Alberta Domestic Well Water Quality Monitoring and Assessment Program

Domestic Well Water Quality in Regions of Alberta

Physical & Chemical Testing

2014

Alberta Government

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EXECUTIVE SUMMARY

Under the framework of the Alberta *Water for Life Strategy* initiative to ensure safe drinking water for all Albertans, Alberta Health initiated a domestic well water quality monitoring and human health assessment program in 2009. The first project was a review of the domestic well quality in all regions of Alberta between 2002 and 2008. The second project was a follow-up domestic well water quality monitoring and human exposure assessment in the Beaver River Basin region.

The third project involved selecting a total of eleven regions in Alberta for domestic well water quality monitoring in 2010 and 2011. The objectives of this survey included:

1. assessing long-term suitability of domestic well water quality for well owners by monitoring physical properties and chemical concentrations in raw and treated domestic well water samples and comparing the chemical levels to both aesthetic quality-based and health-based guidelines;
2. assisting well owners to improve well water quality by providing them with the information about well maintenance and water treatment strategies; and
3. building information and a better understanding of domestic well water quality in selected regions of the province.

The major findings are:

1. overall water quality, measured by using the indicators of pH, alkalinity, conductivity and total dissolved solids, was similar to the provincial average level;
2. sulfate was relatively higher than the provincial average level;
3. hardness of water was classified as “very hard water” in some regions and “soft water” in other regions;
4. levels of fluoride were similar to those across Alberta;
5. nitrate levels exceeding the health-based guideline were observed in certain regions, particularly in the Southern Alberta;
6. fifty five per cent of private well owners treated raw water for household use, including for human consumption;
7. levels of aluminum, arsenic, barium, cadmium, chromium, lead, molybdenum, selenium, and uranium were under the guideline values in 93 per cent of raw water samples; and
8. after treatment, a significant reduction of levels alkalinity, conductivity, hardness, calcium, magnesium, carbonate, bicarbonate, sulfate, iron, fluoride, barium, manganese and titanium, was found.

The recommendations are that:

1. private well owners continue to contact Alberta Health Services to test the well water quality regularly, and
2. local public health officers in Alberta Health Services will routinely discuss well water quality, testing schedule, testing results, treatment methods, well maintenance, well protection and health concerns with private well owners.

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List of Abbreviations and Glossary

$CaCO_3$	Calcium carbonate
EC	Electrical Conductivity
TDS	Total Dissolved Solid
Ca	Calcium
Mg	Magnesium
K	Potassium
HCO_3	Bicarbonate
CO_3	Carbonate
Cl	Chloride
Na	Sodium
SO_4	Sulfate
Fe	Iron
F	Fluoride
NO_3	Nitrate
NO_2	Nitrite
Al	Aluminum
Sb	Antimony
As	Arsenic
Ba	Barium
B	Boron
Cd	Cadmium
Cr	Chromium
Co	Cobalt
Cu	Copper
Pb	Lead
Mn	Manganese
Hg	Mercury
Mo	Molybdenum
Ni	Nickel
Se	Selenium
Ag	Silver
Tl	Thallium
Ti	Titanium
U	Uranium
V	Vanadium
Zn	Zinc
GCDWQ	Guidelines for Canadian Drinking Water Quality
GIS	Geographic information systems
GPS	Global Positioning System
HC	Health Canada
HPLC	High Performance Liquid Chromatograph
IC	Ion Chromatograph
ICPMS	Inductively Coupled Plasma Mass Spectrometer
LOQ	Limit of Quantitation
ORS	Octopole reaction system
PEEK	Polyetheretherketone
PET	Polyethylene terephthalate
PP	Polypropylene
QC	Quality control
SPSS	Statistical Package for the Social Sciences

1. INTRODUCTION

Under the framework of the *Alberta Water for Life Strategy* to ensure safe drinking water for all Albertans, Alberta Health initiated a domestic well water quality monitoring and human health assessment program in Alberta in 2009. The first project entitled “Domestic Well Water Quality – Characterization, Physical and Chemical Testing 2002 and 2008” was completed in 2010 (AH 2013). The average levels of chemicals and spatial patterns in domestic well water across Alberta were reported based on 2002–2008 data. The second project, also completed in 2010, was a follow-up domestic well water quality monitoring and human exposure assessment in the Beaver River Basin region.

