NT was available. If the groundwater is stored in dams and if copper sulphate is added to prevent algal blooms, the potential for increase of Cu beyond the acceptable limit may be tested.

4.2.21 Fluoride

Fluoride has been found in groundwater supplies, and excess fluoride can cause tooth damage to growing animals and bone problems in older animals, as reviewed by Raisbeck et al (2008), who recommend water for cattle contain less than 2.0 mg fluoride/L, which is also the ANZECC guidelines for fluoride. Vegetation can accumulate fluoride from soil, water, and the atmosphere (Kubota et al., 1982). Usually ground water tends to have higher F concentration compared to surface water probably due to the highly mobile nature of the fluoride ion (Stumm and Morgan, 1996).

A review of the groundwater data collected from the northern Western Australia indicates the fluoride level exceeded marginally in about 5% of the collected points only, but below 2 mg/L, which in normal circumstances should not cause acute F toxicity. Signs of acute F toxicity include restlessness, sweating, anorexia, salivation, dyspnea, nausea, gastroenteritis, muscle weakness, clonic convulsions followed by depression, pulmonary congestion and respiratory and cardiac failure. Fluorine is a cumulative toxin, and for this reason animals that live longer (e.g. dairy or beef cows) are more likely to develop chronic fluorosis.

In contrast to F concentration in the groundwater of northern WA, NT and northern QLD elevated concentration in the groundwater. As shown in Table 14, the maximum concentration of WA samples was 1.8 mg/L, but 12.7% of NT samples and 4% of northern QLD showed >2 mg/L of F. Figure 23 illustrates the locations of bores with >2 mg/L of F in the groundwater. The locations with elevated F need to monitor the water quality and adequate steps need to be taken to prevent any cause to animal health due to high F concentration in the groundwater.

Table 14: Statistical analysis of fluoride in groundwater samples

	WA	NT	QLD
Total No of samples	67	17837	38898
Minimum (mg/L)	0.2	0	0
Maximum (mg/L)	1.8	28	760
Average (mg/L)	0.6	1.1	0.61
STD (mg/L)	0.42	1.3	4.96
No of samples with F >2 mg/L	0	2264	1556

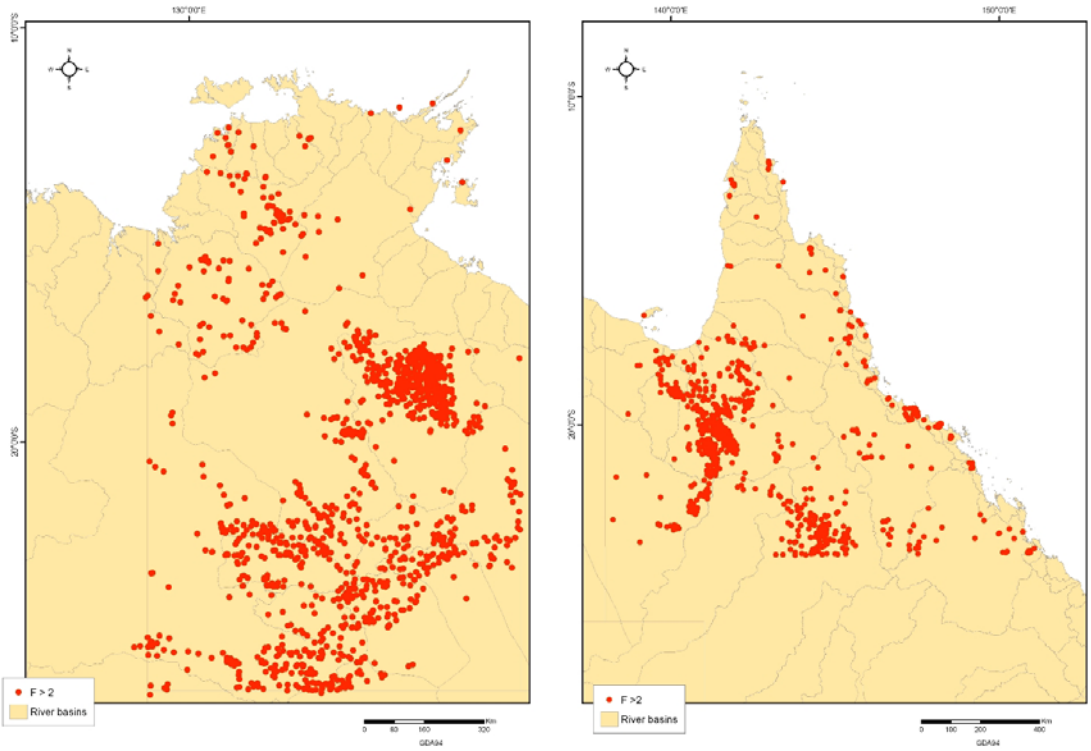


Figure 23: Fluoride concentration (>2 mg/L) of groundwater- NT (left); QLD (right)

4.2.22 Iron

High concentration of iron (Fe) in drinking water can reduce intake by affecting the palatability. However, there is no upper limit for iron for livestock drinking water in most the guidelines (ANZECC, 2000). Iron is present in water in the form of highly soluble ferrous (Fe^{2+}) ions. These are readily absorbed by the intestine cells and pose a risk of iron toxicity. This will result in oxidative stress due to the presence of excessive amount of reactive oxygen species such as peroxides. Oxidative stress disrupts normal cell structure and function and results in compromised immune function, increased fresh cow mastitis and metritis, greater incidence of retained fetal membranes, diarrhoea, sub-normal feed intake, decreased growth and impaired milk yield. Ferrous ions can cause copper and zinc deficiency by interfering with their absorption. US EPA suggests a limit of 2 mg/L of iron.

Table 15: Statistical analysis of iron in groundwater samples

	WA	NT	QLD
Total No of samples	27	28787	26601
Minimum (mg/L)	0.2	0	0
Maximum (mg/L)	1.9	1	34
Average (mg/L)	0.8	0.003	0.25
STD (mg/L)	0.5	0.015	1.46
No of samples with Fe >2 mg/L	0	0	607

The concentration of Fe in the groundwater of WA and NT is relatively low. The mean concentration of Fe in WA was found to be 0.8 mg/L. In the case of NT, no value was higher than 1 mg/L and the average value was 0.003 mg/L for a sample size of 287,787 as shown in Table 15. However, for northern QLD, 2.3% of the groundwater samples showed Fe concentration of >2mg/L and the highest value was 34 mg/L. The elevated Fe values are on the middle part of the east coast of northern QLD and mid central part as well as shown in Figure 24. No plots of Fe concentration of groundwater of WA and NT have been presented as the concentration of Fe is lower than the USEPA value of 2 mg/L.

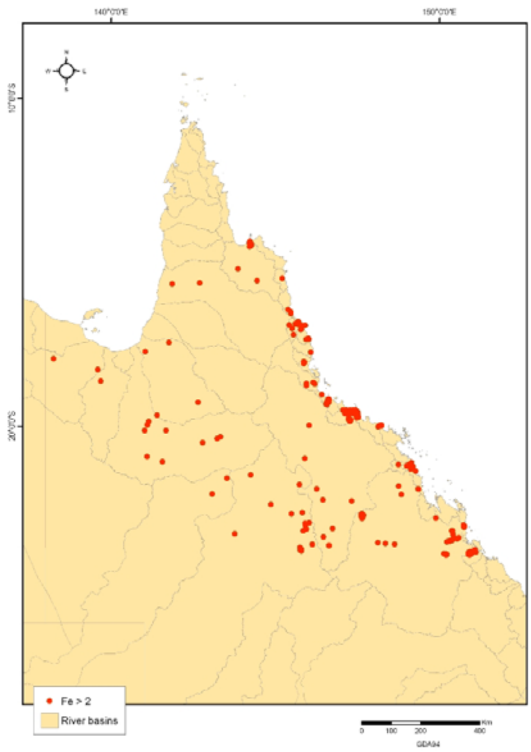


Figure 24: Iron concentration (mg/L) of groundwater- QLD

4.2.23 Lead

According to Australian and New Zealand guidelines for livestock water quality (ANZECC, 2000), the trigger value for lead (Pb) in the groundwater is 0.1 mg/L. The toxicity of lead depends on the type of animal (including its age), the form of lead and the rate of lead ingestion. Lead is accumulated in the skeleton to a critical maximum level, after which circulating concentrations increase until poisoning occurs. Chronic effects such as anorexia and respiratory distress are associated with low level poisoning. Severe poisoning causes acute effects such as frothing at the mouth, uncoordination and convulsions (DWAF 1996).

The average concentration of Pb in groundwater of northern WA was found to be 0.038 mg/L with a standard deviation of 0.045 mg/L. The maximum concentration of Pb was 0.1 mg/L for a sample size of 206. No data on Pb in the groundwater was available for northern QLD and NT. As the maximum concentration is below the threshold limit, no map of Pb concentration has been prepared for WA.

4.2.24 Mercury

Mercury is one of most toxic metals that may be present in the farm animal environment. The concentration of mercury found in unpolluted groundwater. In northern Australia is generally well below 0.001 mg/L. Anthropogenic activities such as mercury manufacture and disposal, fossil fuel combustion, and intensive agricultural practices contribute most of the mercury in the farm animal environment.

At present, recommended maximum concentrations for mercury in livestock drinking water is set at 0.002 mg/L for Australia and New Zealand (ANZECC, 200) and 0.003 mg/L for Canada (CCME, 2005).

Acute poisoning in farm animals is possible under some specific exposure circumstances, but the risk under most practical situations is extremely low. Acute toxic signs include nausea, vomiting, severe gastrointestinal irritation and pain, shock, and cardiac arrhythmias. Death may occur, and is usually associated with uraemia, caused by damage to renal tissue. Chronic, clinical or sub-clinical toxicity scenarios in farm animals are possible in areas where environmental exposure to mercury is high.

Exposure to mercury of livestock can have a detrimental effect on reproductive success. Male reproductive effects associated with mercury include impaired spermatogenesis and sperm motility. In females, mercury increases fetus resorption and induces abortion. Oral administration of methyl-mercury during gestation or lactation may cause developmental problems (Nielsen and Andersen, 1995). No data on groundwater concentration of mercury could be obtained for WA, NT and Queensland.

4.2.25 Molybdenum

Concentrations of molybdenum in livestock drinking water greater than 0.15 mg/L may cause health problems to stock, depending on total dietary intakes of molybdenum, copper, iron and sulfur. At molybdenum concentrations greater than 0.15 mg/L, the animal diet should be investigated to ensure that copper levels are sufficient to account for the total dietary intake of molybdenum.

Molybdenum is usually found at concentrations of 0.05 mg/L or less in natural waters (ANZECC, 2000) and review of groundwater quality data from northern WA shows that the maximum concentration was 0.002 mg/L. No data for molybdenum was available for NT and Queensland.

Health effects on stock are more likely to occur through the ingestion of forages which can accumulate and hence concentrate molybdenum, than through the intake of water.

Ruminants are most susceptible to elevated levels of molybdenum with cattle more sensitive than sheep (NRC 2005). Molybdenosis ('teart' disease or 'peat scours' in New Zealand) in cattle is characterised by severe scouring and loss of condition, and secondary copper deficiency. Inorganic molybdenum combines with sulfide in the rumen to form thiomolybdates, which bind copper and interfere with its absorption.

4.2.26 Other elements

Nickel, selenium, and zinc have been found to be well below their threshold values in the northern Australia and hence no further attention is provided in this report. Also, no data was available for vanadium and uranium for all the states, hence no further discussion in included in the report.

4.2.27 Summary of Water Contaminant Guidelines

A summary of the water contaminant guidelines for Australia and overseas is provided in Table 16. These include Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), 2000; CCME - Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses – Update October 2005; and US-EPA guidelines. Where there is no specific value for a particular contaminant, that cell is left blank. The recommended safe range has been taken from various studies and reports. The percentage of samples that exceeded the limits for each of the case study states is also provided in Table 16.

Table 16: Summary of Water Contaminant Guidelines

Water Contaminant (mg/L)	ANZECC (2000)	CCME (2005)	US-EPA (upper limit)	Recommended Upper safe Levels	% of samples exceeded the values		
					WA	NT	QLD
Aluminium	5			5	3.3	ND	0.4
Arsenic	0.5	0.025	5	0.025	0	ND	0
Beryllium	0.1			NA	ND	ND	ND
Boron	5			5	0.4	ND	0.5
Cadmium	0.01	0.08	5	0.08	0	ND	0
Calcium	1000			1000	0.41	0.16	2.32
Chloride				NA			
Chromium	1	0.05	0.05	0.05	0	ND	0
Cobalt	1	1.0	1	1.0	0	ND	0
Copper	0.5	5.0	1	0.5 to 5.0	0	ND	0
Cyanide		None	-	NA			
Fluoride	2	1 to 2	0.5	1 to 2	0	12.7	4
Hardness		None	-	NA			
Hydrogen Sulphide		None	-	NA			
Iron		None	2	NA	0	0	2.3
Lead	0.1	0.1	NA	0.1	0	ND	ND
Magnesium	-	None	-	5000	0	0.2	0.14
Manganese		None	NA	10	0	0	1.4
Mercury	0.002	0.003	0.001	0.03	ND	ND	ND

Molybdenum	0.15	0.5		NA	0	ND	ND
Nickel	1	1.0		1.0	0	ND	0
Nitrate + Nitrite		100		500	0	0.1	0.1
Nitrate nitrogen	30	23	100	500	ND	ND	ND
Nitrite		10	33	NA	ND	ND	ND
Nitrite nitrogen	10	3.0		3.0	ND	ND	ND
Potassium		None		None			
Selenium	0.02	0.05	0.05	0.05	0	0	0
Silver		None		NA			
Sodium		None		1000	4.7	4.6	13.4
Sulphate	1000	1000		1000	6.3	7.2	12.7
TDS	4000	3000		4000	16	6.27	14.2
Uranium	0.2	0.2		NA	ND	ND	ND
Vanadium	0.1	0.1	0.1	100	ND	ND	ND
Zinc	20	50	25	50	0	0	0

CCME Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses – Update October 2005
NA-recommendation not available; ND – No data available

4.3 Reports of Water Quality Associated Disease

Cases of animal deaths and disease have been reported via the Animal Health Surveillance Quarterly, the Newsletter of Australia's National Animal Health Information System (Animal Health Australia). These reports are available at http://www.animalhealthaustralia.com.au/programs/adsp/nahis/ahsq.cfm.

The two most commonly reported causes of death are cyanobacteria poisoning (blue-green algae) throughout Australia, and salt toxicity.

Blue green algae toxicity was suspected to cause cattle deaths in the Barkley Tableland of Northern Territory, reported in 1996 (Vol 1 issue 3). Micocystis flosaquae was found in dam water consumed by cattle and sheep which died suddenly in autumn in Tasmania (Vol 3 Issue 2, 1998), and deaths stopped after the animals were removed from that paddock. In Northern Victoria, three 2-year-old heifers were sick and another three died and pathology was consistent with blue green algae poisoning, and the dam was visually heavily contaminated with algae (Vol 5 Issue 1, 2000). In Northern Territory, deaths of 7-8% were recorded in cattle over a 2-3 week period in the Katherine region, and this was suspected to be due to blue green algae poisoning, sue to the clinical signs and liver pathology (Vol 5 Issue 3, 2000).

Further cases were reported from Tasmania (Vol 6 Issue 1, 2001) with two probable outbreaks with microcystin-LR confirmed from the water. On one farm, there were three deaths and 30 ill of 500 9-10-month-old calves, while on another farm 20 first calf heifers died suddenly and another 15 were sick. Cases have also been reported from Central Qld (Vol 6 Issue 3, 2001) where 7 weaner cattle died and another 6 were affected due to Cylindrospermopsis poisoning. In NSW, 22/60 cattle died with liver pathology in the Narrendera district, thought due to poisoning by Anabaena circinalis growing on a low level lagoon with dark green water. Deaths were reported from Victoria in 2007 (Vol 12 Issue 1) with 18 cows and 1 bull dying out of a mob of 140 cattle in South Gippsland region. This was thought due to Micocystis aeruginosa growing on a dam, which was at low level but had received an influx of nutrients after recent rain.

Salt toxicity has been reported in animals drinking both surface and bore water. In 1997 (Vol 2 Issue 1) 100 of 300 young weaner sheep in SA died of suspected salt poisoning, from drinking water measured to contain 6500 ppm of salt. In Western NT, chronic weight loss and neurological signs in cattle were suspected to be due to chronic salt toxicity from drinking poor quality bore water (Vol 5 Issue 4, 2000). Salt poisoning was also suspected in Queensland in

2003, where 5-year-old Merino wethers died from drinking very salty bore water, resulting in incoordination and recumbency and death. There are also reports of animals dying from urinary calculi and obstruction, presumed to be due to the high mineral content of the water. Recently reported were deaths of beef cattle in SA where 2 cows died and 2 more became recumbent after drinking from pools of water in the creek. The salt in two pools in the creek was measured at >10 000 mg/L and in other pools 3000-6900 mg/L. It was thought that a combination of hot water, eating dry feed, and lactating resulted in higher water consumption and therefore toxic intake of salt (Vol 14 Issue 1, 2009). In WA in 2009, 150 2-year-old sheep died and others were affected after being transported to Morawa where the water they were accessing was very salty, measured at 6740 millisiemens/metre and 14250 millisiemens/metre.

Other cases of deaths related to water quality occur where water has become contaminated with infectious organisms such as Salmonella, particularly S. typhimurium, as well as Listeria and Burkholderia pseudomallei (causing melioidosis). In Victoria in 2000, 55/135 dairy cows had diarrhoea and 2 died of S. typhimurium 135 which was cultured form the animals and from a small lagoon which supplied the water (Vol 5 issue 1, 2000). In NSW 59 calves and 20 mature cattle from a mob of 140 died over a 4 month period, considered to be associated with the S. Adelaide isolated from water and mud (Vol 12 issue 1, 2007). Additionally, chemical contamination can occur, such as with arsenic or lead from dumps or poorly disposed of chemicals.

There was one report of fluorosis, from Qld in 2003, where 3-year-old Santa Gertrudis cows near Longreach had generalised lameness, thought associated with the high concentrations of fluoride in the bore water, at 18 mg fluoride/L, which is considered a hazardous level (Vol 8, Issue 2, 2003).

4.4 Water Quality – Sampling and Testing for producers

4.4.1 Water quality testing kits

A number of water quality testing kits are available for various characteristics and properties of water. These include test kits for different types of water such as surface water, bore water, rainwater and wastewater.

The parameters (elements and physical and chemical properties) to be tested vary depending on the type of water to be tested and the applications. For example, water testing for irrigation needs to test for sodium adsorption ratio which is not usually tested in the case of surface water quality (river or estuaries). Similarly the groundwater quality tests typically do not consist of bacterial contamination and for algae and organic matter. If the bore water is stored in a dam and has a longer residence time, the dam water may be tested for the above parameters as well.

4.4.2 On-site water quality test kits

A number of water quality field testing kits are available for accurate level analysis of groundwater. Some of the test kits can analyse a number of parameters and with a relatively high level of accuracy. For example, The Hach DR 2800 Portable Spectrophotometer can be used for more than 240 analytical methods. In a typical case, producers do not require such extensive tests and at such levels of accuracy. These types of test kits cost well in excess of $ 5,000.

There are a number of screening tests which are simple to operate, no requirement to handle chemicals or doing complex analyses, cost effective, convenient and easy to use alternative to chemical test kits and instrument tests. However, the tests provide low accurate results and can be used for screening purposes. Most require only a single step but some e.g. arsenic require use of reagents. Test strips with reagents are designed for ease of use and can be used in the field.

Also, if the general water quality data indicate that for that particular area, some parameters are within the range, it may not be required to test for such samples on a regular basis. If regular monitoring is required at a relatively high level of accuracy and staff members with training in operating the test kits are available, a test kit such as Hach kits would be useful.

The recommended tests for groundwater quality are provided in the following section. Note that some of the properties to be tests are not specially included in the ANZECC guidelines as critical to animal health. But they are included as they might affect the palatability of the water.

4.4.3 On-site test parameters

The water quality properties that are identified to be able to be tested on-farm with monitoring kits, without much complexity are presented in Table 17. These are tested either using test strips or simple procedure, as provided in the monitoring kits. The test kits for these parameters are provided in the following section.

Table 17: Water quality parameters for on-site testing

Physical	**Chemical**
pH	Nitrite – N
Alkalinity*	Nitrate – N
Hardness	Arsenic
Turbidity*	Iron*
Salinity as EC	Sulphate

* Included as these properties may affect the palatability, colour or odour of the water.

4.4.3.1 pH

- *Macherey Nagel Pehanon strips pH 4.0 - 9.0*

Macherey Nagel PEHANON pH indicator strips are available for a range of 4.0 to 9.0. Gradation is 0.5 pH units. These strips are designed for measuring pH in coloured solutions. Colours for all the pH steps are included along the strip with a zone in the centre for the actual test. A coloured solution that affects the indicator colour will also change the reference pads by the same amount. So the actual pH can be estimated as easily as it can be in a clear solution.

- *pH and EC combination. Hanna Instruments Combo tester (e.g... HI 98129 / HI 98130)*

The Combo is waterproof hence good for the rugged outdoors. Both record pH from 0 to 14 with 0.01 units resolution. The testers have automatic temperature compensation, and the user can set the TDS factor. This factor converts conductivity readings to an estimate of total dissolved solids.

The calibration is easy and needs only one calibration solution. To calibrate for conductivity just use either the 1413 microS/cm solution for HI 98129 or the 12.88 milliS/cm solution for HI 98130. The tester automatically recognises the solution strength and adjusts. The testers are handheld and lightweight. These testers cost approximately $350.

- *Eutech Testr 35 series*

This tester can measure either three or five combinations and cost from $175. These include pH / Conductivity / Total Dissolved Solids / Salinity / Temperature or any of the combination of pH /

Conductivity / Temperature or pH / Total Dissolved Solids / Temperature. This series testers record pH from 0 to 14 with 0.01 units resolution and can measure low to high Conductivity/TDS ranges. It has up to 5-point pH calibration and 3-point Conductivity/TDS/Salinity calibration.

4.4.3.2 Arsenic

- *Macherey Nagel Quantofix Arsenic LR*

Macherey Nagel arsenic low range test strips.
Range 0 - 0.5 mg/L. Gradation 0, 0.01., 0.025, 0.05, 0.1, 0.5 mg/L.

- *Hach Arsenic test strips*

Hach sells two Arsenic test strips for two ranges, 0 to 0.5 mg/L and 0 to 4 mg/L of Arsenic. The kit consists of reagents for 100 tests, reaction vessel, test strips and comparison chart in a rugged container.

- *VisuPAsS Visual Portable Arsenic System*

The VisuPAsS system from Palintest Ltd uses Gutzeit method where the system operates by converting all Arsenic in the sample to Arsine gas and detecting the gas produced quantitatively using a unique three-stage filter. The filter ensures all Arsine is 'seen' by the detector and also prevents excess Arsine or Hydrogen Sulphide being released during the 20 minute reaction time. Once the reaction is complete the concentration of Arsenic is assessed using a colour chart ranged from 10 to 500 µg/L Arsenic. This system costs about $400.

4.4.3.3 Nitrate

- *Lamotte Insta nitrate / nitrite test strips*

These are designed to test drinking water but they can be used to test a variety of waters for nitrate contamination. Measures 0, 5, 10 25 and 50 ppm as nitrate-N, and 0, 0.5, 1, 5 and 10 ppm as nitrite-N.

- *Hach Aquachek nitrate / nitrite test strips*

Each strip measures nitrate – N: 0, 1, 2, 5, 10, 20 and 50 mg/L and
nitrite – N: 0, 0.15. 0.3, 1, 1.5 and 3 mg/L.

These test strips are suitable for testing nitrate and nitrite in drinking water.

- *Macherey Nagel Quantofix Nitrate / Nitrite*

These strips have a range for:=

nitrate of 0 - 500 mg/L with a gradation of 1 - 10 - 25 - 50 - 100 - 250 – 500 mg/L.
nitrite is 0 - 80 mg/L and with a gradation of 0 -1 - 5 - 10 - 20 - 40 – 80 mg/L.

These strips are suitable for detecting elevated nitrate levels in water.

4.4.3.4 Phosphate

- *Macherey Nagel Quantofix Phosphate strips*

The range of the Macherey Nagel Quantofix Phosphate test strips is 0 - 100mg/L, with a gradation of 0 - 3 - 10 - 25 - 50 – 100 mg/L.

- *Lamotte phosphate test strips*

Lamotte Insta test phosphate test strips are designed for pools and spas but suitable for testing drinking water and environmental testing. These strips can 0, 0.1, 0.2, 0.3, 0.5, 1 and 2.5mg/L. It is expected that most of the groundwater samples would have phosphorus of this range only.

4.4.3.5 Sulphate

- *Macherey Nagel Quantofix Sulphate test strips*

Macherey Nagel Quantofix sulphate test strips have a

range of 200 - 1600mg/L with a
gradation of <200 - >400 - >800 - >1200 - >1600 mg/L.

4.4.3.6 Iron

- *Hach Aquachek total dissolved iron strips*

Hach Aquachek total dissolved iron test strips measure from 0 - 5mg/L with a gradation of 0, 0.15, 0.3, 0.6, 1, 2, 5 mg/L. These strips measure total dissolved ferric and ferrous ions.

- *Macherey Nagel Quantofix Iron*

Macherey Nagel Quantofix iron test strips have a range of 0 – 100mg/L with gradation 0, 2, 5, 10, 25, 50, 100 mg/L. Measure both Fe^{2+} and Fe^{3+}. Also, for these strips, Fe^{2+} can be measured independently by omitting the supplied reducing agent step.

- *Insta-Test iron test strips*

Lamotte Insta iron test strips kit measures copper iron levels in the range 0, 0.3, 0.5, 1, 3, 5mg/L in 15 seconds. The kit includes iron reduction tablets that can be used to reduce all iron to the ferrous form before testing. This gives a measure of total soluble iron.

4.4.3.7 Hardness

Hardness in water is mostly a measure of the amount of calcium and magnesium ions present. The amount of calcium and magnesium in water impacts drinking water quality and irrigation water quality.

- *Macherey Nagel Aquadur strips*

Two types of Macherey Magel Aquadur strips are available. Aquadur Sensitive water hardness test strips measure water hardness in the very low range. These strips measure low range hardness in steps of 0, 5.4, 10.7, 19.6mg/L as $CaCO_3$.

Macherey Nagel Aquadur test strips measure total hardness in the range 0 – 445mg/L as $CaCO_3$. The strips measure from < 53.4, >89, >178, >267, >356, >445mg/L as $CaCO_3$.

- *Hach Aquachek total hardness test strips*

Hach Aquachek Total hardness test strips measure from 0 – 425mg/L hardness as CaCO3, in steps of 0, 25, 50, 120, 250, 425mg/L.