The information generated by these first two projects provided the basis for identifying the regions and potential public health issues for monitoring and human exposure assessment activities for the third project.

Conducted in selected regions in Southern/Central Alberta and the Peace River basin area of Northern Alberta, where more intensive agricultural activities are present, the objectives of the third project included:

1. assessing long-term suitability of domestic well water quality for well owners by monitoring physical properties and chemical concentrations in raw and treated domestic well water samples and comparing the chemical levels to both aesthetic quality-based and health-based guidelines;
2. collecting information on drinking water consumption patterns;
3. assisting well owners to improve well water quality by providing them with the information about well maintenance and water treatment strategies to domestic well owners; and
4. building information and a better understanding of domestic well water quality in specific regions of the province.

In this report, the results are discussed based on:

1. levels of physical properties and chemicals in the raw and treated water samples;
2. changes in chemical levels before and after water treatment in relation to treatment methods used;
3. amount and patterns of water consumption; and
4. well maintenance.

2. METHODS AND MATERIALS

2.1 Questionnaires

Criteria for Well Selection

The criteria for selection of the domestic wells were the regions with intensive livestock activities and use of fertilizers and pesticides.

Recruitment

The technicians conducted an initial telephone interview to potential, eligible participants to explain the purposes of the survey, and identify whether or not the well owners were willing to participate in the survey. Appointments for home visits were made after the owners agreed to participate in the survey.

Site-Visit Questionnaire

During the home visit, the information letter and consent form were reviewed and signed by the participant and technician. The in-person interview was conducted in order to collect the following information:

1. previous water testing results if available;
2. well identification number, well depth, well maintenance and protection;
3. well water treatment methods;
4. sources of water used for human drinking (e.g. tap water or bottled water; and
5. amount and patterns of water consumption.

2.2 Field Collection

For Routine and Trace Element Testing

Six or eleven well water samples per household or eleven well water samples per household were collected depending on the well water treatment status. If owners use raw well water as drinking water, five kitchen tap water samples per household were collected plus one stabilized sample from the well head. If owners treated their well water for drinking, five kitchen tap water samples (treated well water) and five raw well water samples taken from the well head per household were collected plus one stabilized sample from the well head.

For Pesticide Testing and Bacteria Testing

In some regions, one additional raw water sample per household was collected for pesticide testing. The sample bottles were prepared by Alberta Centre for Toxicology.

In some regions, one additional raw water sample per household was collected for bacteria testing. The sample bottles were prepared by the Alberta Provincial Public Health Laboratory for Microbiology.

Sample Collection for Routine, Trace Element and Pesticide Analysis

All collection supplies: requisition forms, sample labels, 500-mL polyethylene terephthalate (PET) bottles, 125 mL amber glass bottles with polytetrafluoroethylene lined plastic caps, tri-wall plain Ziplock bags and ampoules of 5-mL 70% nitric acid with plastic ampoule breakers were provided by the Alberta Centre for Toxicology for all sample collections. All lots of collections bottles were verified to be free of contamination for routine analyses and trace elements.

Raw water samples were collected from the *kitchen tap* if the water was *not treated*. Raw water samples were collected from the *hosebibs* prior to treatment or *well head* if the water was *treated*. After purging for 5 minutes, each sample was collected. The first sample was collected in a 500-ml PET bottle without adding nitric acid for routine chemical analysis. The second sample was immediately preserved with 5 mL nitric acid in a 500-ml PET bottle for trace element analysis. The third sample was collected in 125 mL amber glass bottles for pesticide analysis.

The bottles were tightly capped and inverted several times to completely mix the sample. The technician filled out a standard requisition form. The bottle was properly labeled for routine chemical analysis and trace metal analysis with a unique sample identification number.

Sample Collection for Arsenic Species

A third set of samples, raw and treated, was taken to assess the species of As in the water. Acetic acid and EDTA were used as preservatives and were added to the sampling bottles to reach final concentrations of 87 mM acetic acid and 1.34 mM EDTA. Two 250-mL polypropylene (PP) bottles, each containing 10.8 mL of 2.0 M acetic acid and 3.35 mL of 0.1 M EDTA solutions, were supplied to each sampling site. All treated water samples were taken from the kitchen tap. Water samples were also collected from kitchen tap if the water was not treated. If the water was treated, raw water samples were collected from the hosebibs or well head. After purging for 5 minutes, each sample was collected in 250-mL PP bottles.

Sample Transportation

All the samples were kept at 4°C in the refrigerator prior to shipping. Routine and trace element samples were packed in the cooler and shipped through the regional public health offices to the Alberta Centre for Toxicology in Calgary via over night courier. Arsenic species samples were packed in the cooler and shipped through the Provincial Public Health Laboratory for Microbiology to the Analytical and Environmental Toxicology Division at the University of Alberta in Edmonton.

2.3 Laboratory Analysis

Routine Physical and Chemical Analysis

The pH was determined with a pH probe. A set of calibrators and quality controls (QCs) were run before and after each batch.

Alkalinity was determined using an auto titration system (PC-Titrate, Man-Tech Associates Inc) in conjunction with a conductivity electrode and pH electrode. (USEPA method 310.1 – the Titrimetric method). A set of calibrators and QCs were run before and after each batch. Results were expressed as (mg/L) $CaCO_3$ which is a convention used for convenience of reporting but which otherwise has no chemical meaning or interpretation.

Total hardness was determined from the concentrations of calcium and magnesium as determined by ICP-MS. Results were expressed as an equivalent concentration of $CaCO_3$, which is a convention used for convenience of reporting but which otherwise has no chemical meaning or interpretation.

Carbonate (CO_3) and bicarbonate (HCO_3) were calculated from the pH titration results and were transformed automatically to alkalinity as $CaCO_3$.

Electrical conductivity (EC) was determined using the auto titration system (PC-Titrate, Man-Tech Associates Inc) in conjunction with a conductivity electrode and pH electrode. A set of calibrators and QCs was run before and after each batch.

The determination of total dissolved solids (TDS) was performed by ICPMS, PC-Titrate and IC, and calculated from the concentrations of the cations (positively charged) and anions (negatively charged) in the water sample. This calculation procedure is commonly used for freshwater where TDS is relatively low, but the absolute measure of TDS is based on filtering a water sample to remove any suspended matter, followed by evaporation of the water and measurement of the resulting dried residue.

Nitrate is the most completely oxidized form of nitrogen. Nitrate/nitrite concentrations were determined using the Metrohm 761 Ion Chromatograph (IC) in conjunction with a chemical suppressor and conductivity detector. The results in this report are expressed as the mg of nitrogen present in either nitrate or nitrate.

Trace Element Analysis

Analysis of trace elements was performed on the Agilent 7500c Inductively Coupled Plasma Mass Spectrometer (ICP-MS) with Octopole Reaction System (ORS). The sample was delivered by peristaltic pump directly into the ICP_MS through a MicroFlow PFA-100 nebulizer. The sample aerosol was then ionized by the argon plasma source. When the ions entered the ORS, they interacted with the reaction gas (either hydrogen or helium), resulting in a reduction of any molecular interference. The ions were focused into a quadrupole mass analyzer and separated based on their mass/charge ratio.

Method for Arsenic Species Analysis

Arsenic species analysis in water was performed by using HPLC-ICP MS.

Arsenic species in water samples were quantified using high performance liquid chromatography (HPLC) separation with inductively coupled plasma mass spectrometry (ICPMS) detection. An Agilent 1100 series HPLC system was coupled with Agilent 7500cs octopole ICPMS system (Agilent Technologies, Japan). The ICP was operated at a radio frequency power of 1550 W, and the argon carrier gas flow rate was 0.9 –1.0 L/min. The ICPMS was operated with helium mode, and the introduction of helium (3.5 mL/min) to the octopole reaction cell was to reduce isobaric and polyatomic interferences. Arsenic was monitored at m/z 75.