4.4.3.8 Alkalinity

Alkalinity is caused mostly by bicarbonates at under pH 8.3 and by hydroxides if pH is over 8.3. Alkalinity partly determines pH in water and as levels rise becomes increasingly important in maintaining a stable pH. It is an important factor to consider in a wide range of applications such as aquaculture, industrial processes, irrigation and plant protection. As such there is no specific standard for livestock industry in ANZECC guidelines.

- *Hach Total alkalinity test strips*

Hach Total alkalinity test strips measure alkalinity as $CaCO_3$ in mg/L. The range is 0 - 240mg/L with gradations 0, 40, 80, 120, 180, 240mg/L.

- *Quantofix carbonate hardness / alkalinity strips*

Quantofix carbonate hardness / alkalinity strips measure hardness in the range 0, 53.4, 106.8, 178, 267 and 356mg/L as $CaCO_3$.

4.4.4 On-site water quality multi-parameter portable Laboratories

- *HACH DR 2800™ Portable Spectrophotometer*

Figure 25 : HACH DR 2800™ Portable Spectrophotometer

The Hach DR 2800 Portable Spectrophotometer can be used for more than 240 analytical methods. These methods include more than 30 TNTplus™ reagent vial tests that provide innovative barcode labeling for reliable, automatic method detection. All of the chemistries and supplies needed for these tests are available from Hach. The spectrophotometer can store up to 50 user programs and 500 data points, including sample and operator ID.

Depending on the number of parameters to be tested for, the cost of the DR 2800 Portable Spectrophotometer and components would be between $5,000 and $10,000 plus reagents that would cost approx $0.50 per test.

- *The Palintest Photometer 7500*

Figure 26: The Palintest Photometer 7500

The Palintest Photometer 7500 has automatic wavelength selection for each of its pre-programmed methods. Method selection is either from a simple on-screen menu or by direct entry. There are up to 15 user definable test methods allowing full flexibility in a range of applications. The Photometer 7500 is available in two kits, each complete with a carry case with space to store reagents

Some of the features of this equipment include fully waterproof with IP67 rating, rugged, portable design with no moving parts, Automatic method set up for each parameter, USB port for easy computer interface, 500 test results stored on board. The unique adaptive cell holder automatically adjusts to any round tube size - allowing easy analysis of a range of samples without needing adapters. Palintest photometer 7500 costs $1799.00 plus delivery and GST.

4.4.5 Contact address for on-farm test kits

- **Apps Laboratories**

  115 Collie Rd Gembrook
  VIC 3783
  Australia
  Tel: 03 5968 1401
  Contact: Dr Tim Apps
  Web: www.appslabs.com.au
- **Watertest Systems Pty Ltd**
  Unit 4, 13 Swaffham Road
  Minto, NSW 2566
  Australia
  Tel: 02 87065400
  Contact: Steven Easton
  http://www.chemetrics.com.au/

- **Palintest Australia & Asia Pacific**
  1/53 Lorraine Street,
  Peakhurst Business Centre,
  Peakhurst NSW 2210, Australia
  Tel: 1300 131516 Fax: 1300 131986
  Email: palintest@palintest.com.au
  Website: www.palintest.com.au
  Contact: Warren Thomas BSc, Dip Mtg

4.4.6 Tests to be done at external laboratories

The previous chapter on groundwater quality and the maps of various parameters provide an indication of potential requirement of additional testing required on a specific property. If a particular property falls into a location with a potential water quality problem due to any particular parameter, the first step would be to collect any data available from the respective state water quality database or other resources. The sources of groundwater data have been provided in the Chapter 3 (Methodology) of this report.

Table 18 provides list of parameters that need to be tested at external laboratories. If the concentration of a particular contaminant or impurity is below the guidelines limit as provided in the previous section, testing for such parameters may not be necessary. However, one off tests may confirm if any of the above chemicals exceed in the local bore water due to either historic anthropogenic activities or local natural occurrence.

Table 18: Water quality parameters for off-site testing

Water quality parameters for testing at external laboratories	
Aluminium	Lead
Beryllium	Magnesium
Boron	Mercury
Cadmium	Molybdenum
Calcium	Nickel
Chromium	Selenium
Cobalt	Uranium
Copper	Vanadium
Fluoride	Zinc

4.4.7 Standard procedure for sample collection, storage and delivery

4.4.7.1 Sample Collection

Standing water within a bore is exposed to atmospheric conditions and can undergo changes to its physical and chemical characteristics and is not representative of the water in the aquifer. For this reason, boreholes should be purged (Yeskis and Zavala 2002) before sampling by pumping ‘to waste’ a volume of water equivalent to at least 4 to 6 times the internal volume of the borehole. It is recommended that parameters such as pH, electrical conductivity, sulphide, nitrite, dissolved oxygen and other parameters that may be affected while collection, storage and transportation during collection may be carried out in the field or determined as soon as possible after the sample has been collected.

On-site filtration is a necessary step in the process of groundwater quality sampling if determination is required of the ‘dissolved’ fraction such as metals (Murray- Darling Basin Commission, 1997). Reasons for filtering include:

- Removal of particulate matter.
- The adsorption-desorption equilibrium between water, sediments and particles occurs within 72 hours.
- Bacterial growth can cause the redistribution of metal ions between solution and particulate phases.

The common standard pore size of filter used in groundwater quality sampling is 0.45μm. Filtration should be performed on-site as soon as possible after collection.

4.4.7.2 Integrity of samples

It is very important for the reliability and interpretability of the collected data, a proper documentation system and chain of custody information is in place. This includes recording of sample movement from collection to data reporting and ensuring that analytical data is ascribed to the correct location. Appropriate chain of custody information for collected samples commences with the completion of a sampling report. Sampling reports should contain the following information to a minimum:

- Location of the bore, with coordinates and any other relevant information to identify the bore later;
- Details of bore, e.g. depth, casing condition if available;
- Standing water levels if available
- Volume of water purged from bore or duration and rate of pumping prior to sampling;
- Time of sampling;
- Name of sampler;
- Preservation procedure;

- Water quality parameters collected in the field;
- Any information which may affect the results of analysis, e.g. high rainfall prior to sampling, generation of bubbles, smell, colour, sediment etc.

Once collected, samples should be stored, handled, and transported in such a manner as to:

- prevent damage to containers or labels;
- if samples are to be frozen, do not fill the container full;
- minimise or eliminate degradation of the sample;
- Prevent contamination of the sample.

Upon delivery to the analytical laboratory information relating to the time between sample receipt and analysis, storage and preservation methodology employed at the laboratory, and analytical technique used should be collected and documented for future reference.

4.4.7.3 Pump sampling

This section refers to collection of samples from monitoring bores for groundwater monitoring. However, some aspects of this session could be used for collection of samples from regular water supply bores for livestock feeding.

Samples should be collected only after the pump has been running for sufficient time to remove all of the standing water in the borehole. This will ensure that stable chemistry is reached. Also, handheld pH meter, dissolved oxygen meter or strips could be used to check the chemistry is nearly hugely varying. It can be assumed that stable chemistry is achieved when there is no significant variation in the physical parameters. That is changes of less than ± 10% for pH, conductivity or dissolved oxygen or less than ± 0.2°C.
Once stable water chemistry (as inferred from stability in physical parameters measured) is reached, the sample can be collected and transferred to an appropriate container.

4.4.7.4 Equipment

Equipment to be used to collect samples must be appropriately cleaned and decontaminated. Water quality field test kits such as pH meter should be calibrated according to the manufacturer's instructions and a sufficient number of sample bottles be prepared.

The types of container to be used for sampling and sample storage are dictated by the chemical parameters to be tested in external laboratories, such as plastic or borosilicate glass. If possible, rinse the container in water to be tested.

An example of the equipment necessary for the collection of ground water samples is provided below (MCA, 1997):

- Field sheets, sample labels, and chain of custody forms.
- Pump or bailer appropriate for the dimensions (diameter and depth) of the borehole(s) to be sampled if required
- Container for collecting sample.
- Powder-less nitrile gloves.
- Sample bottles.
- Filtration equipment.
- Field parameter meters and test kits (e.g.. pH, conductivity, chloride test kit).
- Esky or portable refrigerator.
- If required, appropriate preservative – e.g. Nitric acid.
- Personal Protective Equipment, first aid and communication equipment where required.

4.4.7.5 Collection for external laboratories

It is possible that physical and chemical changes to ground water can occur following removal from the aquifer through exposure to the atmosphere, changes in temperature, and changes in pressure and handling (e.g. Vigourous shaking). It is important to minimise the handling of samples following collection. The samples are delivered to the laboratory in tightly sealed containers that have not been exposed to excessive heat or light.

If properly trained staff and equipment are not available at the livestock production facilities, it is not recommended to carry out field filtration.

4.4.7.6 Preservation, transport & storage

Australian and New Zealand Standard 5667.1:1998 provides a comprehensive table of parameters/contaminants of interest and the appropriate sample container, preservation technique, and holding time as provided Table 19.
The key aspects of effective transport and storage are to:

- ensure samples are appropriately packed to avoid breakage and cross-contamination
- reduce sample degradation through appropriate preservation
- ensure time between sampling and analysing does not exceed holding time.

Sample containers should be sealed, carefully packed with an appropriate packing material, chilled or frozen (as required) and transported in an appropriate cooler (esky) or fridge. It is sometimes necessary to take further action to prevent cross contamination, either between samples or from ice, during transport. This could include placing sample containers in snap-lock bags or airtight, plastic tubes with screw caps before transport.

Table 19 Extracts from Australian and New Zealand Standard 5667.1:1998 for preservation procedure for water samples for chemical analysis

Determinant	**Type of container**	**Preservation procedure**
Metals	Acid washed plastic or glass	Acidify with nitric acid to pH 1 - 2 and refrigerate. Filtration of the sample must be performed prior to acidification. If it is not possible to filter and acidify at site, handover the samples to the laboratory as soon as possible.
Major cations, e.g. Calcium	Plastic	Acidification is not required, though the addition of nitric acid sufficient to lower pH to 1 - 2 will enable determination of concentration with metals analysis.
Chloride	Plastic or Glass	None required.
Nitrate	Plastic or Glass	Filter on site if possible and freeze.
Nitrite	Plastic or Glass	Freeze
Phosphorus	Plastic or Glass	For dissolved concentration determination filter on site and freeze. For total concentration determination, freeze.
Sulfate	Plastic or Glass	Refrigerate

If a courier is to be employed, sample security, Chain of Custody and refrigeration issues need to be considered prior to transporting the samples. If a courier is not able to meet all the requirements an alternative form of transport should be found (Murray-Darling Basin Commission 1997, Sundaram et al 2009).

4.4.7.7 Quality Assurance / Quality Control procedures

Quality assurance (QA) and quality control (QC) procedures must form an integral part of the testing activities to ensure the representativeness and integrity of water samples and that the resulting data used in review and reporting is accurate and reliable. Use of a laboratory certified by the National Association of Testing Authorities (NATA) provides assurance that suitable QA/QC procedures including equipment, reagents and analytical methods are employed in the analysis of collected samples.

4.4.7.8 Selection of appropriate sampling and preservation methodology:

Sample collection methodology should be easily reproducible and designed to minimise potential contamination of samples occurring. Appropriate preservation of the collected sample depending on the analyte of interest should be undertaken to ensure representative results.

4.4.7.9 Duplication of samples:

Separate samples collected from the same site at the same time are used to determine the extent of impact (if any) of heterogeneity of the water being sampled and can be used to give a measure of the sampling precision.

4.4.7.10 Collection of field and sample blanks:

Water of a known low analyte concentration is used as a ‘blank’ sample to detect whether sample contamination is occurring during the sampling process. Field blanks are samples of water of a known low analyte concentration that are exposed to field conditions during the sampling activity.

4.4.8 The Potential Sources of Error in groundwater testing program

The potential sources of error noted are presented in the Figure **27** .

Step	Sources of Error
Sampling site condition ↓	Improper well construction/placement; inappropriate materials selection
Establishing a Sampling Point ↓	
Field Measurements ↓	Instrument malfunction; operator error
Sample Collection ↓	Sampling mechanism bias; operator error sample exposure, degassing, oxygenation; field

	conditions
Sample Delivery/Transfer ↓	Operator error; matrix interferences Instrument malfunction; field conditions
Field Blanks, Standards ↓	Matrix interferences; handling/labelling errors
Field Determinations ↓	Delay; sample loss
Preservation/Storage ↓	
Transportation	

Figure 27 Steps in ground-water sampling and sources of error

These potential sources of error conclude essential elements of sampling quality control (Barcelona et al 1985). These are:

- Proper calibration of all sampling and field measurement equipment
- Assurance of representative sampling, particularly with respect to site selection, sampling frequency, well purging and sample collection
- Use of proper sample handling precautions.

4.5 Opportunities to treat or prevent water quality problems

4.5.1 Relevant water treatment technologies

This section discusses some of the appropriate technologies and methods suitable for groundwater treatment for northern beef producers. A number of these technologies, individually or in combination can decrease considerably or completely eliminate the water quality issues. Some technologies or combination of technologies provide a much better solution, but for treating water for livestock consumption, the capital and operating costs are an important issue (Olkowski, 2009). . These technologies are commonly used in Australia for industrial sector and may be considered for northern beef industry. While for some technologies, size or scale may play a significant role in the cost, there are now small scale packaged plants such as air strippers, RO plants, sand filters that would be suitable for northern beef industry applications.

4.5.2 Activated Carbon Filters

Activated carbon (AC) filters are generally used in water treatment for removing free chlorine, some organic compounds associated with coloration, odour and taste of water, mercury, some pesticides and volatile organic compounds. AC filtration does not remove microbes, sodium, nitrates, fluoride, and hardness. Lead and other heavy metals are removed only by a very specific type of AC. The filters must be inspected and replaced frequently. Poor filter maintenance will decrease effectiveness, and may result in bacterial growth on the filter, causing potential contamination of the water with pathogens.

4.5.3 Air Stripping

Air stripping is the process of forcing air bubbles through polluted water to remove harmful or unwanted chemicals. The air moving through the water causes the chemicals to change to a gaseous state. This gas is then bubbled out of the water with the air. This air and other gas mixture is then collected and cleaned if required. This method may be effective in removing hydrogen sulphide, some odours and tastes, and some volatile organic chemicals.

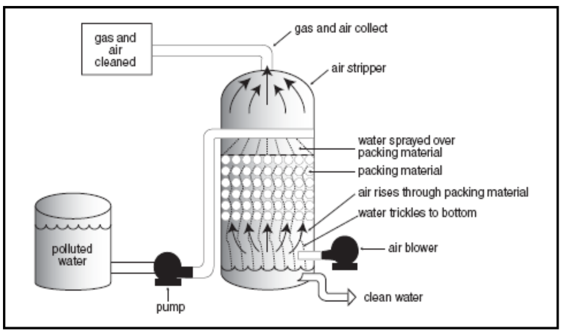


Figure 28 A sketch of a packed tower air stripping system

While simple in principle, packed tower systems, like other air stripping systems, are prone to clogging because of particulate build up, rust-producing bacteria, and the precipitation of calcium carbonate.

4.5.4 Biological Filters

This method is effective at removing iron, arsenic (Pokhrel and Viraraghavan, 2009; Katsoyiannis and Zouboulis, 2004), and organics. Manganese can be removed with a pre-treatment of a strong oxidant (Olkowski, 2009). A microbiological layer is used to filter and consume contaminants. Biological filters usually require infrequent backwashing, however, some are sensitive to variable flow rates and perform better with a constant flow rate. With sufficient aeration, biological filters can convert ammonium N to nitrate N. Also, there are biological filters designed for nitrate removal, with addition of an external carbon source.

4.5.5 Chlorination

This is one of the most common methods in water treatment for pathogen reduction in drinking water for livestock. Chlorination is much more effective if it follows a filtration system to remove large particles that can house bacteria. In particular, this is an effective and widely used method to kill many kinds of microorganisms in water. It also aids in removal of unwanted color, odour, or taste from water and will also remove hydrogen sulphide and dissolved iron and manganese, if followed by mechanical filtration. However, if the system is not properly operated, it can be potentially hazardous. In typical systems the chlorine content of the treated water should be closely monitored so it is not harmful to animals. High concentrations of chlorine released to the dairy water system may affect water intake and performance of cows. Chlorination of water containing high levels of organic contaminants may result in the formation of potentially toxic compounds.

4.5.6 Coagulation and flocculation

Coagulation/flocculation is a process used to remove colloids, suspended solids, color, and some bacteria from water. These particles have a negative charge, so the positively charged coagulant chemicals neutralize them during coagulation. In the flash mix chamber, chemicals are added to the water and mixed violently for less than a minute. These coagulants consist of primary coagulants and/or coagulant aids. Then, in the flocculation basin, the water is gently stirred for 30 to 45 minutes to give the chemicals time to act and to promote floc formation. During flocculation, the particles are drawn together by van der Waal's forces, forming floc. The floc then settles out in the sedimentation basin. The coagulation/flocculation process is affected by pH, salts, alkalinity, turbidity, temperature, mixing, and coagulant chemicals.

4.5.7 Electro-dialysis reversal (EDR)

EDR (Electrodialysis Reversal) is an electrolytic process that removes ionic species from a brackish water or wastewater source. Ionic species or dissolved solids in water migrate through ion exchange membranes under the influence of electrical current, to produce water that meets drinking water standards. The EDR process involves reversal of the water flow in order to break up and flush out scales, slimes and other foulants deposited in the cells before they can build up and create major fouling problems. This flushing also allows the ED unit to operate with fewer pretreatment chemicals, hence minimising costs. EDR can produce a high recovery ration (85 to 94%), can have a life expectancy of 7 to 10 years. One of the disadvantages is that the process is not efficient for removal of bacteria, non-ionic substances and residual turbidity. This process can be a real alternative for RO process.

4.5.8 Ion (Cation or Anion) Exchange

This treatment system is based on removal of ions by replacing one or more chemical ions with another. The most commonly used systems contain resin beads to trap ions. Cation exchange is based on the principle that positively charged sodium (Na^{+}) ions attached to the resin are replaced (exchanged) with other positively charged ions such as Ca^{2+}, Mg^{2+} and Mn^{2+}. Heavy metals will also be removed if they are present in an ionized state. Anion exchange systems remove negatively charged ions such as Cl, I, F, as well sulphates and nitrites/nitrates.

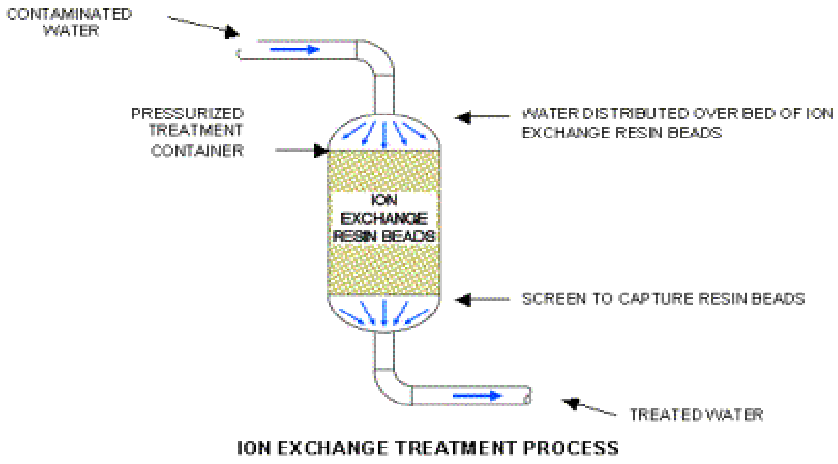


Figure 29 A sketch of ion exchange reactor

The most common application for cation exchange is in the water softening process where metals, that are the main contributors to water hardness (Ca^{2+}, Mg^{2+}), are removed from water during treatment. Cation exchange resins also remove barium, cadmium, copper, iron, manganese, radium, zinc, and other metallic, positively-charged ions.

After a long period of operation, very few sodium ions remain on the resin, which means, no more calcium or magnesium ions can be removed from the groundwater. The resin at this point is said to be “exhausted” or “spent” and cannot accomplish further water treatment until it is “recharged” or “regenerated.” This can be done by backwashing with a sodium carbonate solution.

One of the negatives of cation exchangers is that the treated water will have elevated sodium ion concentrations. This may be a consideration in overall sodium status of animals.

4.5.9 Mechanical or media filters

This method is used to remove insoluble contaminants including some forms of oxidized iron and manganese, as well as sand and silt. Mechanical filters such as multi-media filters only remove particles greater than 10 microns therefore are ineffective on fine particles and micro-biological particles. Mechanical filters consisting of marble chips or a slowly dissolved liming agent can neutralize acidic water when it is forced through the filter.

4.5.10 Nanofiltration

Nanofiltration processes are capable of removing hardness, heavy metals, particulate matters and a number of other organic and inorganic substances in one single treatment step. This technology uses membranes similar to reverse osmosis membranes, but because the pore size in the NF membrane is much larger (0.5 -5 nm), it takes less pressure (10 to 50 bar) (Thorsen and Fløgstad, 2006) to force the water through the membrane.

Nanofiltration takes out about 90% of the dissolved solids and 95% of the hardness, therefore it is often referred to as the softening membrane. Water wasted is usually between 15% and 30% and is not as much of a concern as RO membranes. The added benefit is that the water is not nearly as corrosive as from RO membranes therefore chemicals rarely need to be added following treatment (Olkowsky, 2009). Pre-treatment devices are usually needed.

A serious problem in NF systems and a limiting factor for its proper operation is membrane scaling. In brackish and hard waters, $CaCO_3$ and gypsum are the most common scalants for which pre-treatment should be considered (Thorsen and Fløgstad, 2006).

4.5.11 Oxidation followed by filtration

This method is applied to remove some contaminants by chemical oxidation reactions followed by filtration. This method is usually employed for removing, iron, and manganese as well as hydrogen sulphide. The common oxidants used are aeration, chlorine, potassium permanganate and ozone (Olkowsky, 2009). Strength and type of oxidant varies based on the targeted dissolved ion to be removed.

4.5.12 pH adjustment

When the groundwater pH is not in the optimal range, it can be easily adjusted with addition of an acid or an alkaline substance to the water supply. The appropriate acid or alkaline may be injected into the pipeline for automated systems or mixed in a tank for manual systems or larger volumes of water. The use of an acid (such as sulfuric acid or hydrochloric acid) will lower the pH, while an alkaline (for example, lime) will increase the pH.

4.5.13 Reverse osmosis (RO)

This technology is more and more applied in the treatment of water for livestock. Basically, water impurities are filtered out through a system of membranes which have small pores that allow passage of water but not the contaminants.

When saline bore or groundwater is placed under an external pressure which is greater than the osmotic pressure, the water will move in the opposite direction, from the solution of greater concentration to the dilute source. As the salts cannot pass through the semi-permeable membrane they are left behind. This results in potable water on one side of the osmotic membrane, and very salty water (brine) on the other side, where the pressure was applied.

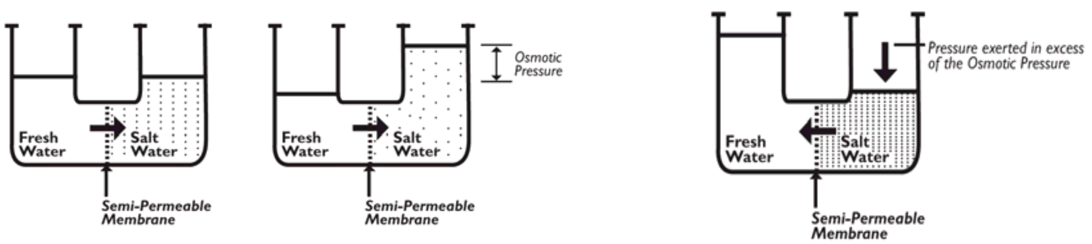


Figure 30 A sketch of the operation of reverse osmosis system (Parr & Rogers, 2007).

Depending on the system, over 99% of contaminants can be removed by reverse osmosis, and the product of this process is highly purified water. Reverse osmosis may be expensive, such as \$1 to \$2 per m^3 of production water. It may also require periodical membrane replacement, and needs consistent maintenance. Depending on the size of the system, the pressure, and the water quality, reverse osmosis systems waste between 50% and 90% of the water. The filtrate containing high concentration of contaminants must be disposed of in some manner, which may be an issue for sensitive inland areas.

4.5.14 Slow Sand Filters

This method is a type of biological filter that is simple and relatively inexpensive. It will remove fine particles and iron. It will also remove arsenic if iron is present and manganese with some pre-treatment. As with most biological filters, it is sensitive to variable flow rates. The filters require periodic backwashing. It is an essential component of traditional town water supply systems.

4.5.15 Ultraviolet radiation

Ultraviolet radiation system uses a special light source that generates ultraviolet radiation. It is a very effective method for disinfection, including against micro-organisms in water, including pathogens. However, but it may not work if the water is turbid or cloudy. It may be difficult to assess the efficiency of UV or if it is working at all unless it is equipped with an intensity monitor. Water should be monitored for bacteria.

4.5.16 Approximate Costs of Water Treatment

A recent study in Canada (Olkowski, 2009) summarized the treatment costs for water treatment for a 100 and 500 cattle herd. These costs, presented in Table 20, would vary based on a number of parameters, including but not limited to the concentration of the contaminants, economic conditions and the level of controls and monitoring. These costs are indicative only for northern Australian conditions, and vary significantly with respect to the pre-treatment requirements and the environmental regulations with respect to disposal of rejects and waste streams.

Table 20: Approximate Annual Treatment Costs (Canadian dollars) (2008) for a 100 and 500 Cattle Operation (Olkowski, 2009)

Treatment System	**Contaminant Removed**	**Cost/animal/y (100 cattle)**	**Cost/animal/y (500 cattle)**
Air Stripping	Hydrogen Sulphide, Methane, ammonia	$2	$0.5
Chlorination	Bacteria, Oxidize metals	$2	$1.5
Multi-Media Filter	Large particles, Oxidize metals	$2	$1.5
Ultraviolet Radiation	Bacteria	$4	$2
Ion Exchange (softening)	Hardness, Iron, Nitrate and Nitrite*, Sulphate*	$6	$5
Slow Sand Filters	Iron, Arsenic	$7	$4
Oxidisation & filtration	Iron, Arsenic, Manganese*	$10	$4
Activated Carbon Filters	Taste, Odour, Chlorine	$10	$6
Ozonation	Bacteria, Oxidize metals	$12	$6
Biological Filters	Iron, Arsenic, Organics, Nitrate and Nitrite*, Sulphate*	$19	$10
Coagulation	Particles, Iron, Arsenic, Manganese	$20	$20
Nanofilters	TDS, Hardness, Arsenic, chloride Sulphates, Fluoride Manganese, Iron*, Lead, Magnesium, Molybdenum, Nitrate and Nitrite, Seleneium, Sulphate	$45	$20
Reverse Osmosis (RO)	TDS, Sulphates, Hardness, Fluoride, Chloride, Arsenic, Magnesium, Manganese, Iron*, Lead, Molybdenum, Nitrate and Nitrite, Seleneium, Sulphate	$50	$20

* Removal will require additional equipment and cost

Typically the cost of RO for brackish groundwater cost is between A$1 and $2 and for EDR, between $1 and $3 per m^3 of produced water. However, the capital costs vary significantly with respect to the capacity.