Chromatographic separation of inorganic arsenite (AsIII) and arsenate (AsV) was achieved on a reversed-phase ODS-3 column (Phenomenex, 30×4.6 mm, 3-µm particle size) with an ODS guard cartridge (4×3 mm). The column was placed inside a column temperature compartment, which was maintained at 50°C. The aqueous mobile phase contained 5 mM tetrabutylammonium hydroxide, 5% methanol and 3 mM malonic acid (pH 5.65), and its flow rate was 1.2 mL/min. An aliquot of 50 µL water samples was injected for analysis. The effluent from the HPLC column was directly introduced into the nebulizer of the ICPMS system using a polyetheretherketone (PEEK) tubing. Chromatograms from HPLC separation and IC_MS detection were recorded and processed using the ChemStation software (Agilent Technologies, Santa Clara, CA).

A standard reference material SRM1640 Trace Elements in Natural Water (from National Institute of Standards and Technology, Gaithersburg, MD) was used for QC. The method detection limits for both AsIII and AsV were 0.0001 mg/L.

<u>Pesticide Analysis</u>

Pesticide analysis was performed by using an Agilent 6410 liquid chromatograph triple quadrupole mass spectrometer (LC-MS/MS) with electrospray ionization (ESI) source, and an Agilent 6890 gas chromatograph single quadrupole mass spectrometer (GC-MS) with electron impact ionization (EI) source. Both methods employ multiple reaction monitoring (MRM), a tandem mass spectral detection technique whereby a specific analyte mass-to-charge ratio (m/z) was selected in the first quadrupole, the selected ions fragmented in the second quadrupole, and a specific fragment ion m/z selected in the third quadrupole. Nitrogen was used as the collision gas, and two MRM transitions were monitored for each analyte. For all methods, the retention times and intensity ratios of the ions/transitions monitored were used for positive analyte identification.

2.4 GIS Mapping

The coordinates for every well were stored as GPS coordinates (collected in the field) and legal land descriptions. The coordinates were loaded into a GIS (Manifold GIS v8), along with the legal land description boundaries to check for discrepancies between the two data sources. No major discrepancies were found in the GPS coordinates vs legal land descriptions. The coordinates of the centre of the quarter section were used in those instances where these coordinates were not collected with a GPS.

All maps were created using Canvas+GIS v11. The location of each well is shown in the approximate location as some were moved slightly to remain visible in the final maps.

Two sets of maps were produced: one set for raw (untreated) water and the second set for treated water. Comparisons of the raw and treated water map for a particular test provide a visual illustration of the effects of water treatment for the parameter selected. The classification scheme was consistent for each parameter for both raw and treated water.

Some of the parameters tested have corresponding a Guidelines Canadian Drinking Water (GCDWQ) value that provides context of values that should not be exceeded for personal water consumption, commonly based on lifetime consumption. This means that modest (up to 10x), short term (days to months) exceedance of a GCDWQ health-based value does not pose a substantial health risk. Maps of parameters with corresponding guidelines are shown using a maximum of four categories: green colours highlight wells with results below guidelines and orange/red highlight wells with results above guidelines for a particular parameter. Dark green was used to show values substantially below guidelines, light green those just below guidelines, orange those just above guidelines, and red substantially above guidelines. The values used for creating these categories appear in the corresponding legends of the maps. Some maps show fewer categories according to the data distribution characteristics.

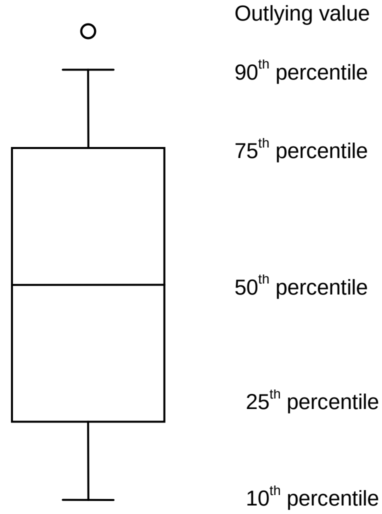
For those parameters without GCDWQ values, the mapping technique was based on the distribution characteristics of the data. Three different scenarios were encountered:

1. If all values were less than detected limits, all sites were shown using a single colour indicating that all sites were below detected limits;
2. If the median was less than detected limits but not all values were less than detected limits, the maps showed sites below and above detection. Two colours were used to identify sites below detected limits and values above detected limits; and
3. If the median was greater than detected limits, the mapping categories were the median, and 50% of the median above and below the median. For example, with a median of 0.002, the class breaks were 0.001 (0.002 – 0.001), 0.002 (median), and 0.003 (0.002 + 0.001), where 0.001 is 50% of the value of the median.

2.5 Statistical Analysis

The statistical analysis was performed by using SPSS (Version17) package. The distribution of each parameter was found to not fit a normal (Gaussian) distribution. The distributions were generally right -skewed (except for pH) meaning that the distribution showed an extended tail for higher values to the right of the median. This characteristic is also evident when the mean substantially exceeds the median. For a normal distribution these two measures would be equal. Right–skewed distributions are commonly found with environmental data. The statistical summaries were performed for mean, median, standard deviation, minimum value, maximum value, and the 10^{th}, 25^{th}, 75^{th}, 90^{th} percentile values.

A box plot was used to demonstrate the changes of chemical levels before and after treatment. A box plot is a summary plot that plots data as a box representing statistical values. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median (50^{th} percentile), and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. The dots outside the box indicate outlying values below 10% or above 90%.



2.6 Interpretation

Virtually any chemical substance has some solubility in water, making water essentially a universal solvent. One liter of pure water contains more than >33,000,000,000,000,000,000,000,000 (3.3×10^{25}) molecules of water. The most sensitive detection limit for any chemical mentioned in this report (0.0001 mg/L for zinc) corresponds to more than 920,000,000,000,000 atoms of zinc which could be present and still report as non-detectable. Clearly, being non-detectable (i.e. less than the Limit of Quantitation, see section 3.2) does not mean that there is no zinc in a liter of water, i.e. non-detectable is not zero. This reality does not mean that there is a cause for health concern because there can be immeasurably small quantities of chemicals in water. What always matters is how much of a chemical is present relative to the amount necessary to cause a health effect. The process of setting a health-based GCDWQ for a chemical is about estimating, normally with a high degree of caution, how little of a substance in drinking water might pose a health concern.

3. RESULTS AND DISCUSSION

3.1 Selected Regions

Eleven regions with agricultural activities in Alberta were selected (Figure 1):

1. Bragg creek
2. Cardston
3. Edmonton region
4. Grande Prairie
5. Lethbridge
6. Carstairs
7. Peace River
8. Red Deer
9. Stettler
10. Stavely
11. Vermillion

The land formation of the sampling sites is illustrated in Figure 2.

3.2 Sample Summary

A total of 397 domestic well sites were selected. The wells were drilled between 1940 and 2011. The well depth was 47 m on average and 40 m on median with a range of 2 – 160 m. The levels of all chemicals tested were not correlated with the well depth ($p > 0.05$). All wells except for five wells marked as unknown were tested for chemicals before this survey. Among these wells (2 with unknown), 179 well owners used raw water and 216 well owners used treated water for household use. The summary of sample size is shown below (note: there were repeated samples in some of the same wells):

Region	Routine		Trace Element		Pesticide	Bacteria
	Raw	Treated	Raw	Treated	Raw	Raw
Bragg creek	30	21	30	22		30
Cardston	31	16	31	16		
Edmonton	56	30	56	29		56
Grande Prairie	49	28	49	29		
Lethbridge	3	2	3	2		
Carstairs	32	15	32	15		32
Peace River	29	18	26	18		
Red Deer	51	25	50	26	50	
Stettler	31	21	31	21	30	
Stavely	44	14	44	14		44
Vermillion	41	25	41	25		
Total	**398**	**215**	**397**	**217**	**80**	**162**