5. Success in achieving objectives

The project has met with success in achieving nearly all the objectives. Details are provided under each objective.

1. Complete a literature review on all aspects of water quality and its impact on the water intake, health, productivity and grazing behaviour of ruminants.

Incorporating both published peer reviewed papers, conference papers, and government and industry publications as well as discussions with industry experts, this objective was completed successfully.

2. Identify water tests suitable for use on-property and laboratory options for north Australian beef producers.

Water tests suitable for on-property and the test kits and their accuracy, cost of the test kits and complexity involved have been provided in the report. In addition, the tests required to be carried out external laboratories; sample collection, storage and transportation procedure, common mistakes in sample handling have been provided.

3. Provide case studies and examples of the losses in productivity that have been recorded in beef cattle.

There is only limited published literature in this area. While we have collected and provided the available information, we contacted producers, industry experts for reliable unpublished reports and data. This is an area which needs further investigations and documenting at a primary level.

4. Produce maps showing different aspects of underground water quality for Australia, and highlight those regions where water quality is likely to impact on water intake, health and productivity.

We have produced maps of various water quality parameters of concern for rumen health in northern Western Australia, NT and northern Queensland for northern beef industry. The data for these maps have been obtained from the government authority in charge. Not all parameters have been analysed in all the states, and some parameters are extensive and some are limited.

5. Make recommendations where possible on measures to treat or prevent water quality problems.

A detailed section is provided in the report that deals with treatment options for improving water quality for problem contaminants. A number of technologies that can be applied for northern beef producers and approximate cost per cattle herd is provided. This section will provide directions to producers and policy makers on the choices of technologies and options to treat water quality problems.

6. Impact on meat and livestock industry – Now and in five years time

Availability of good quality water is the basic requirement for livestock industry. With the impact of climate change, El-Nino and unprecedented extreme weather events, both the quantity and quality of water for livestock pose a major threat to the livestock industry.

Groundwater is considered to be an alternative source for water for livestock industry in northern Australia. This report addresses groundwater quality in northern Australia, and discusses Australian and international standards of various components in the groundwater and its effect on rumen livestock.

This report is a quick reference book which includes a literature review on all aspects of water quality and its impact on the water intake, health, productivity and grazing behaviour of ruminants; a list of water tests suitable for use on-property and laboratory options for north Australian beef producers; case studies and examples of the losses in productivity that have been recorded in beef cattle; maps showing different aspects of underground water quality for northern Australia and recommendations where possible on measures to treat or prevent water quality problems.

The report also indicates the gap of knowledge and data, particularly in regard to case studies on animal fatalities due to poor water quality and the associated economic loss. Not many scientific reports are available that point on the exposure duration and its impact on animal death. It is expected that the meat and livestock industry would focus on further investigations in this area.

It can be assumed that this report provides a quick reference for the meat and livestock industry on the above issues. The contents, particularly the treatment technologies and approximate costs would relevant for the next five years.

7. Conclusions and recommendations

This report has reviewed Australian and overseas water quality guidelines for livestock, and plotted the available data of groundwater quality on selected parameters for northern Australia as geo-referenced
maps.

The groundwater quality data sets used for this study were provided by the Department of Water, Government of Western Australia; the Department of Natural Resources, Territory Government; and Department of Environment and Resource Management, Queensland Government.

About 8% of the total data showed a pH value of over 8.5 for northern WA, 6.7% of samples for NT and 4.1% of northern QLD were of pH < 5.5. Alkaline water with pH greater than 8.5 may result in higher risk of metabolic alkalosis and may cause digestive upsets, reduced water and/or feed intake and can cause reduced milk yield and milk fat, low daily gains, increased susceptibility to infectious, metabolic disorders, and reduced fertility. However, this research concluded that the accepted ranges for drinking water pH (a low of 5.5-6.5 and a high of 7.5-9.0) were excessively conservative for rumens health point, though not sufficient experimental or clinical data is available to offer a specific alternative.

The desirable maximum value of total dissolved solids (TDS) in the drinking water for healthy growth of dairy cattle is 2500 mg/L and beef cattle is 4000 mg/L, and the maximum concentration that may be safe for a short duration for cattle is 10,000 mg/L. Analysis of the available groundwater data concluded that 6.8% of QLD and 1% of NT data were above a TDS value of 10,000 mg/L; 16% of WA, 6.2% of NT and 14.2% of QLD data showed TDS values over 4,000 mg/L. The high TDS water was found in the top north part of WA and below the mid southern part of NT and south east part of QLD. High TDS water may be unpalatable to animals, and may decrease feed intake.

The critical concentration of sulphates allowed in drinking water for cattle may depend on the sulphur in the feed. The acceptable and safe limit of sulphate in the drinking water for animals on normal feed is below 1,000 mg/L and above 1,800 mg/L of sulphate may cause the possibility of death of cattle. The mean SO_4 of the groundwater samples collected from northern WA, QLD and NT is below 500 mg/L, however, 6.3% of WA (near Wyndham and Ord River reserve areas), 7.2% of NT (in the central and the south regions) and 12.7% of QLD (the central areas and east coast) samples showed SO_4 concentration above 1,000 mg/L and about 5% of the samples only showed SO_4 above 1,800 mg/L. Excessive intake of sulphur may cause direct toxicity, but mostly the detrimental effects are associated with metabolic interference.

The average value of Al in WA and QLD is <1 mg/L and 0.04 mg/L respectively, and the 3.3% of WA samples (Ord River region) and 0.04% of QLD samples (middle of the east coast) were excess of the ANZECC guideline value of 5 mg/L of Al. No data on Al was available for NT. Ruminants may tolerate much higher levels of aluminium as long as there is sufficient phosphorus in the diet to compensate for the effects of aluminium.

Boron concentrations in excess of 150 mg/L in drinking water for cattle would result in loss of weight and reduced hay consumption. The average concentration of B in the groundwater of WA and QLD was found to be below 0.5mg/L and only less than 0.5% of samples in these states showed B concentration in excess of 5 mg/L in the groundwater.

Fluorine is a cumulative toxin, and therefore animals that live longer (e.g. dairy or beef cows) are more likely to develop chronic fluorosis. Signs of acute F toxicity include restlessness, sweating, anorexia, salivation, dyspnea, nausea, gastroenteritis, muscle weakness, clonic convulsions followed by depression, pulmonary congestion and respiratory and cardiac failure. The F concentration in the groundwater samples of WA was found to be below the limit of 2 mg/L, but 12.7% of NT and 4% of QLD samples were above this limit. The high F areas were in the eastern side of NT and the throughout the western side and the east coast of QLD.

The upper safe limit of Ca is 1,000 mg/L as per ANZECC guidelines, and 0.4% of WA and 0.16% of NT and 2.3% of QLD groundwater samples exceeded this limit. The higher values of Ca were mostly located at bores in the middle centre and mid - south part of NT, and at the middle of eastern coastal boundary of QLD. Ca levels above 1,000 mg/L may cause phosphorus deficiency by interfering with P absorption in the gastrointestinal tract and prolonged consumption of water of this level of Ca may cause osteoporosis, vertebral ankylosis and degenerative osteoarthritis.

Other contaminants of concern in the groundwater such as arsenic, cadmium, chromium, cobalt, copper, lead, nickel, selenium and zinc were found to be within the limit in the study area. No data was available for beryllium, mercury, nitrite, uranium and vanadium in the groundwater database of WA, NT and QLD.

It may be noted that the groundwater quality data were obtained from different agencies, - samples were collected and analysed by different laboratories and at different periods of time. The maps prepared in this study present an indication of the groundwater quality only. The producers are advised to carry out further investigation of groundwater quality of their site if groundwater is to be used as the source of drinking water for cattle.

If a particular property falls into a location with a potential water quality problem due to any particular parameter based on the maps developed by this study, the first step would be to collect any data available from the respective state water quality database or other resources before proceeding for further tests- both on-site or at external laboratories.

The recommended on-site tests for groundwater quality are pH, alkalinity, turbidity, electrical conductivity, nitrite, nitrate, arsenic, iron and sulphate. These parameters include both the listed ones in the guidelines as critical to animal health and the ones that might affect the palatability, colour and odour of the water.

There are a number of screening tests which are simple to operate, no requirement to handle chemicals or doing complex analyses, cost effective, convenient and easy to use alternative to chemical test kits and instrument tests. Most require only a single step but some e.g. arsenic require use of reagents. Test strips with reagents are designed for ease of use can be used in the field.

A number of water quality field testing kits are available for accurate level analysis of groundwater. Some of the test kits can analyse a number of parameters and with a relatively high level of accuracy. For example, The Hach DR 2800 Portable Spectrophotometer can be used for more than 240 analytical methods. In a typical case, producers do not require such extensive tests and at such levels of accuracy. These types of test kits cost well in excess of $5,000 and required only if regular testing is to be carried out.

A number of technologies, individually or in combination can decrease considerably or completely eliminate the water quality issues subject to the capital and operating costs and complexity of operations. While for some technologies, size or scale may be significant for costing, there are small scale packaged plants such as air strippers, RO plants, media filters that would be suitable for northern beef industry applications.

It is recommended MLA develop an interactive CD or internet link for producers, which would provide map of northern Australia, with time series data of groundwater quality embedded at the sampling locations.

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9. Appendix

PLOTS

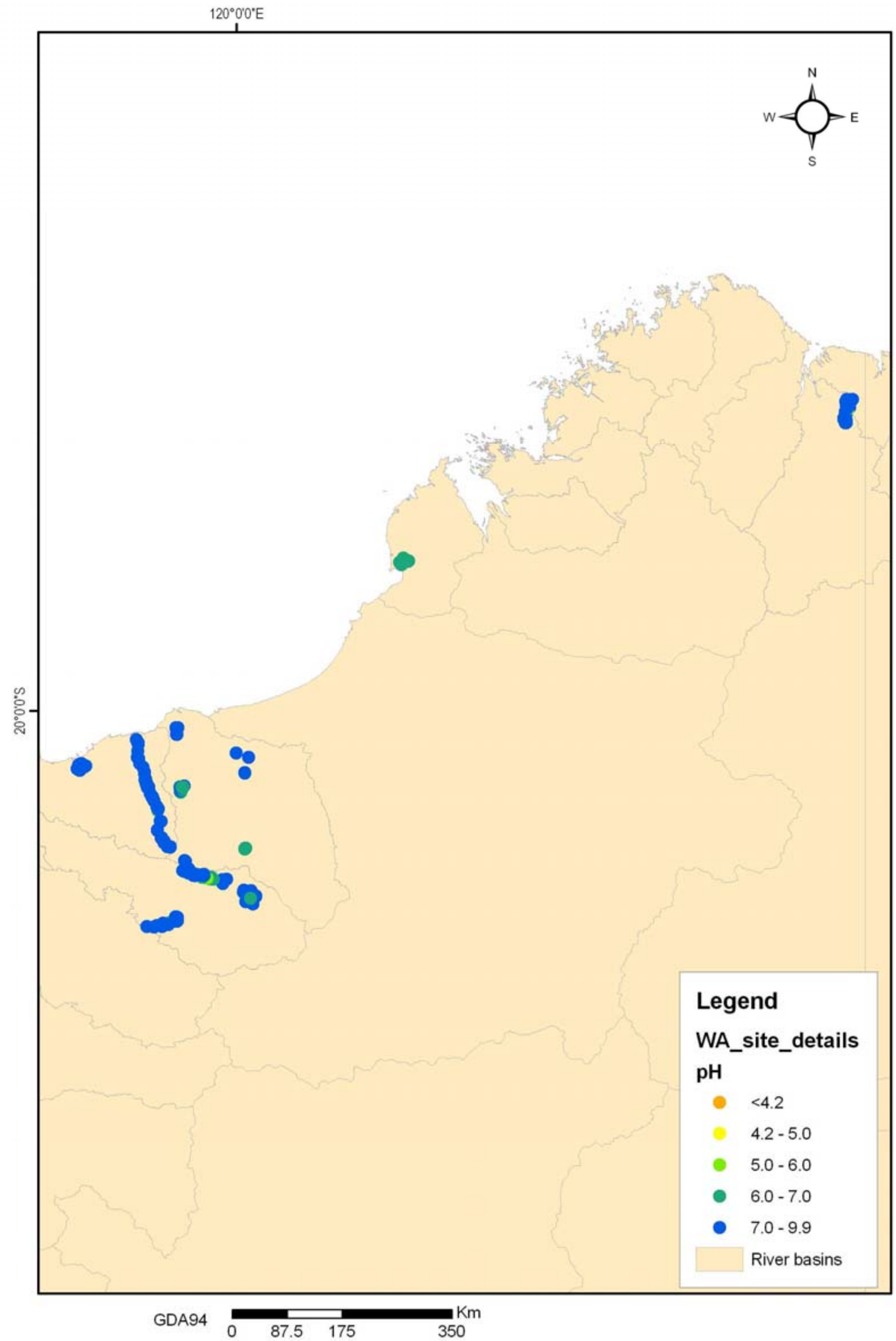

Figure 4: 1 pH WA

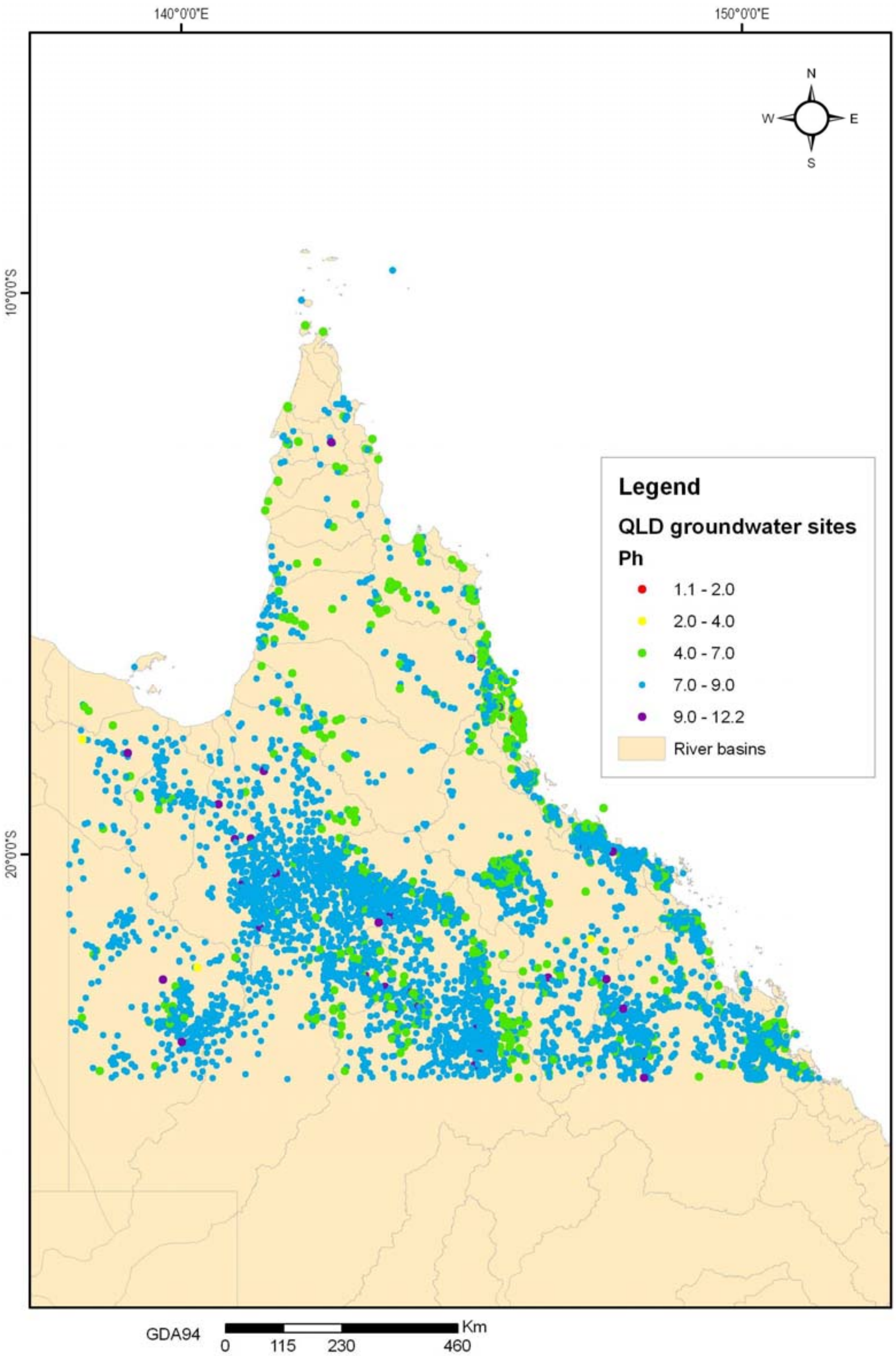

Figure 4: 2 pH Queensland

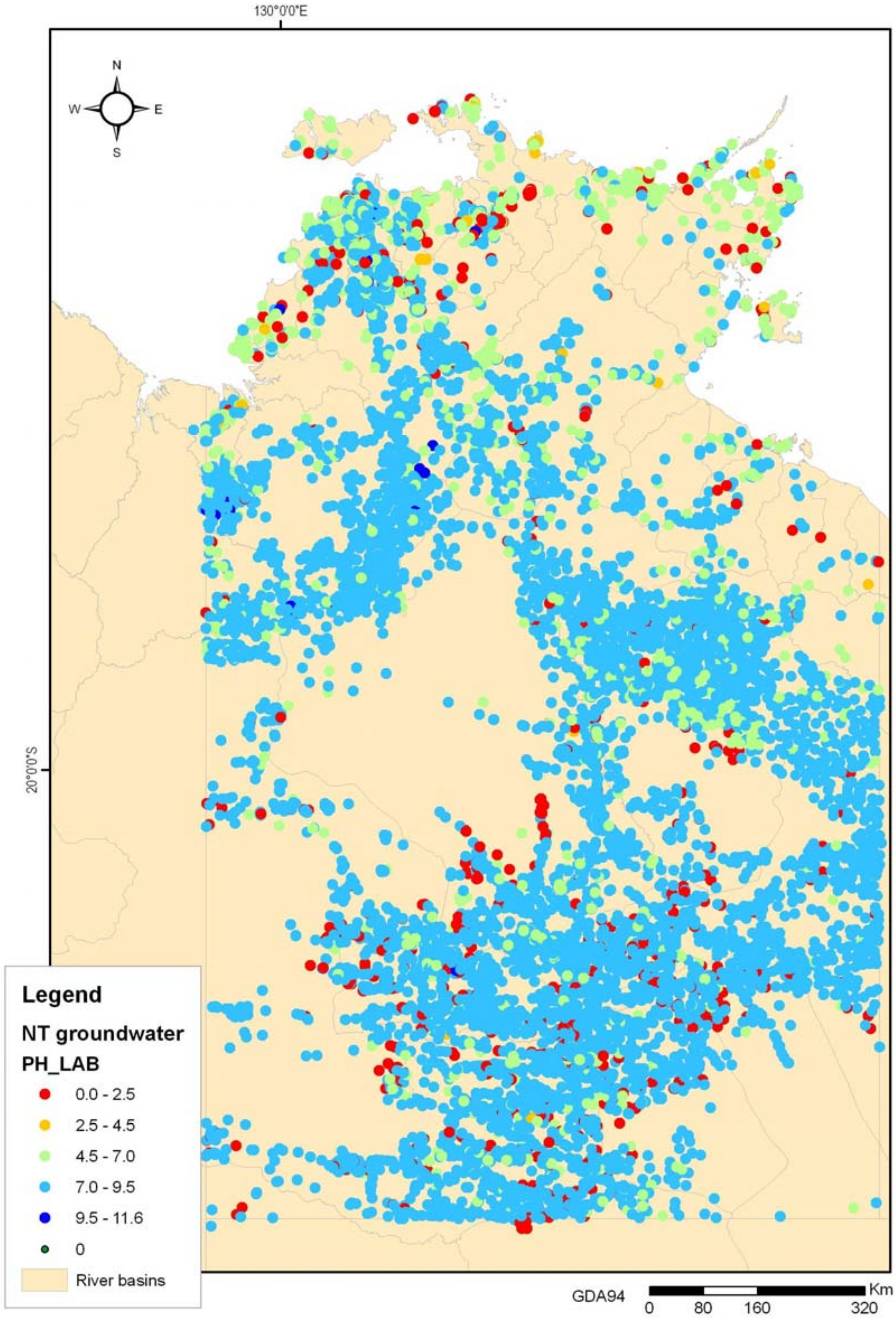

Figure 4: 3 pH NT

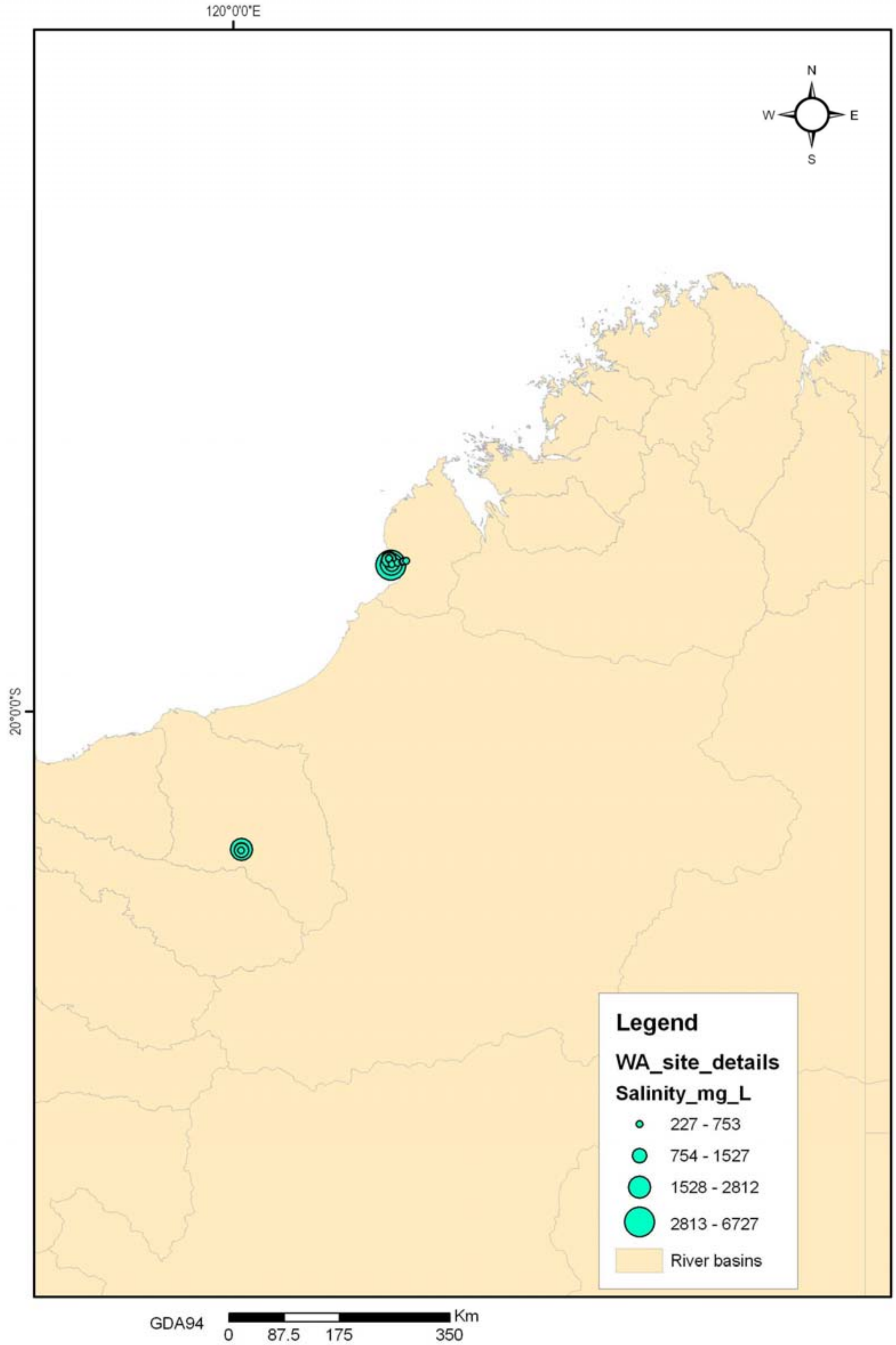

Figure 4: 4 Salinity WA

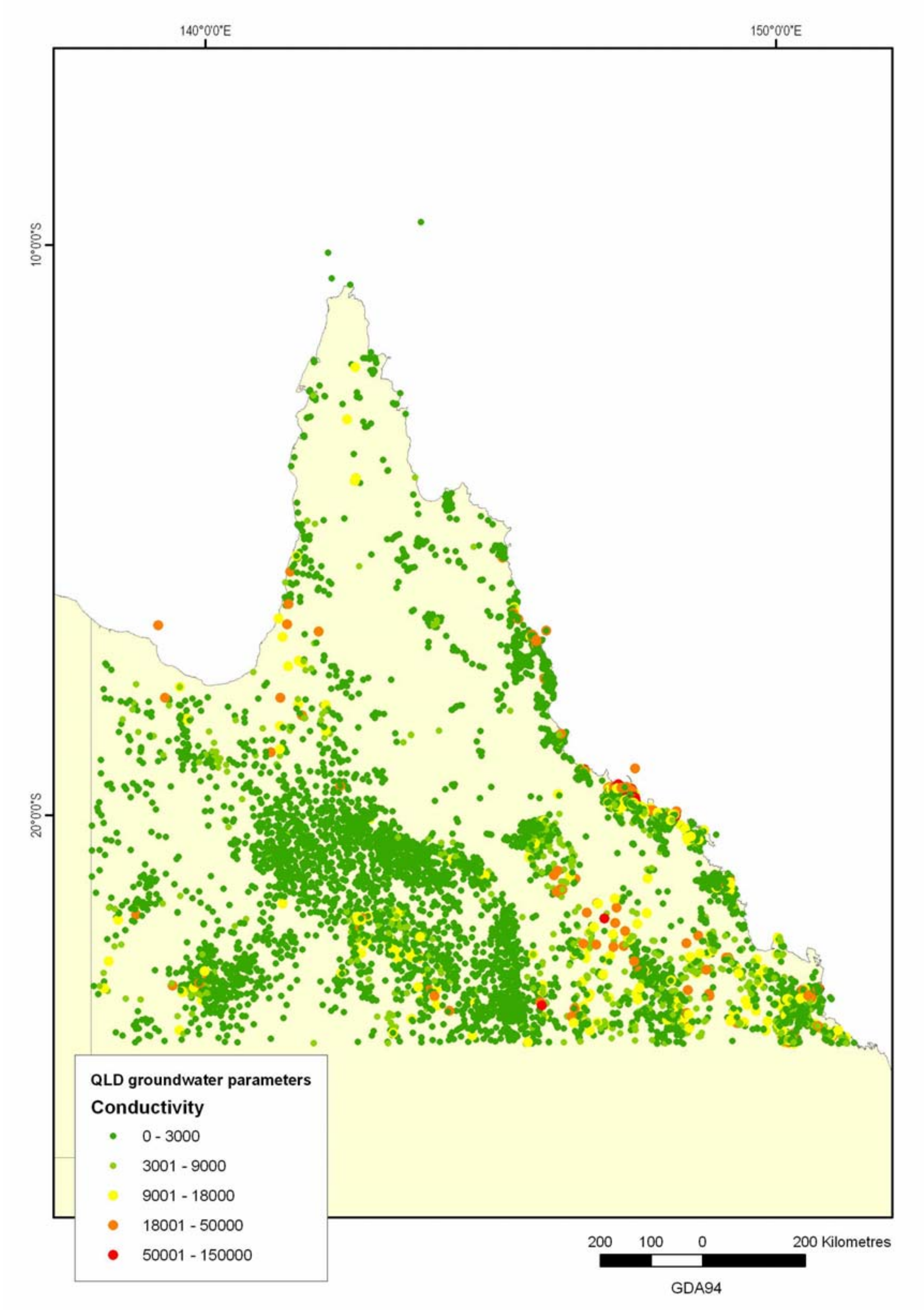

Figure 4: 5 Queensland Conductivity

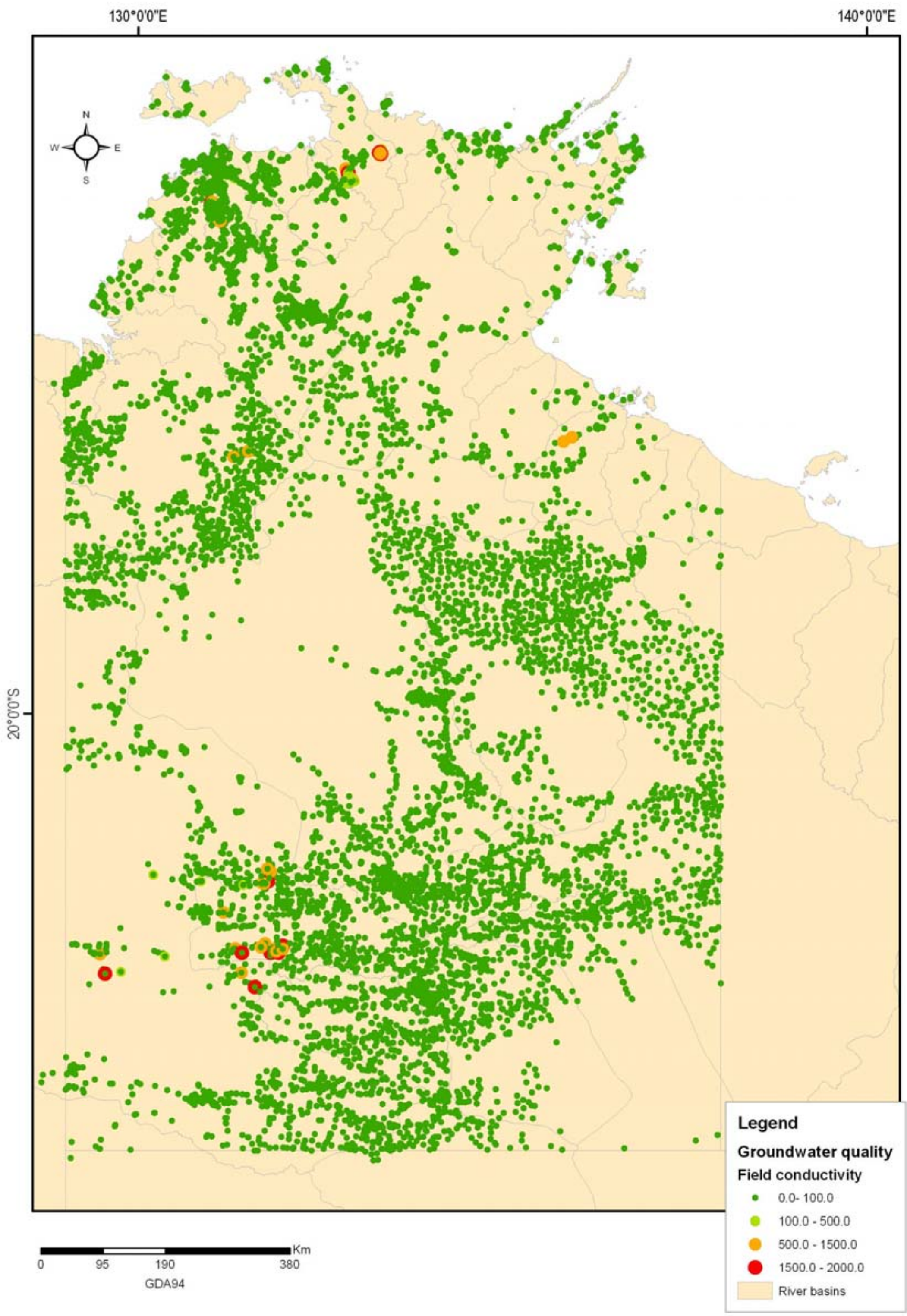

Figure 4: 6 NT Conductivity

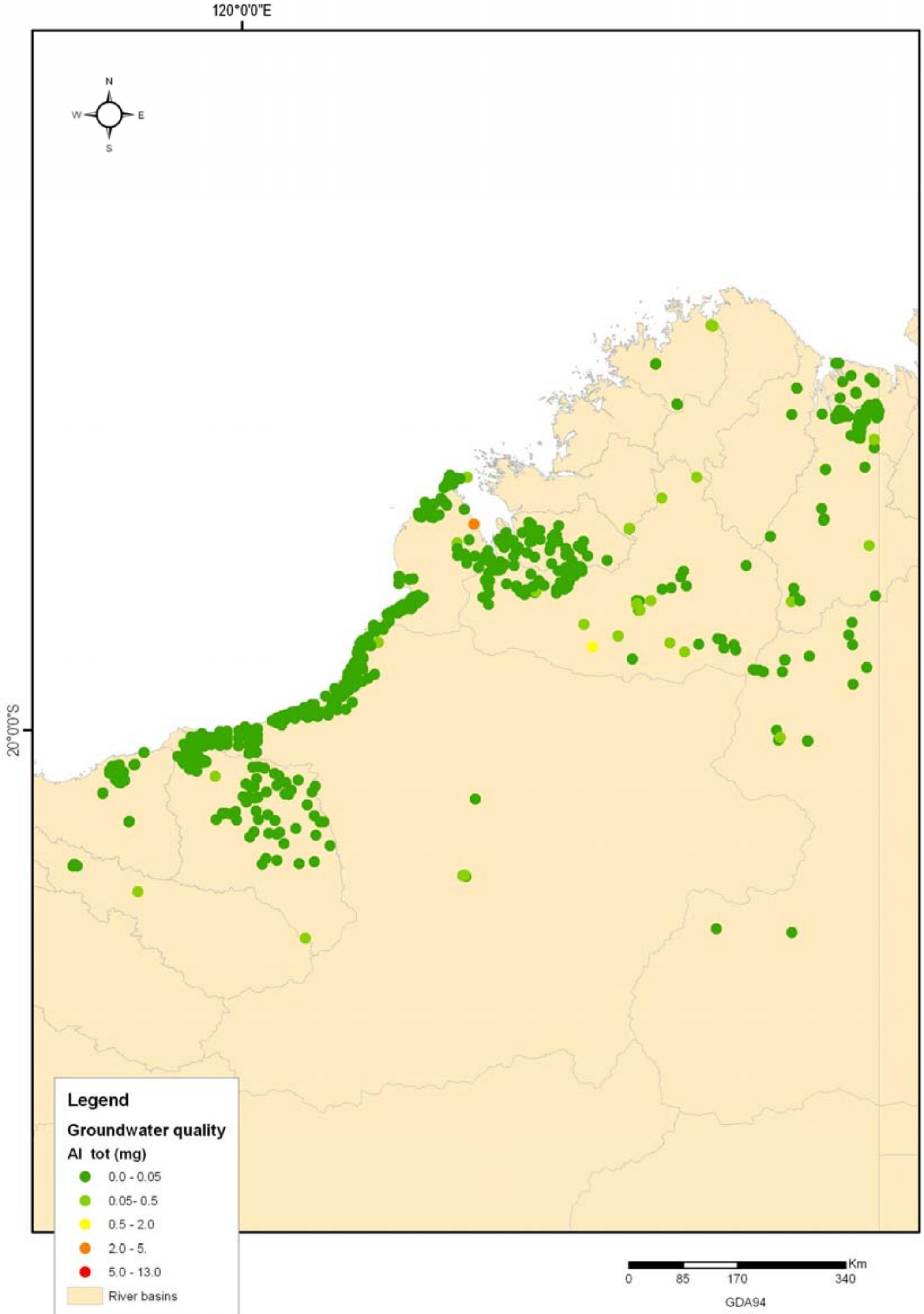

Figure 4: 7 WA Aluminium - Total mg/L

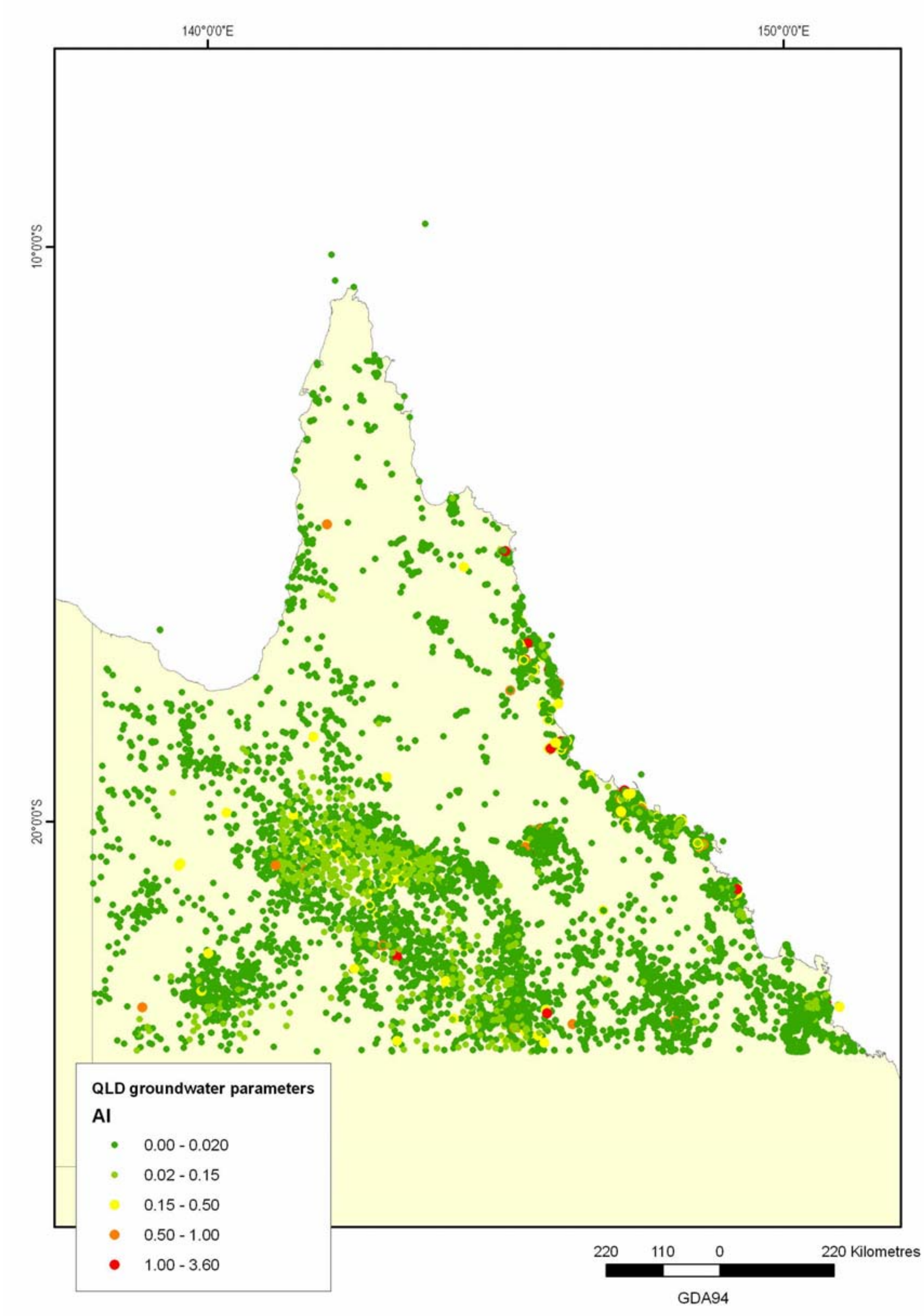

Figure 4: 8 Queesland Aluminium Total (mg/L)

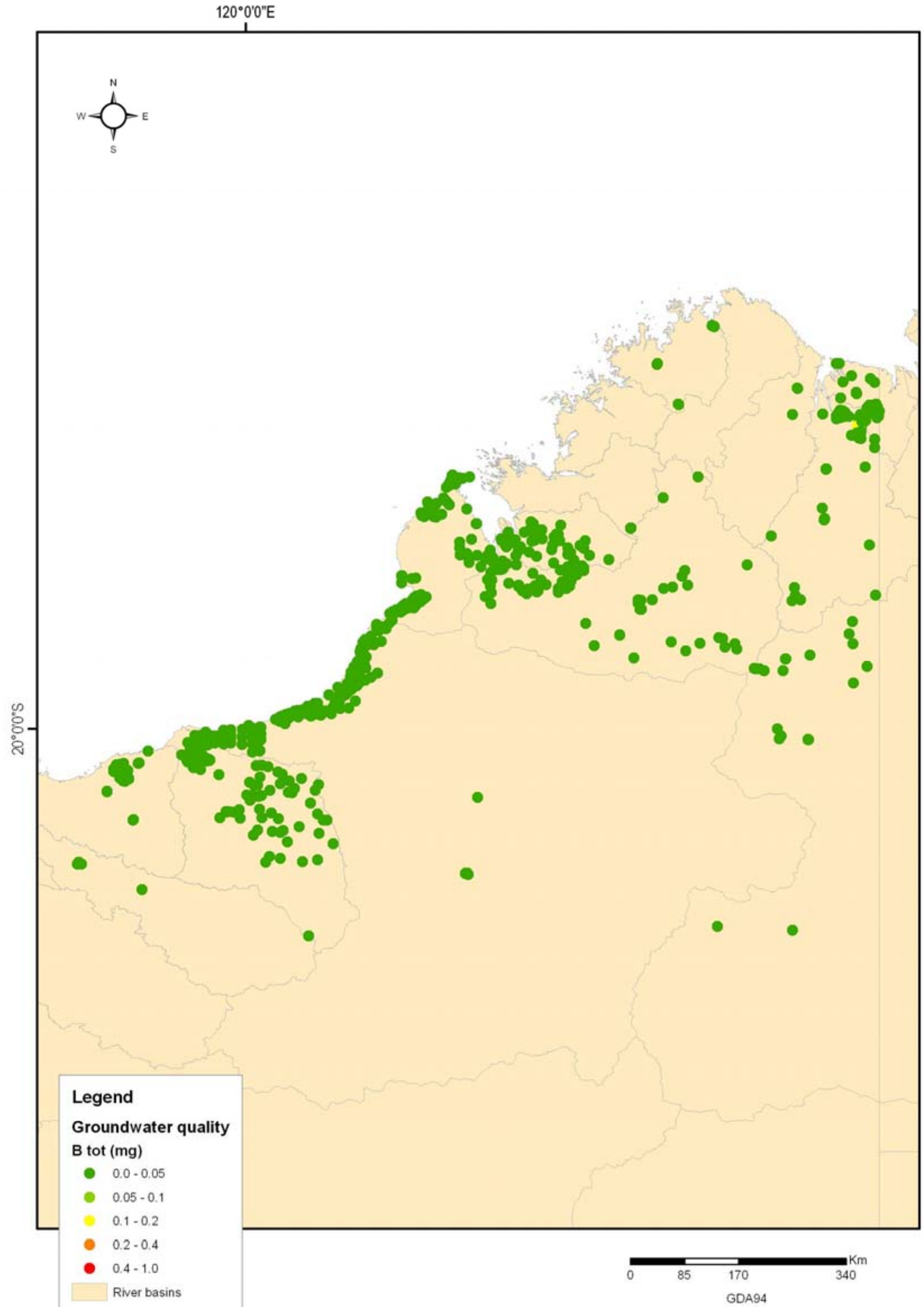

Figure 4: 9 WA Boron (mg/L)

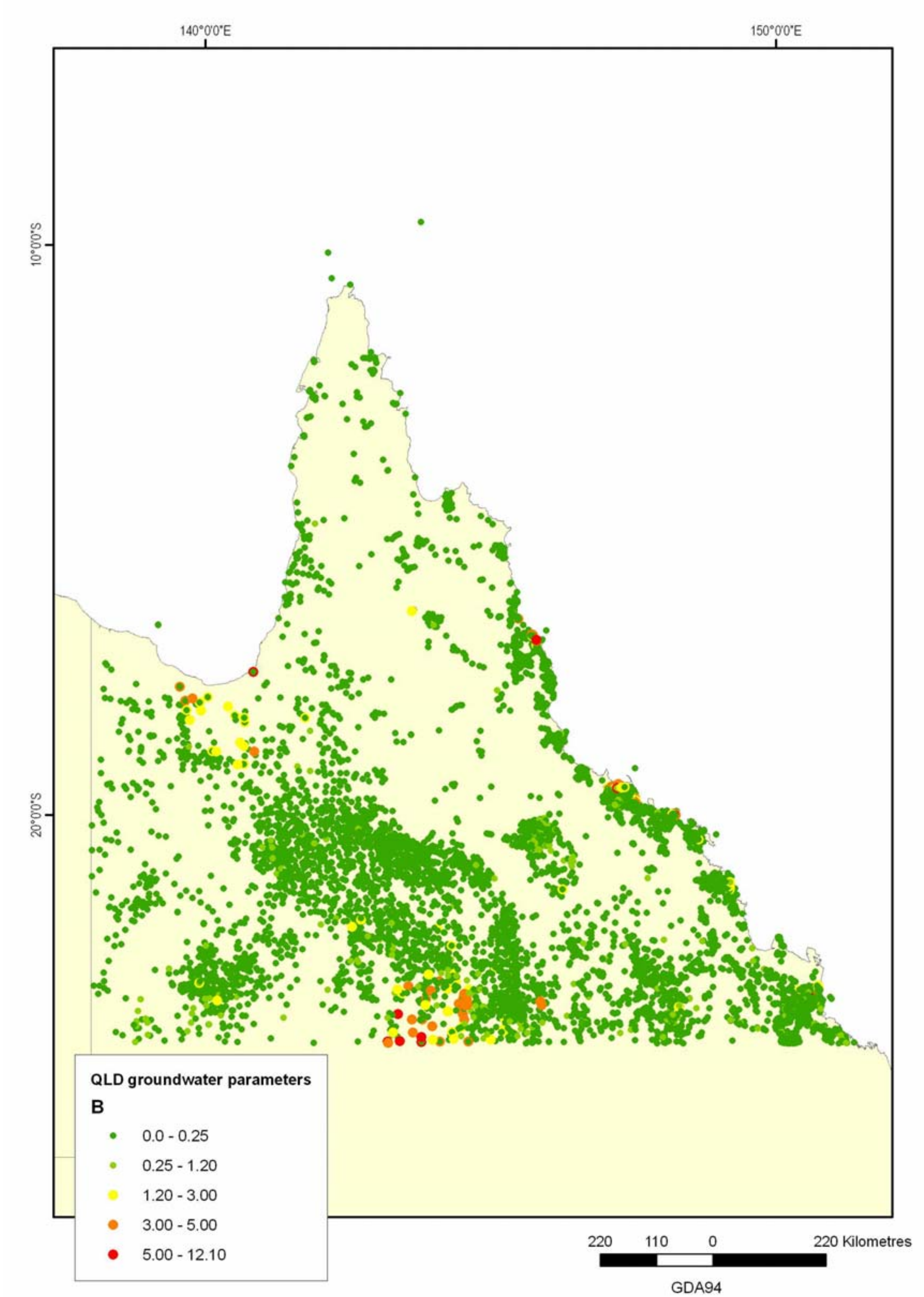

Figure 4: 10 Queensland Boron (mg/L)

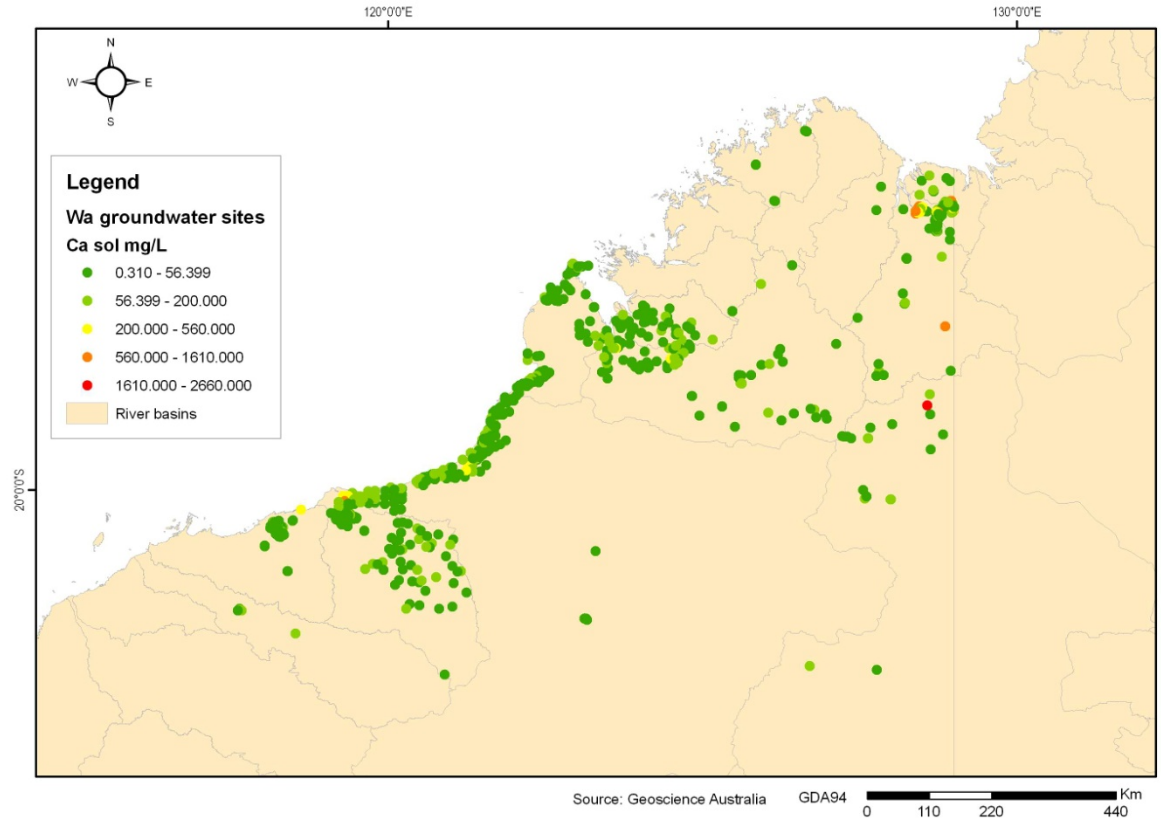

Figure 4: 11 WA Calcium (mg/L)

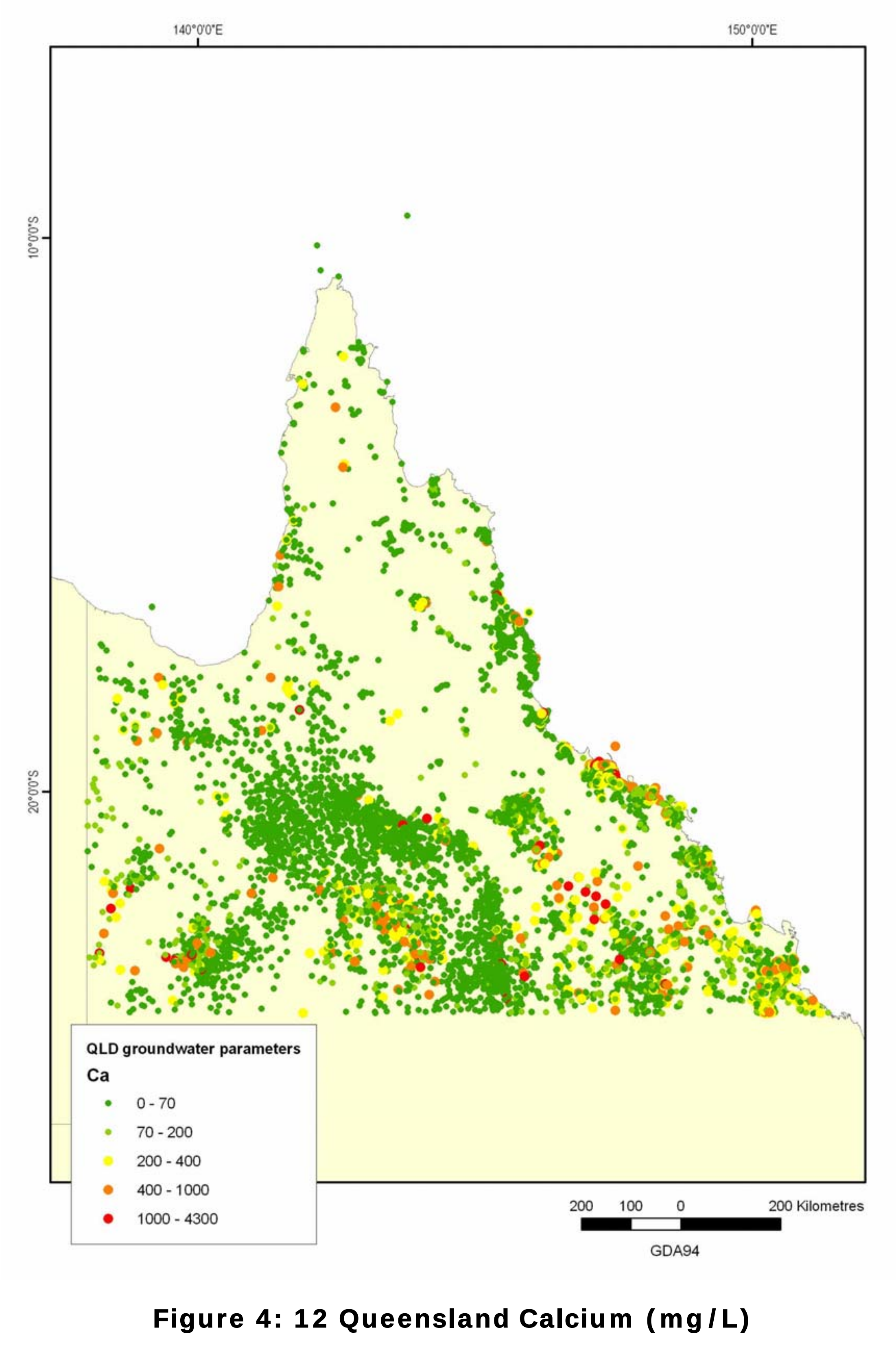

Figure 4: 12 Queensland Calcium (mg/L)

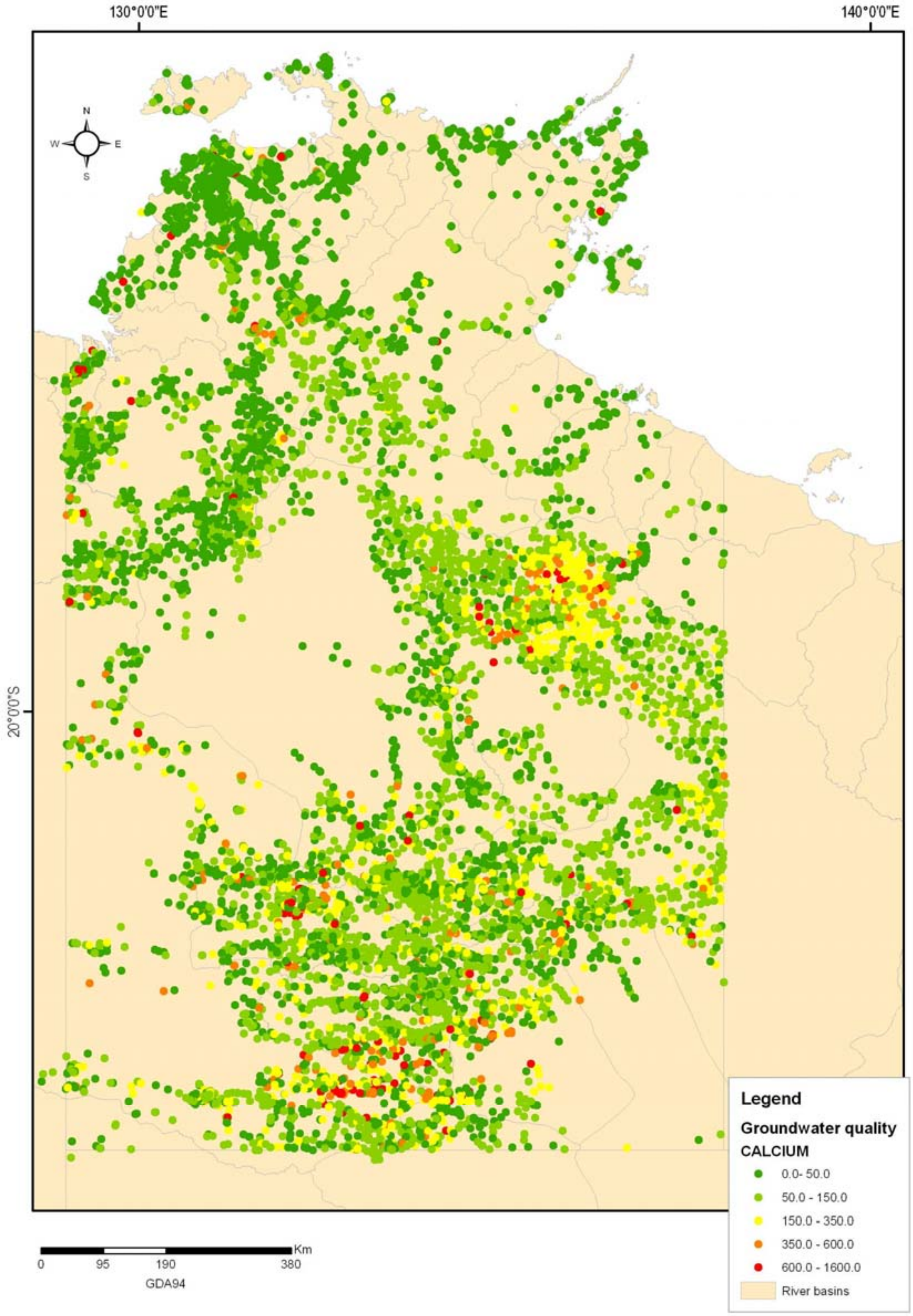

Figure 4: 13 NT Calcium (mg/L)

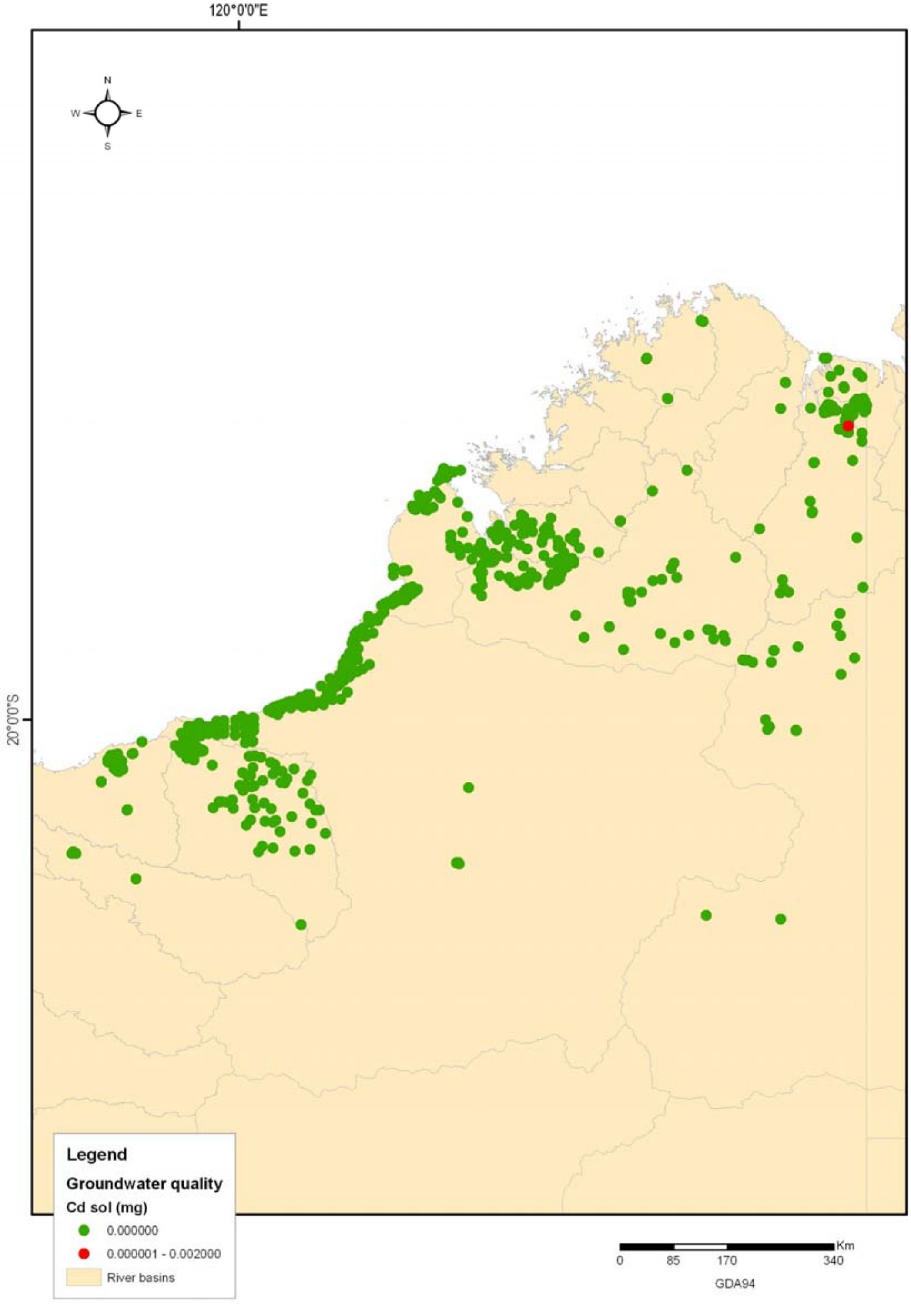

Figure 4: 14 WA Cadmium (mg/L)

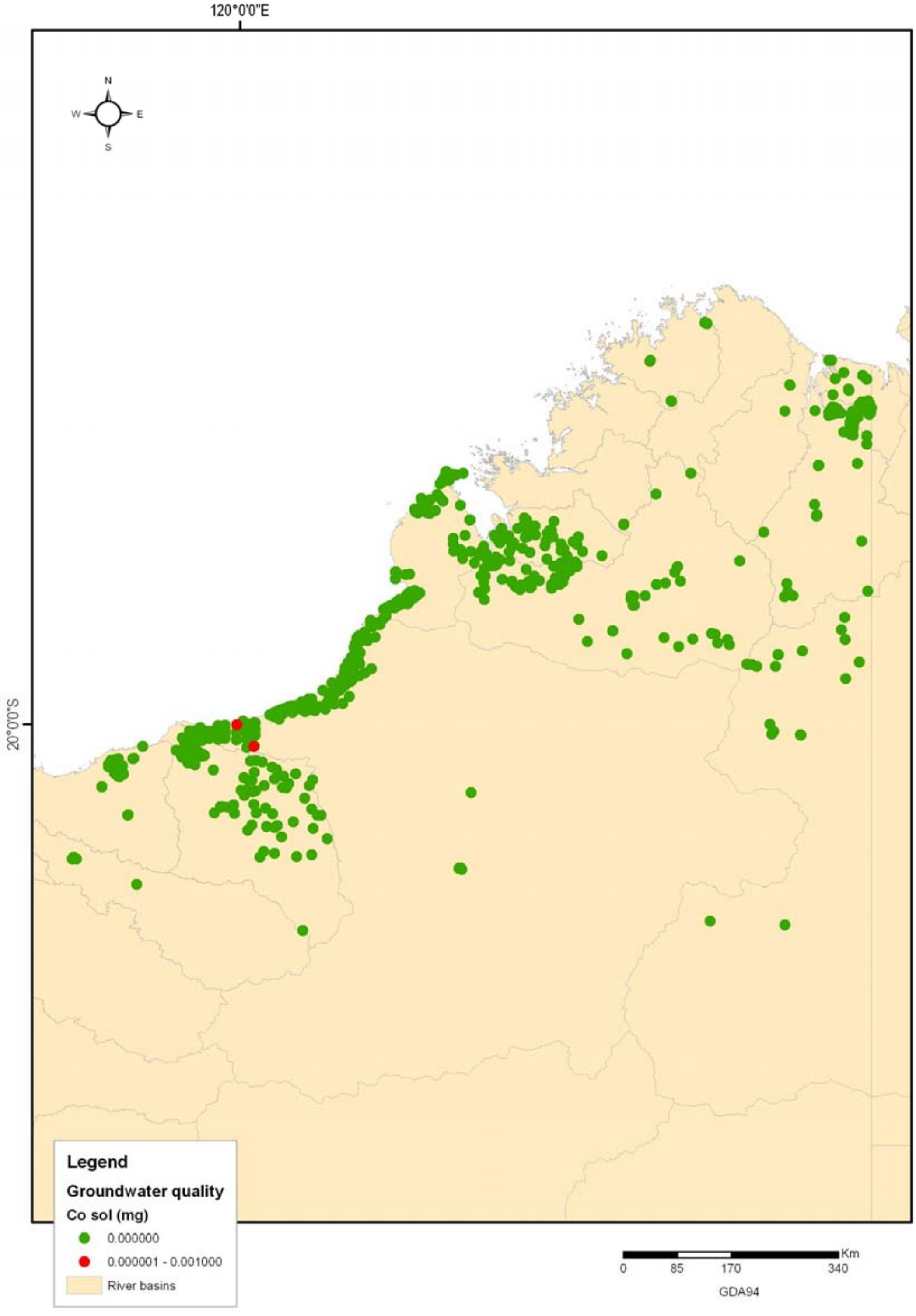

Figure 4: 15 WA Cobalt (mg/L)

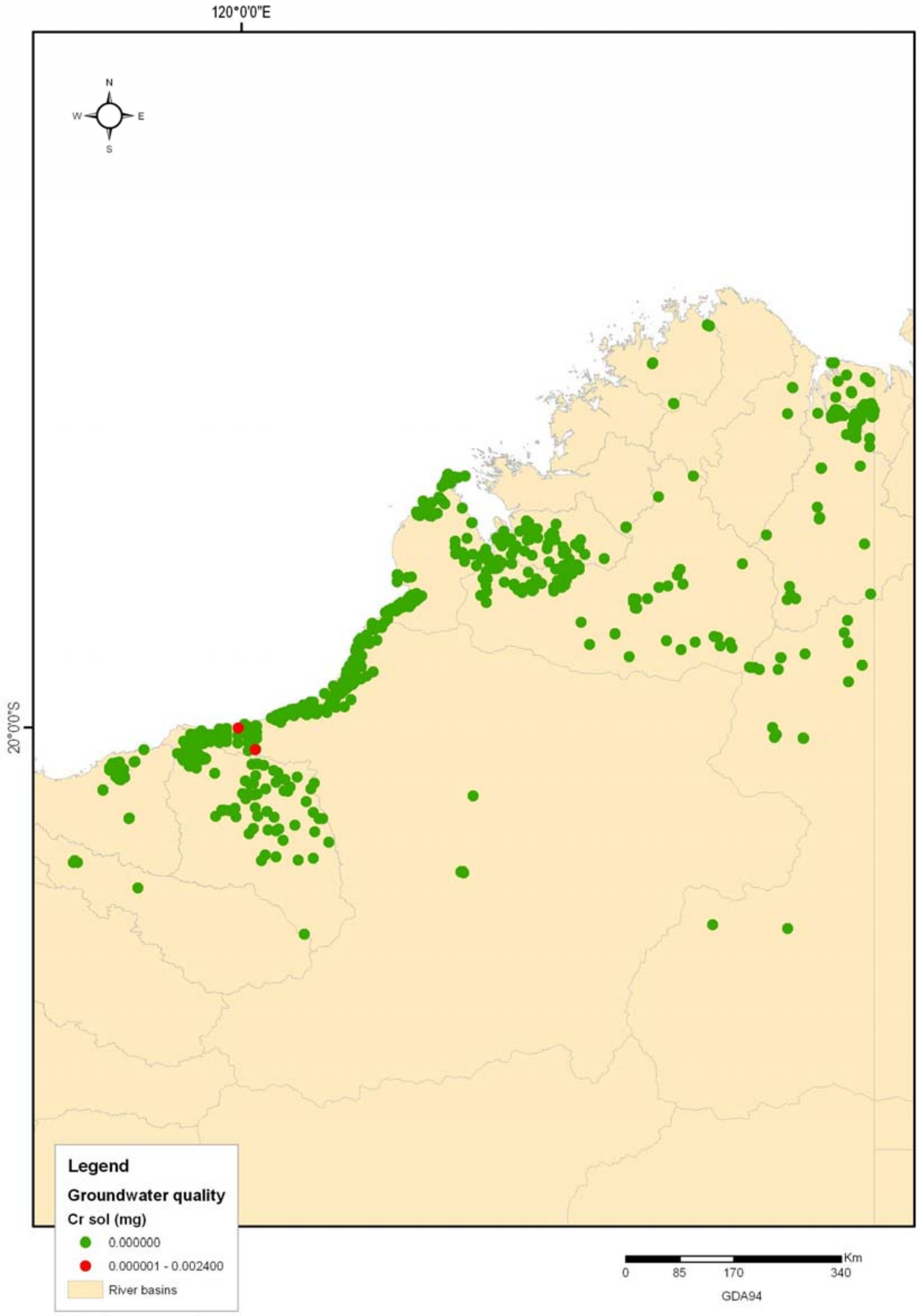

Figure 4: 16 WA Chromium (mg/L)

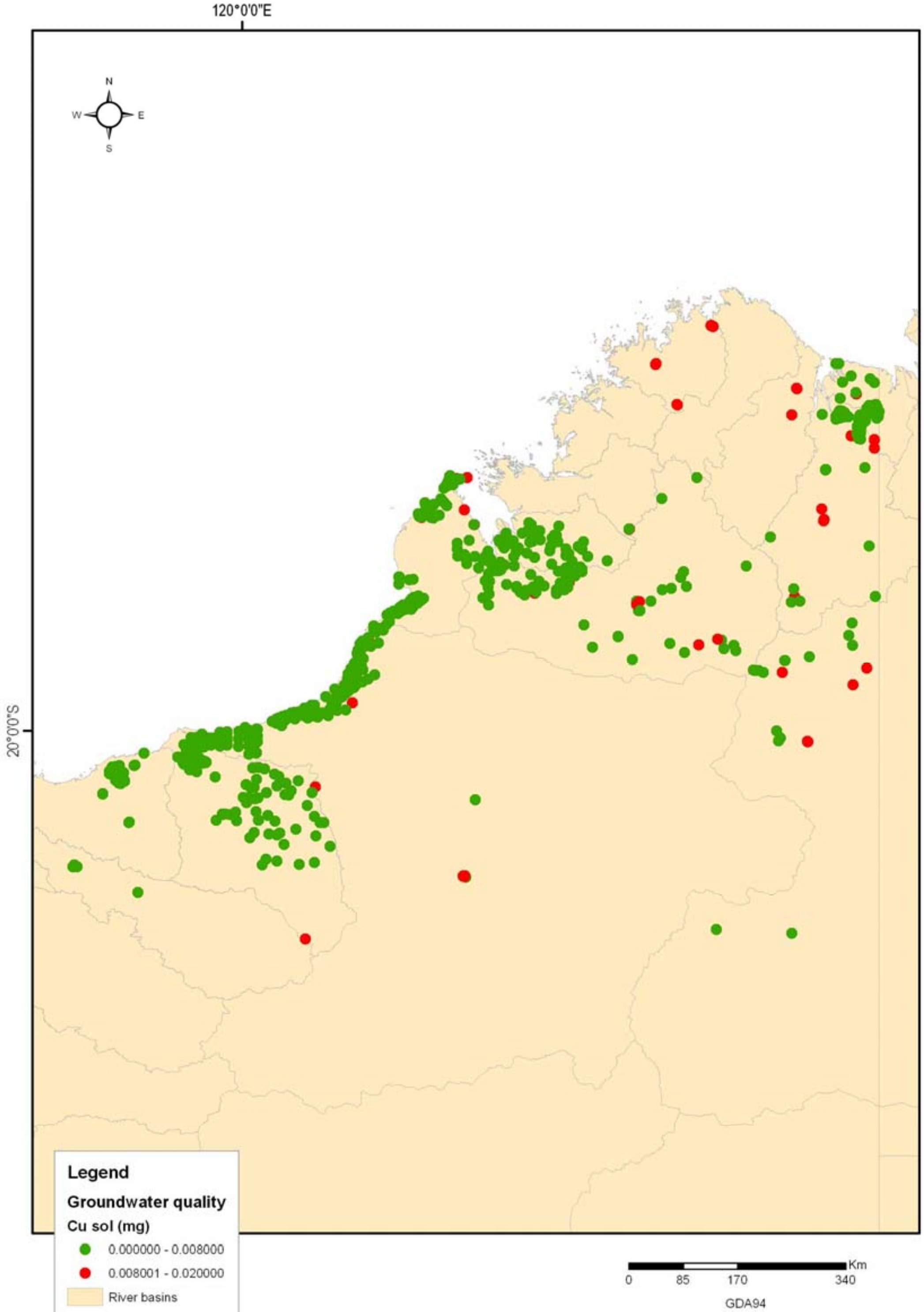

Figure 4: 17 WA Copper (mg/L)

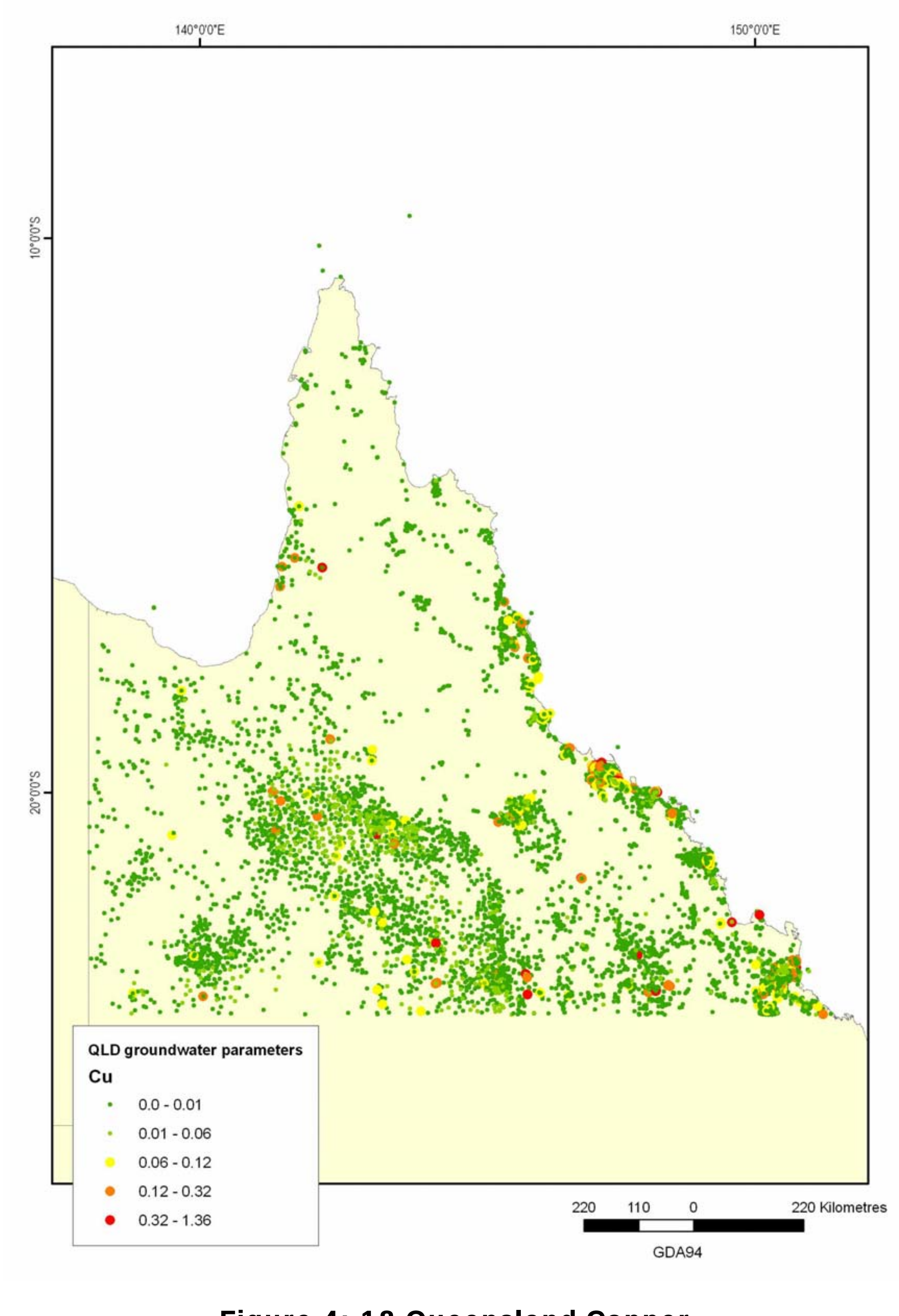

Figure 4: 18 Queensland Copper

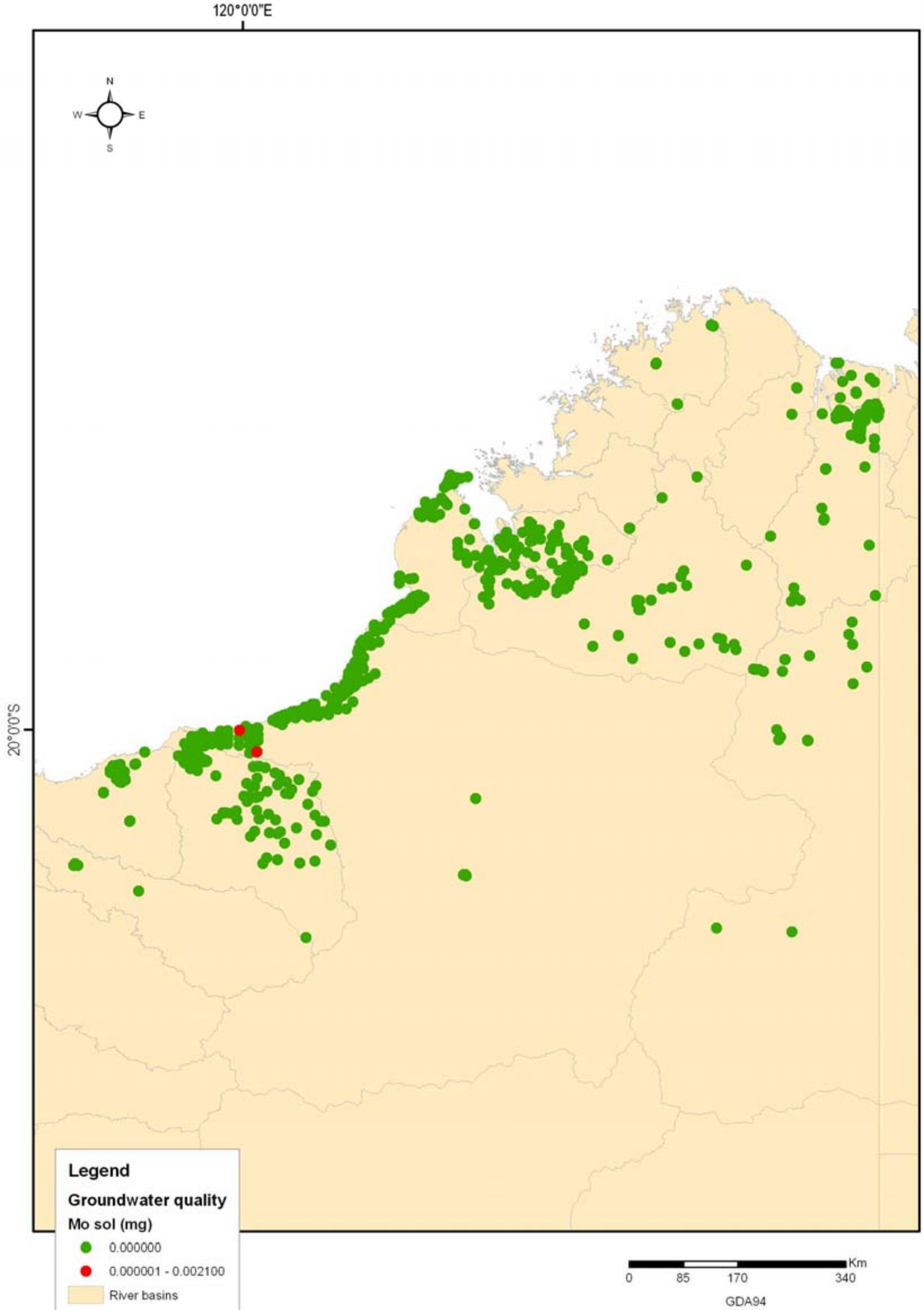

Figure 4: 19 WA Molybdenum (mg/L)

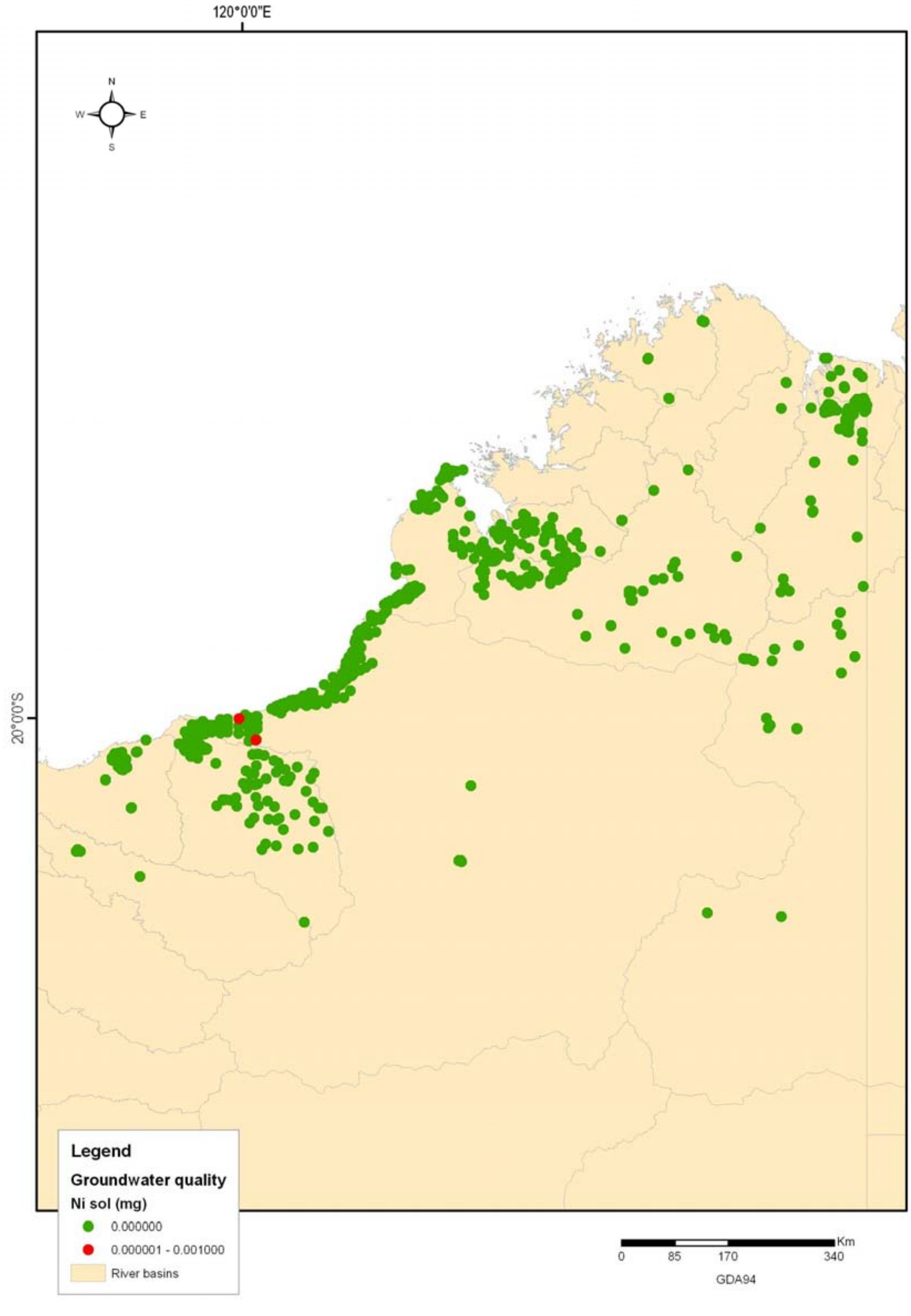

Figure 4: 20 WA Nickel (mg/L)

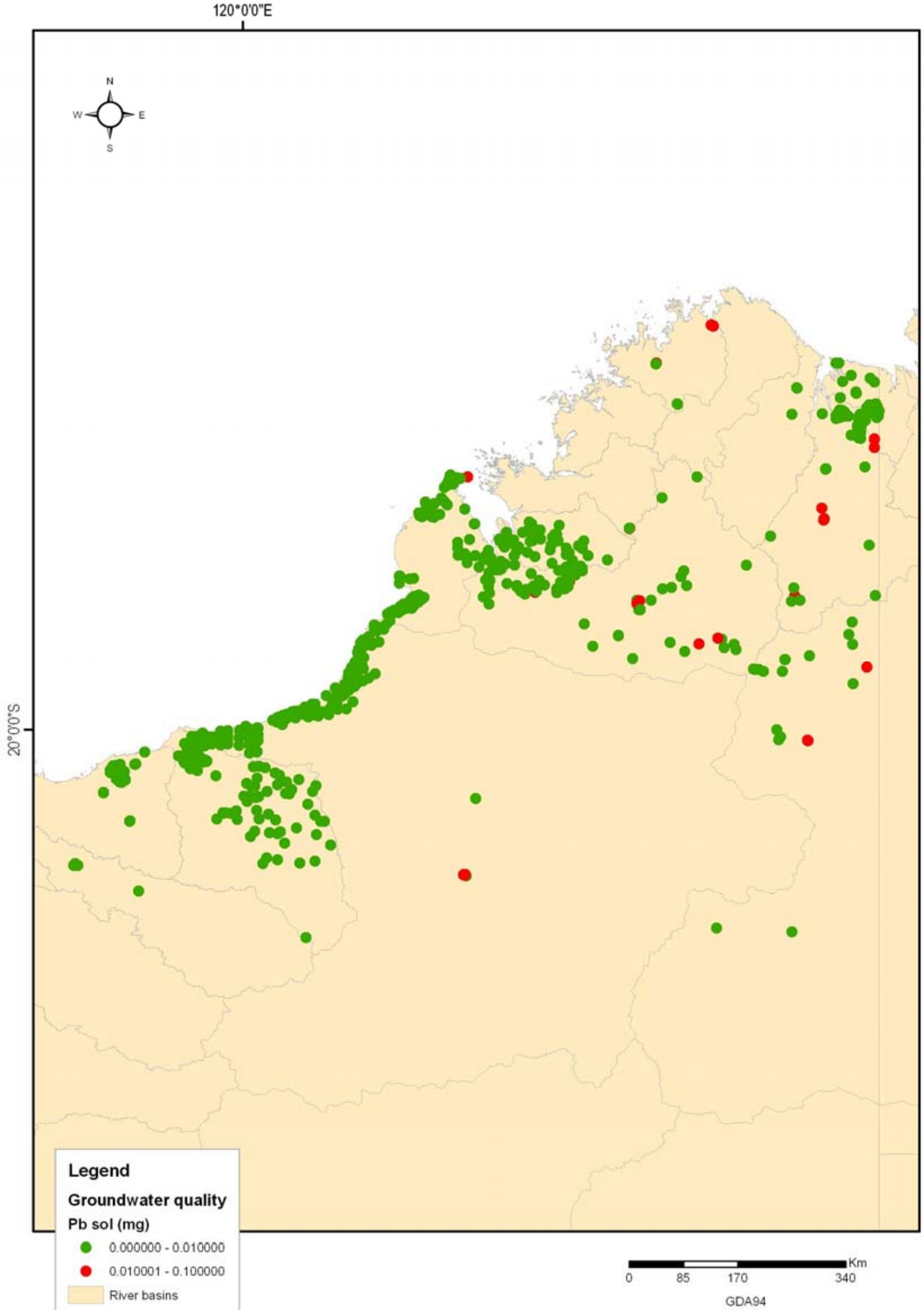

Figure 4: 21 WA Lead (mg/L)

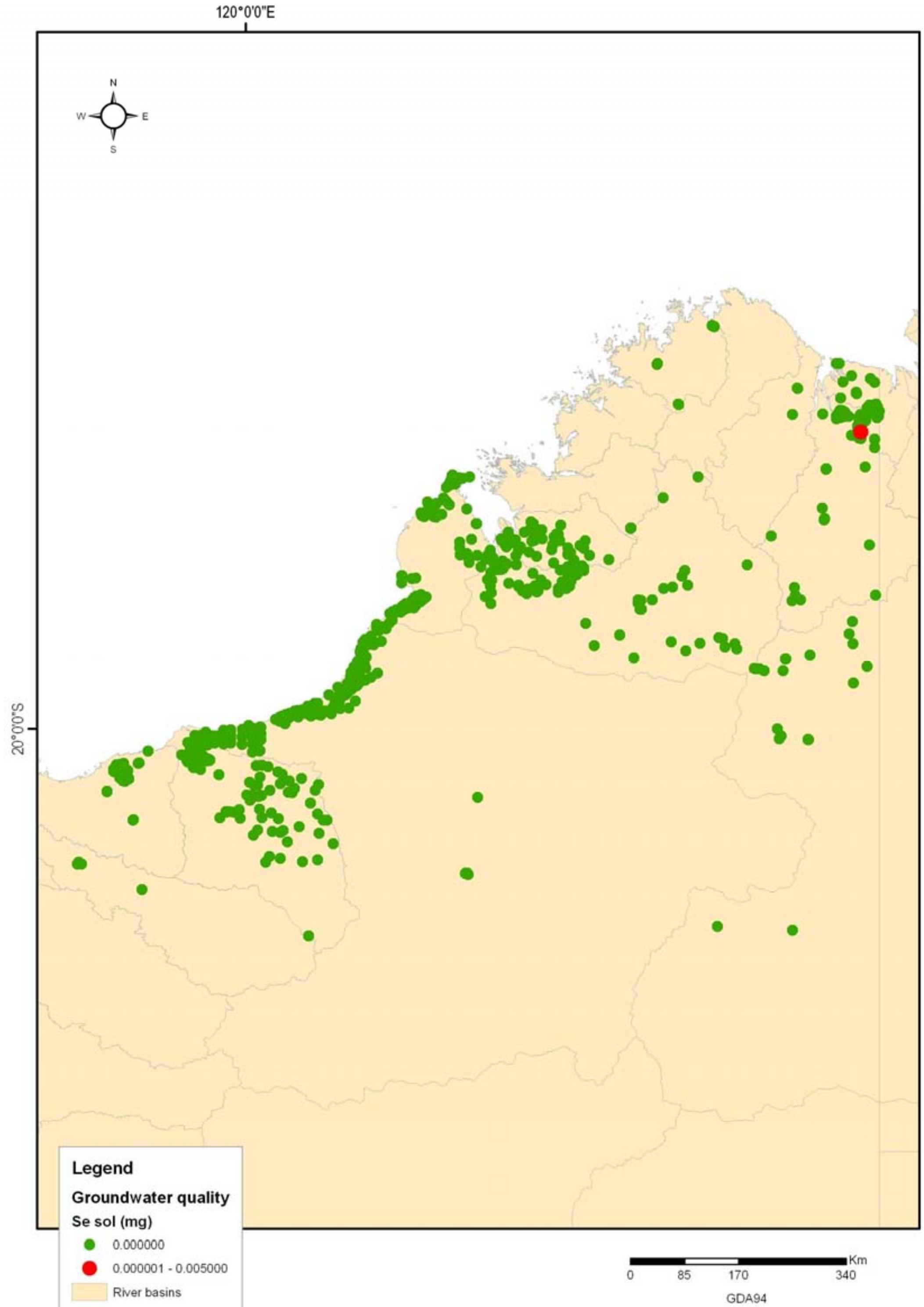

Figure 4: 22 WA Selenium (mg/L)

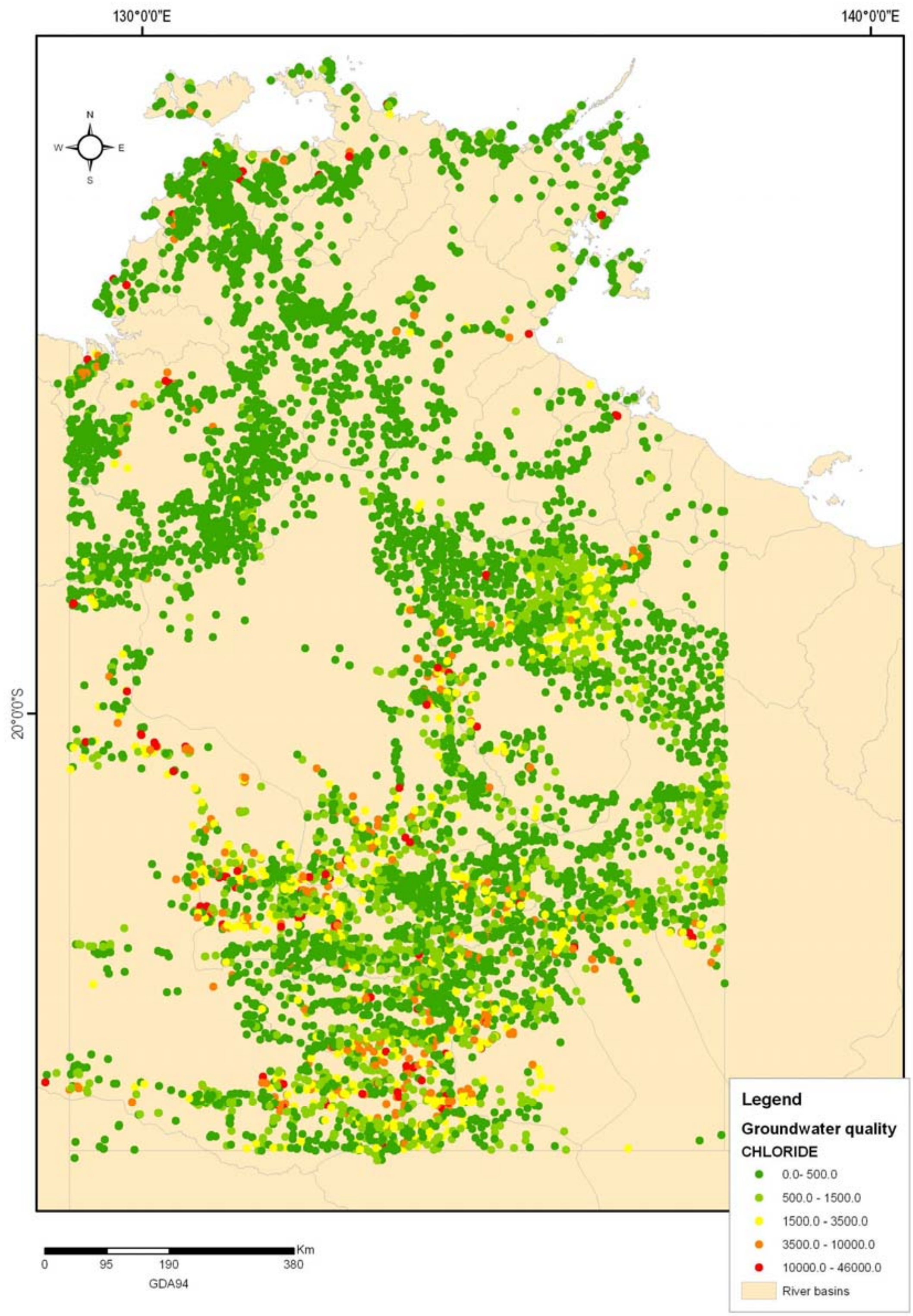

Figure 4: 23 NT Chloride (mg/L)

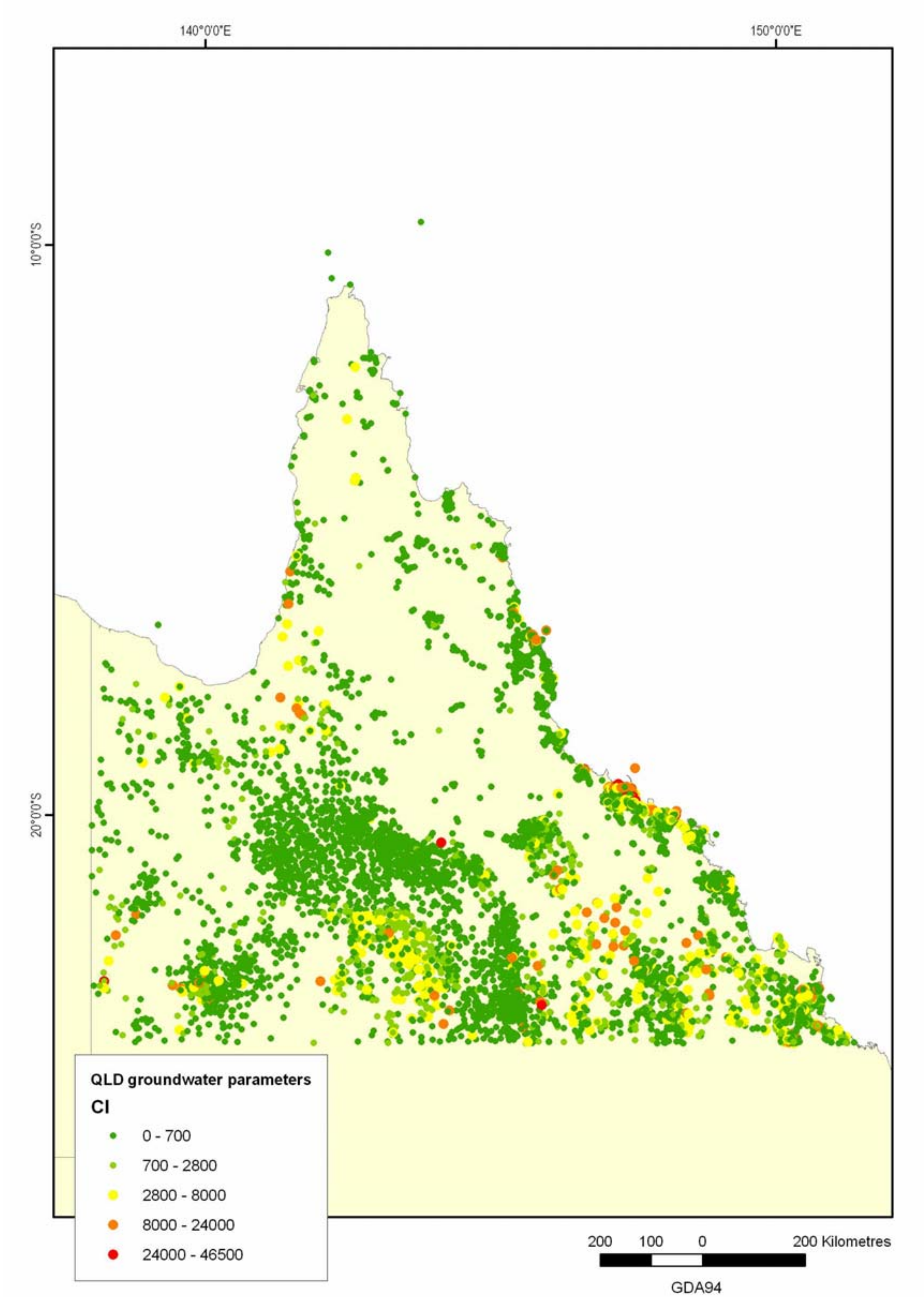

Figure 4: 24 Queensland Chloride (mg/L)

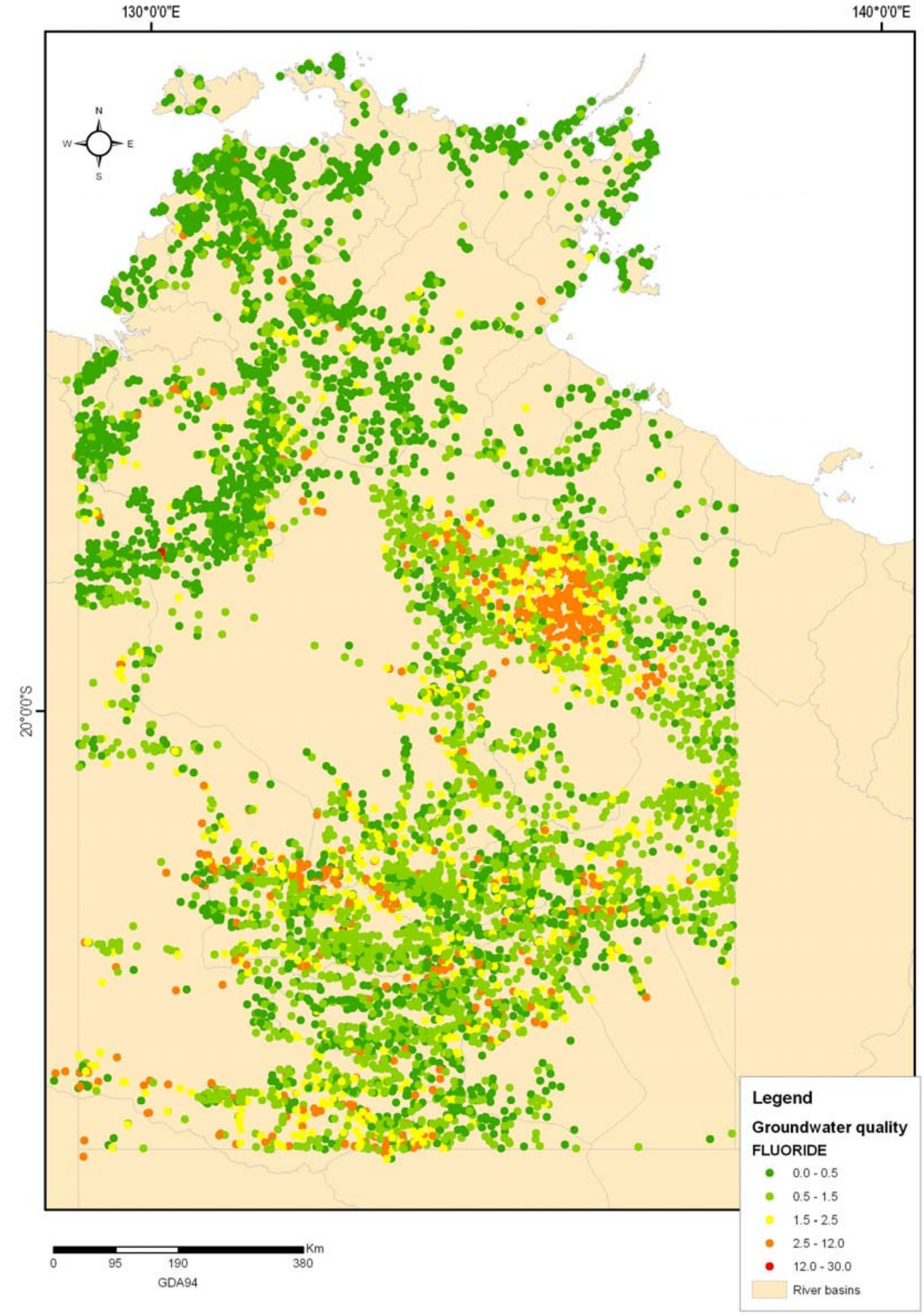

Figure 4: 25 NT Fluoride (mg/L)

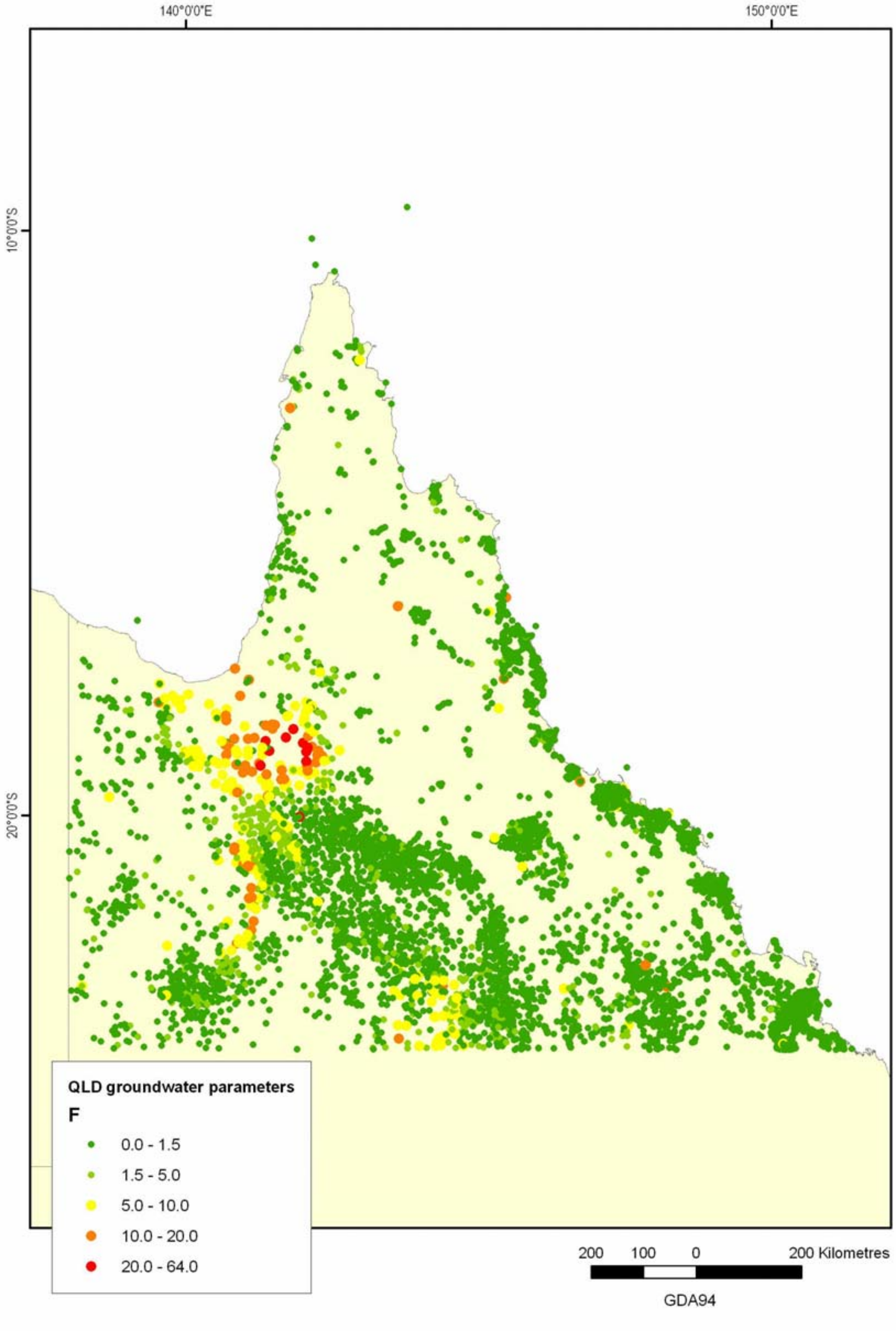

Figure 4: 26 Queensland Fluoride (mg/L)

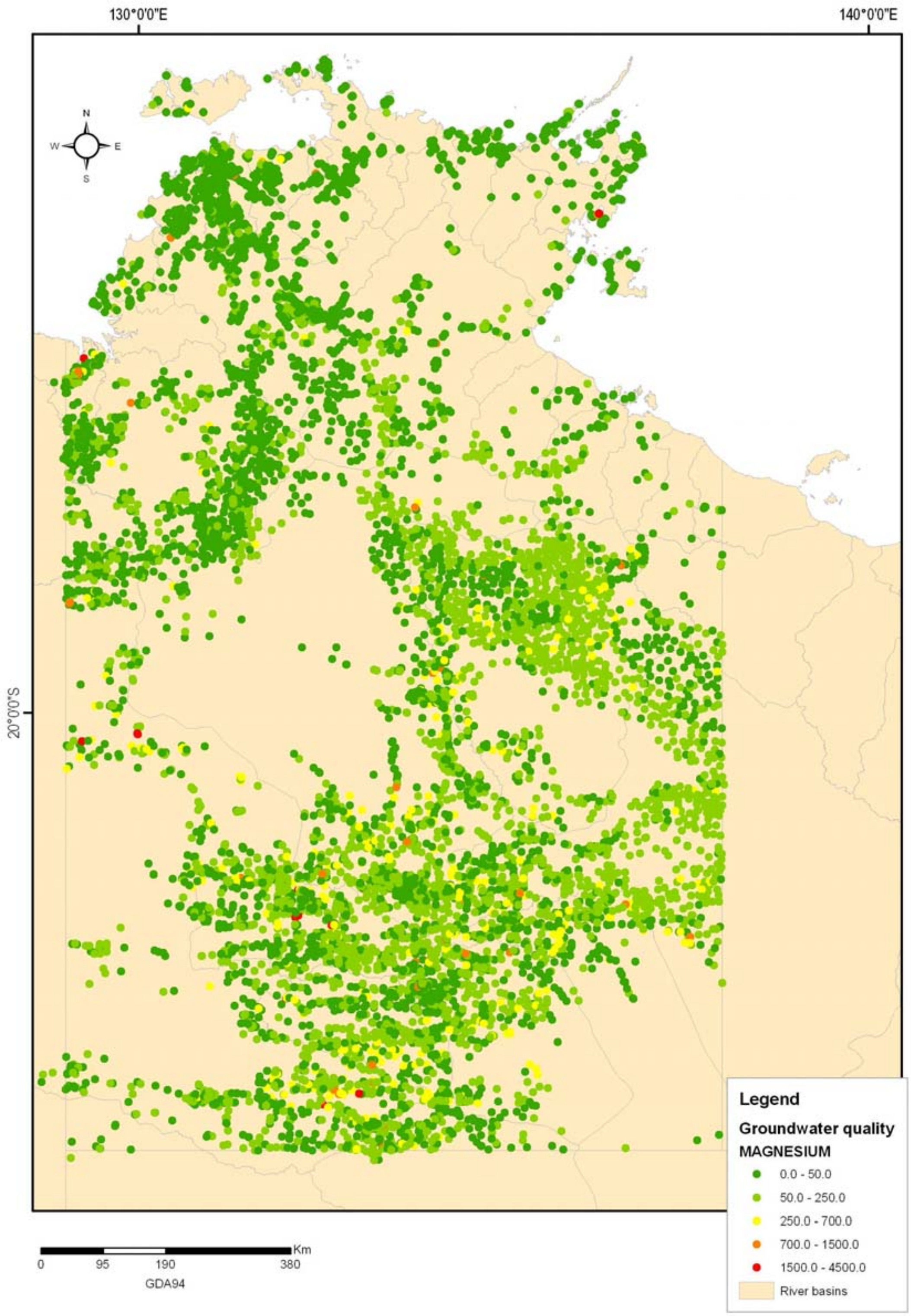

Figure 4: 27 NT Magnesium (mg/L)

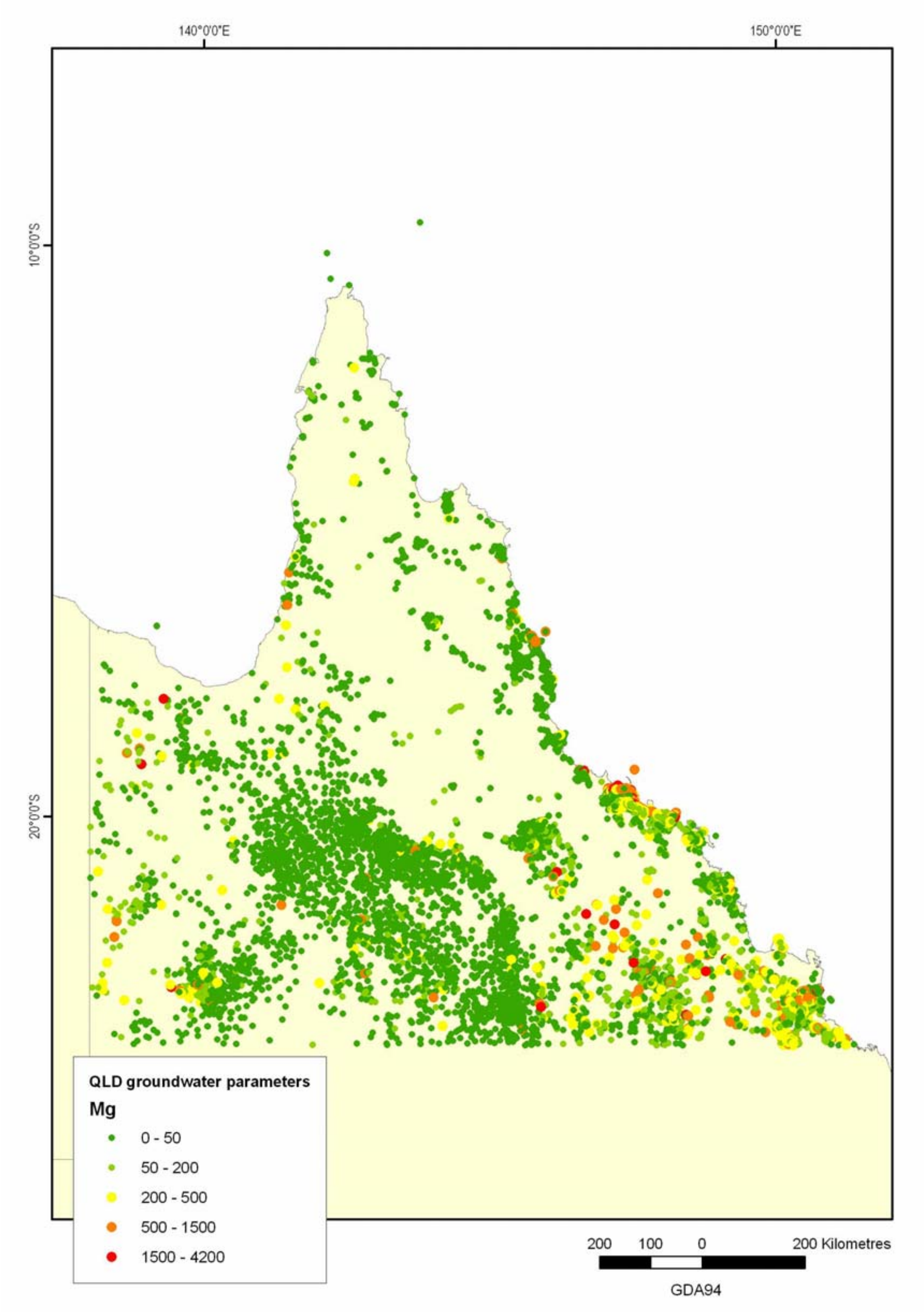

Figure 4: 28 Queensland Magnesium (mg/L)

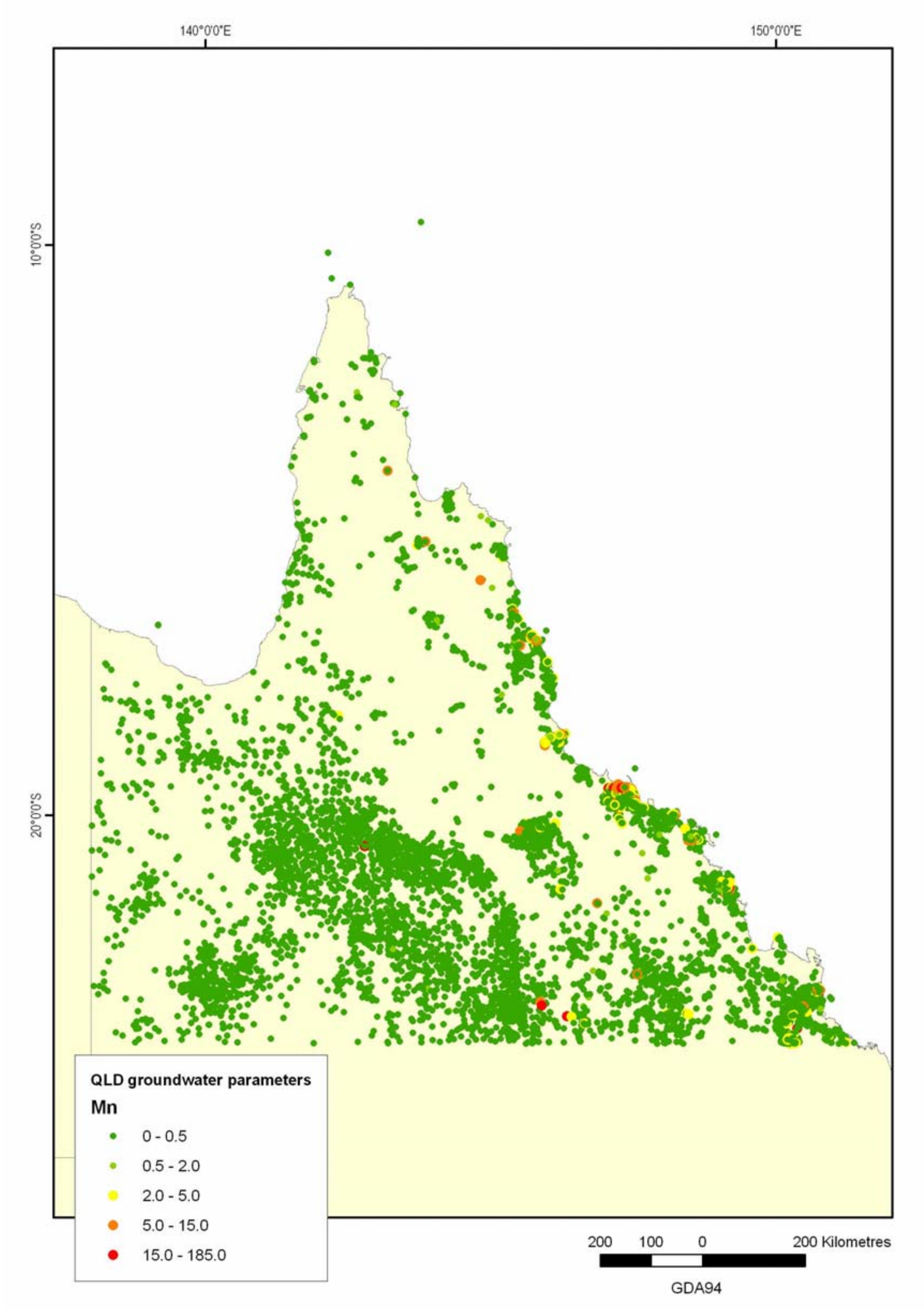

Figure 4: 29 Queensland Manganese (mg/L)

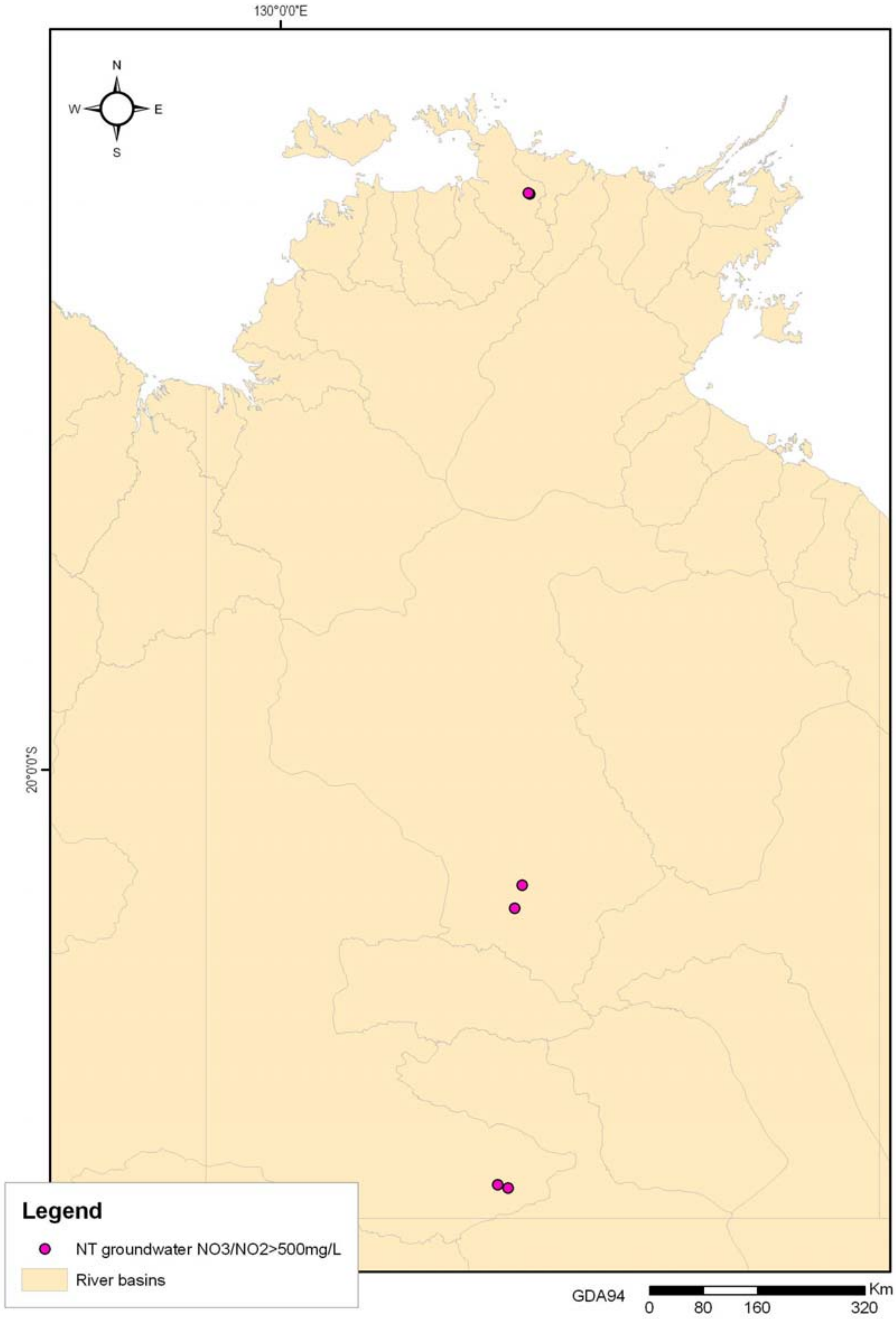

Figure 4: 30 NT - NO3 + NO2 > 500 mg/L

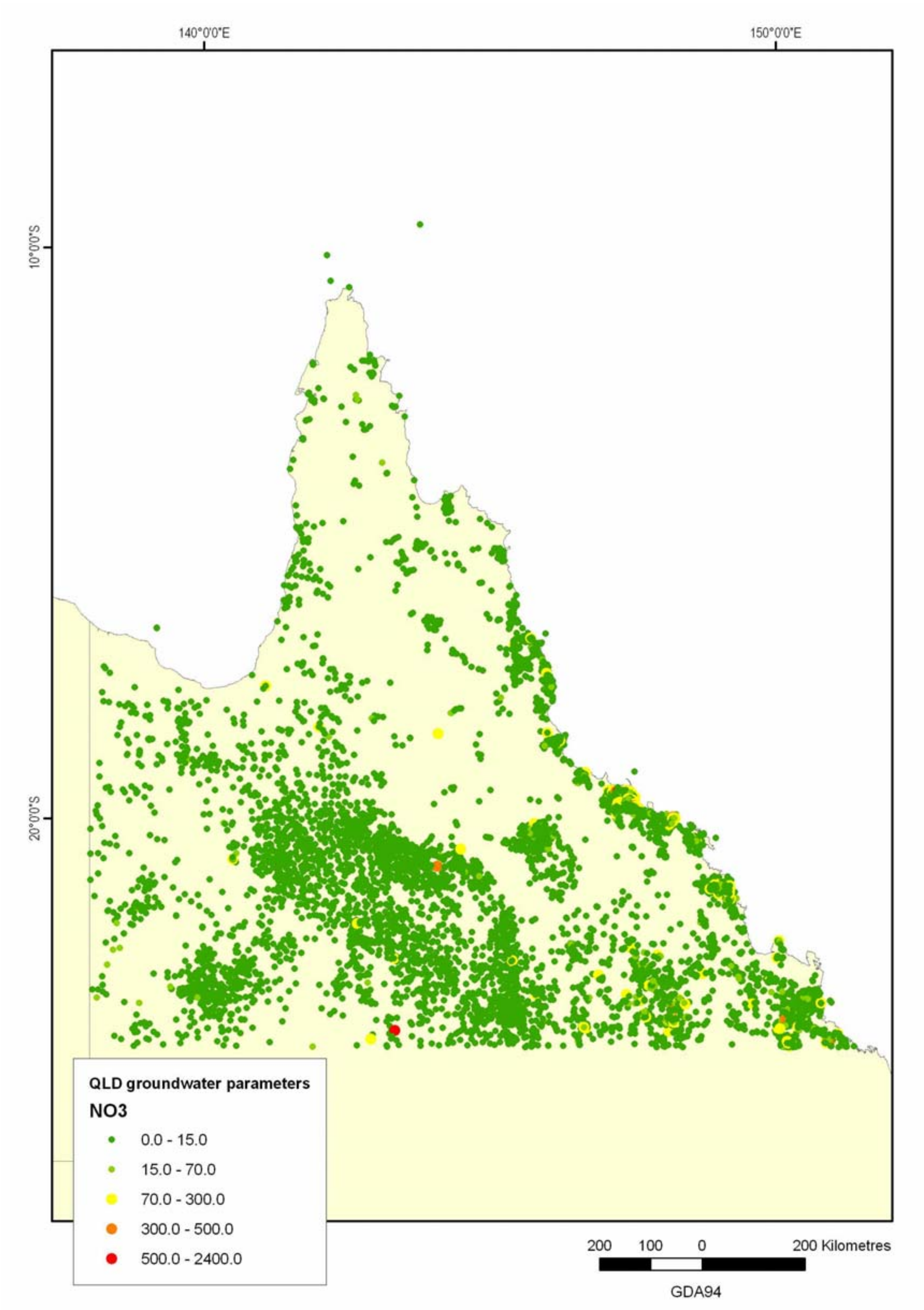

Figure 4: 31 Queensland Nitrate N (mg/L)

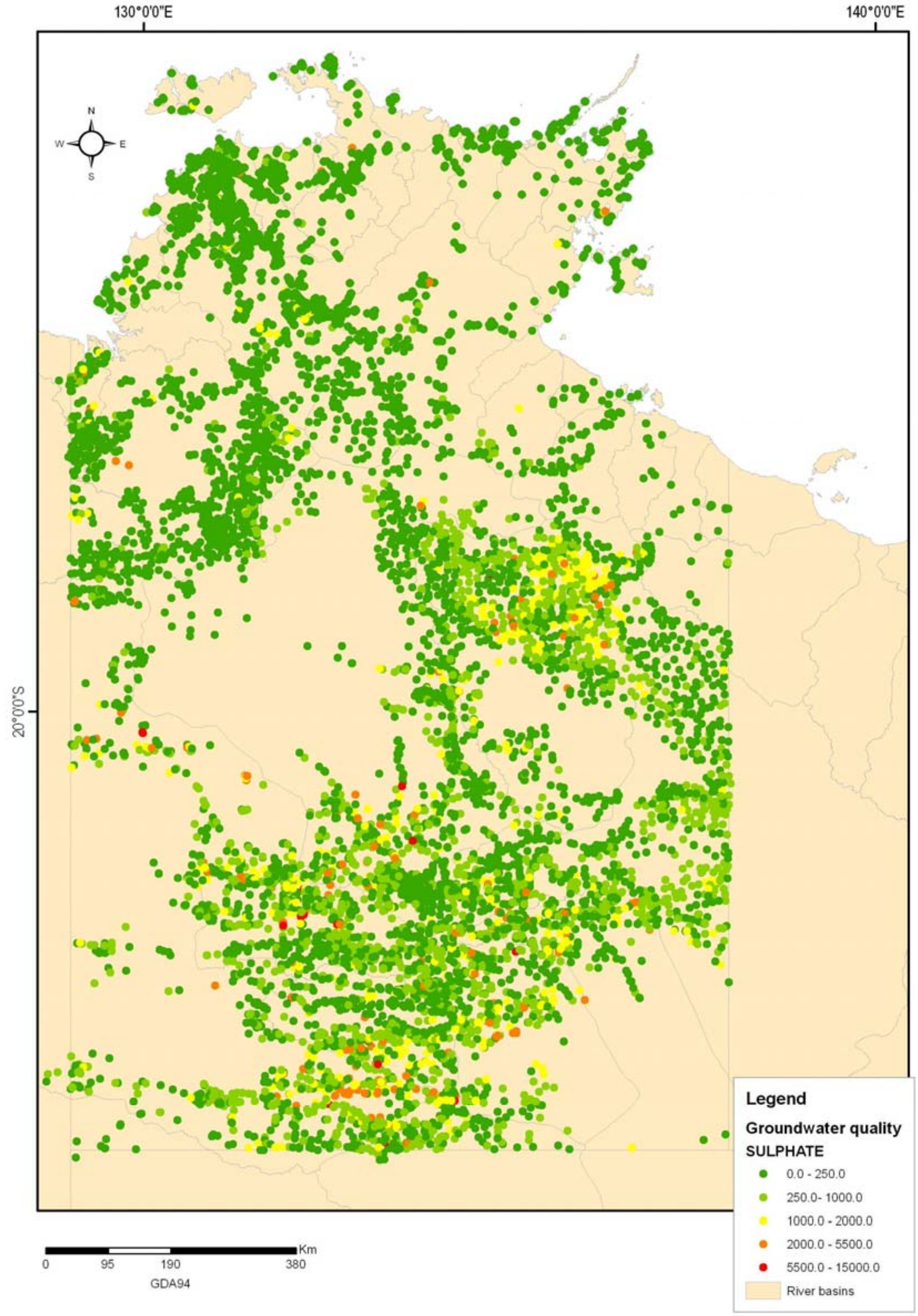

Figure 4: 32 NT Sulphate (mg/L)

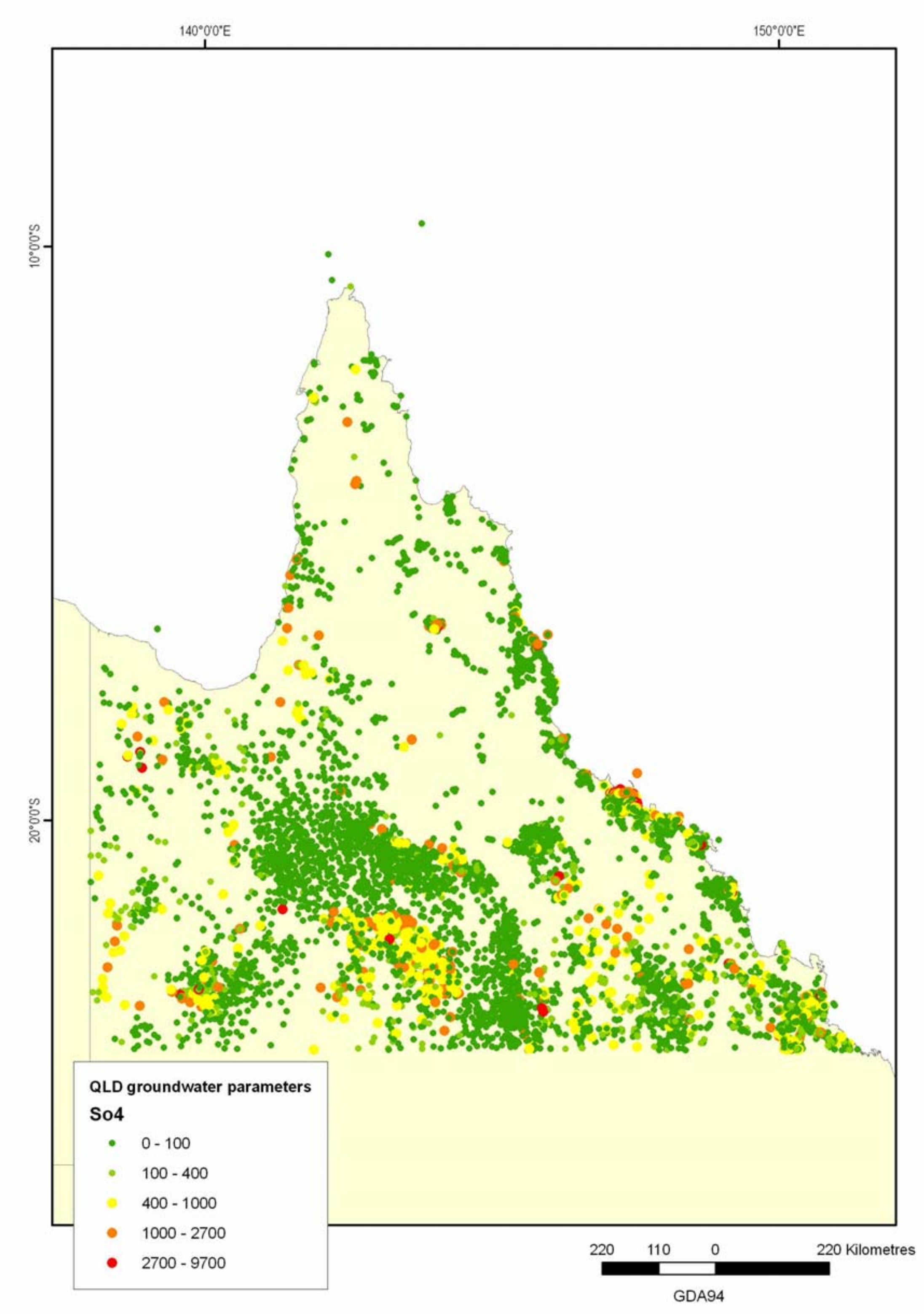

Figure 4: 33 Queensland Sulphate (mg/L)

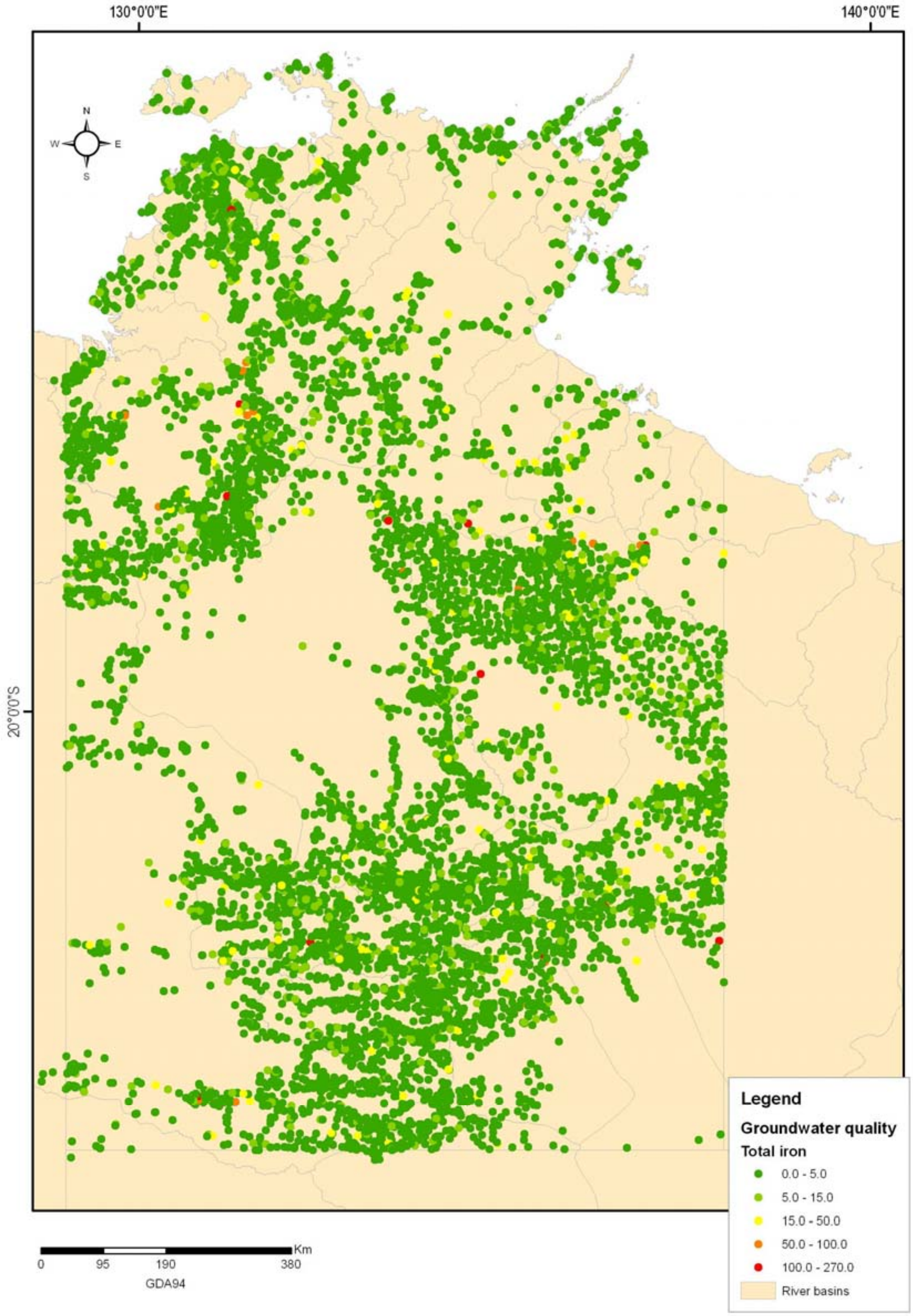

Figure 4: 34 NT Total Iron

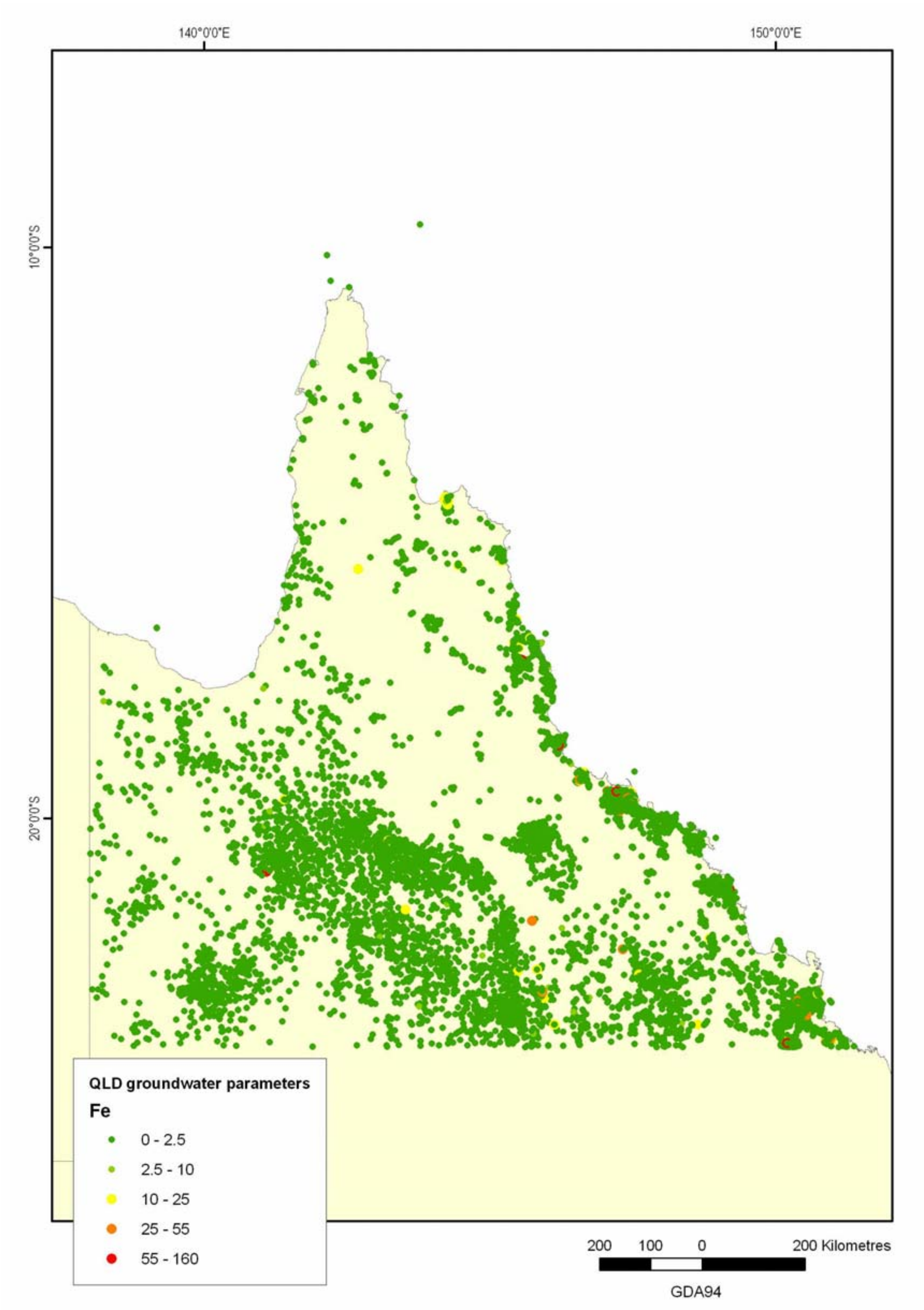

Figure 4: 35 Queensland Iron (mg/L)

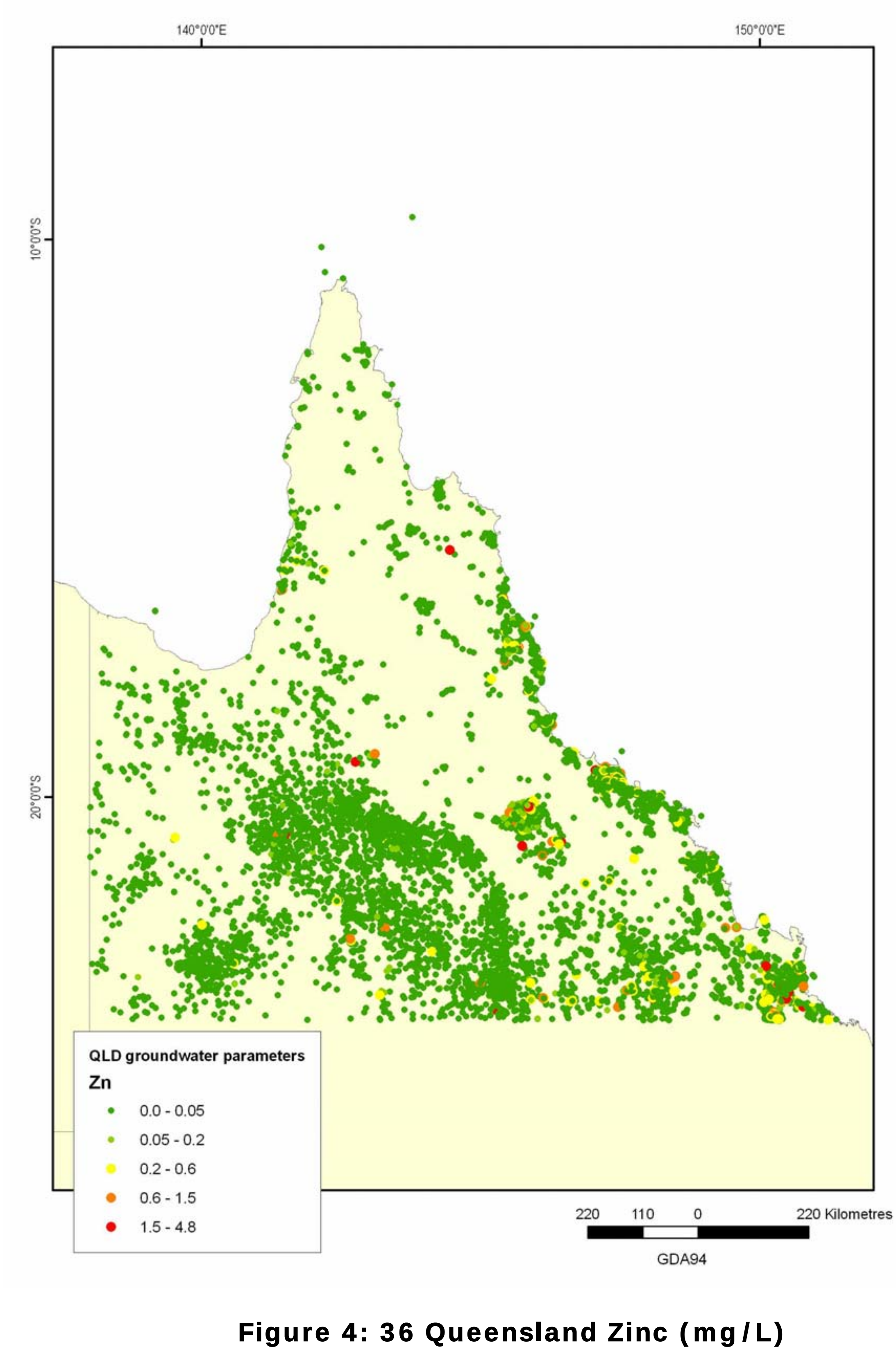

Figure 4: 36 Queensland Zinc (mg/L)

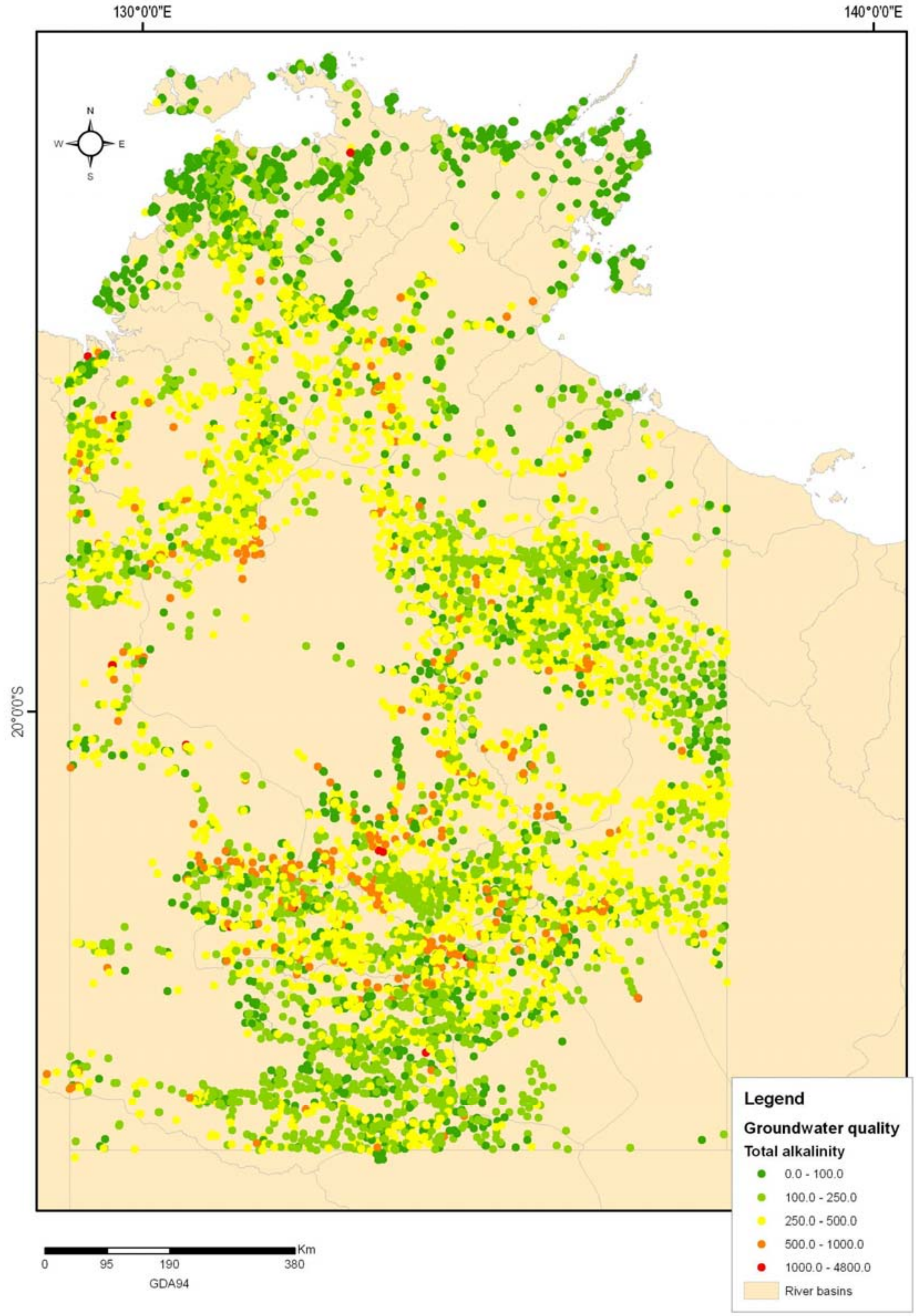

Figure 4: 37 NT Total Alkalinity (mg/L $CaCO_3$)

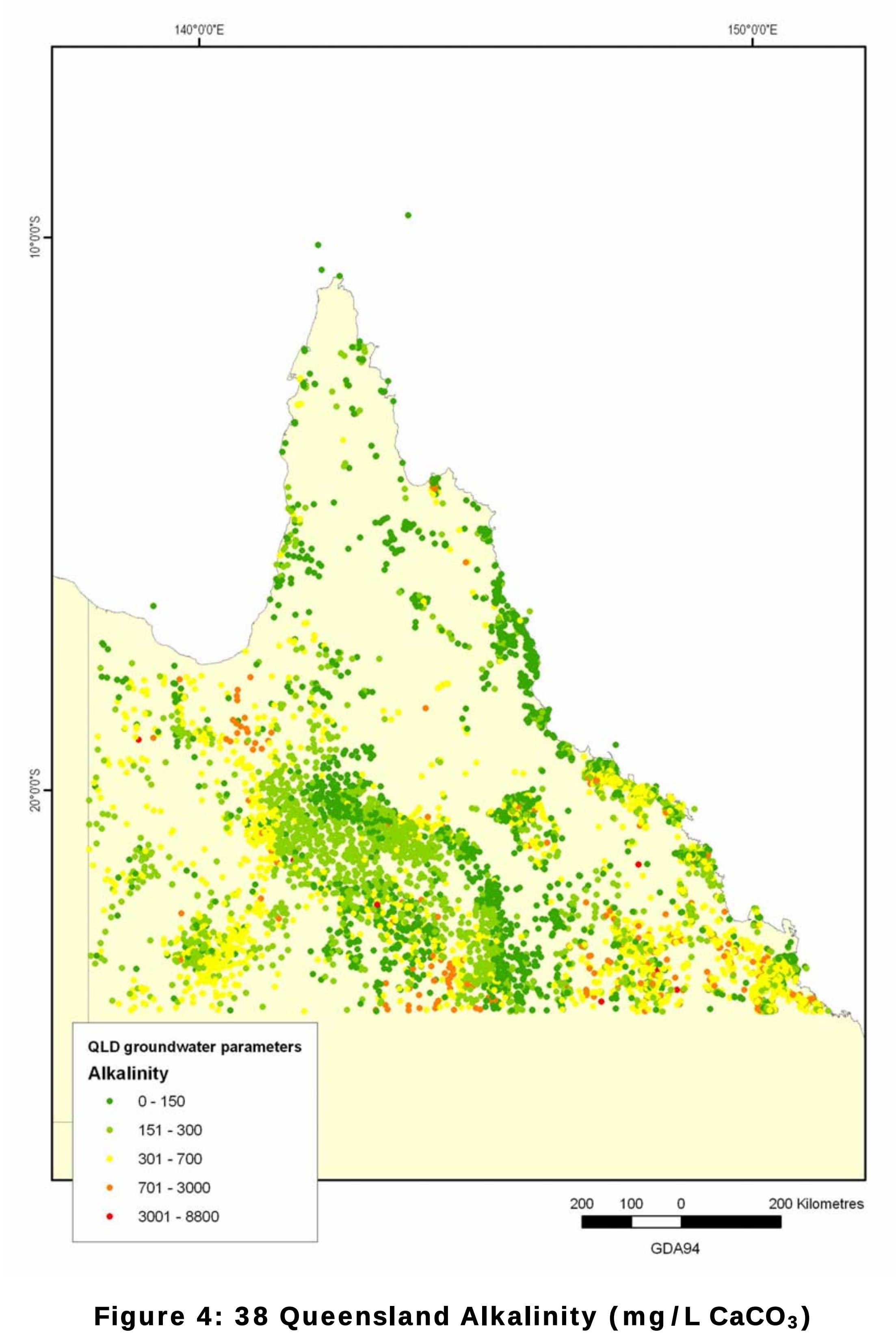

Figure 4: 38 Queensland Alkalinity (mg/L $CaCO_3$)

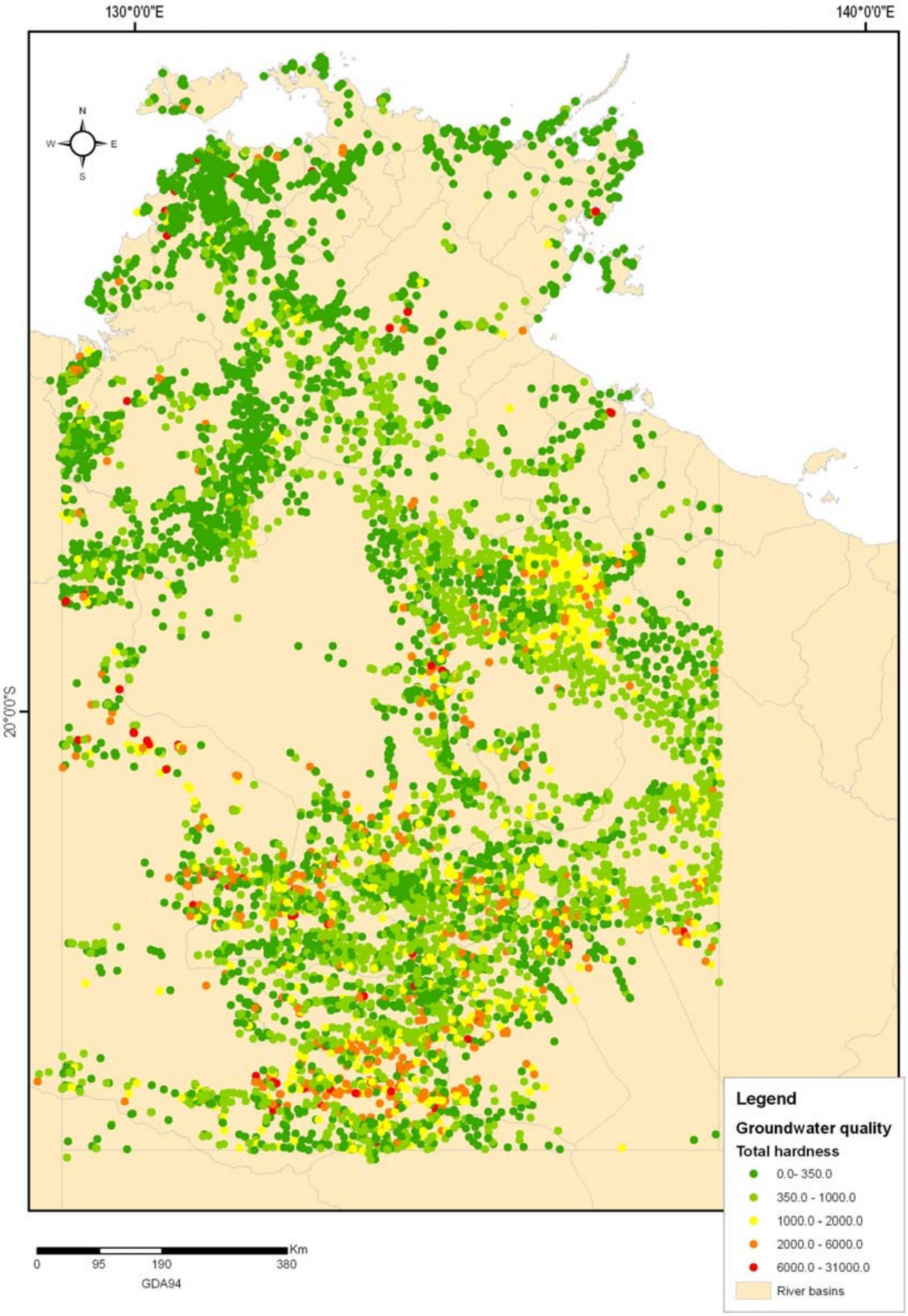

Figure 4: 39NT Total Hardness (mg/L $CaCO_3$)

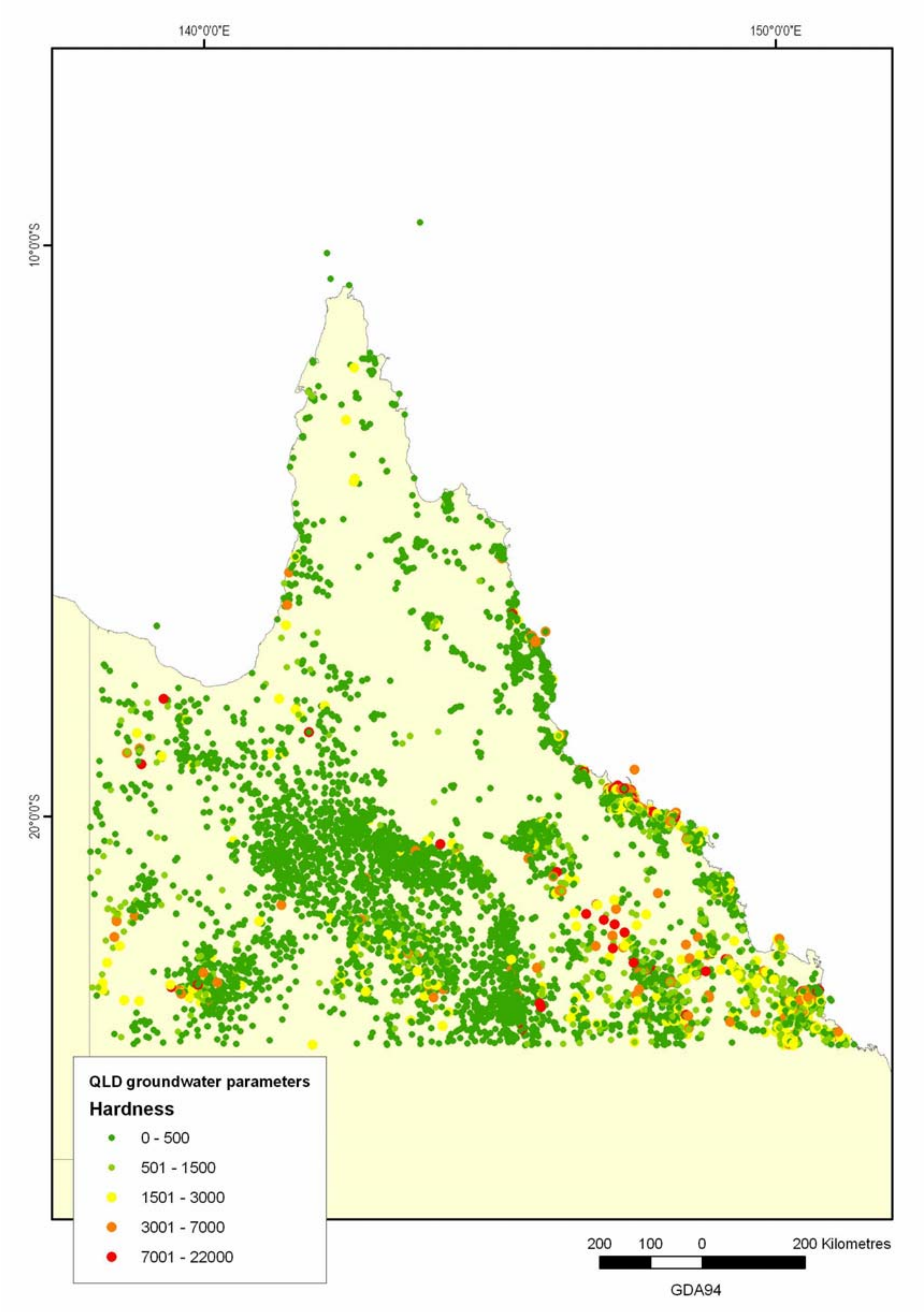

Figure 4: 40 Queensland Total Hardness (mg/L $CaCO_3$)