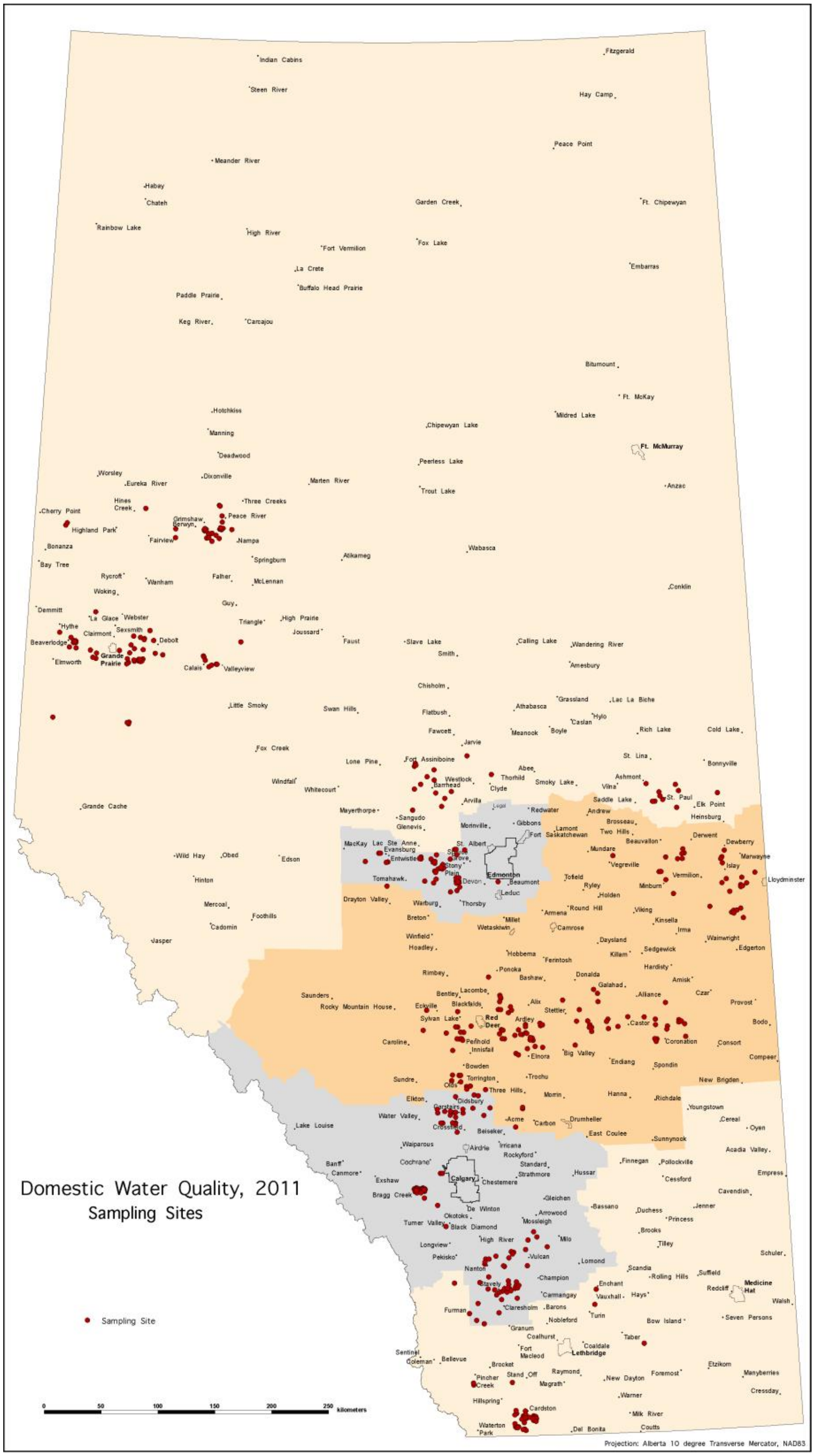


Figure 1 Location of the Sampling Sites

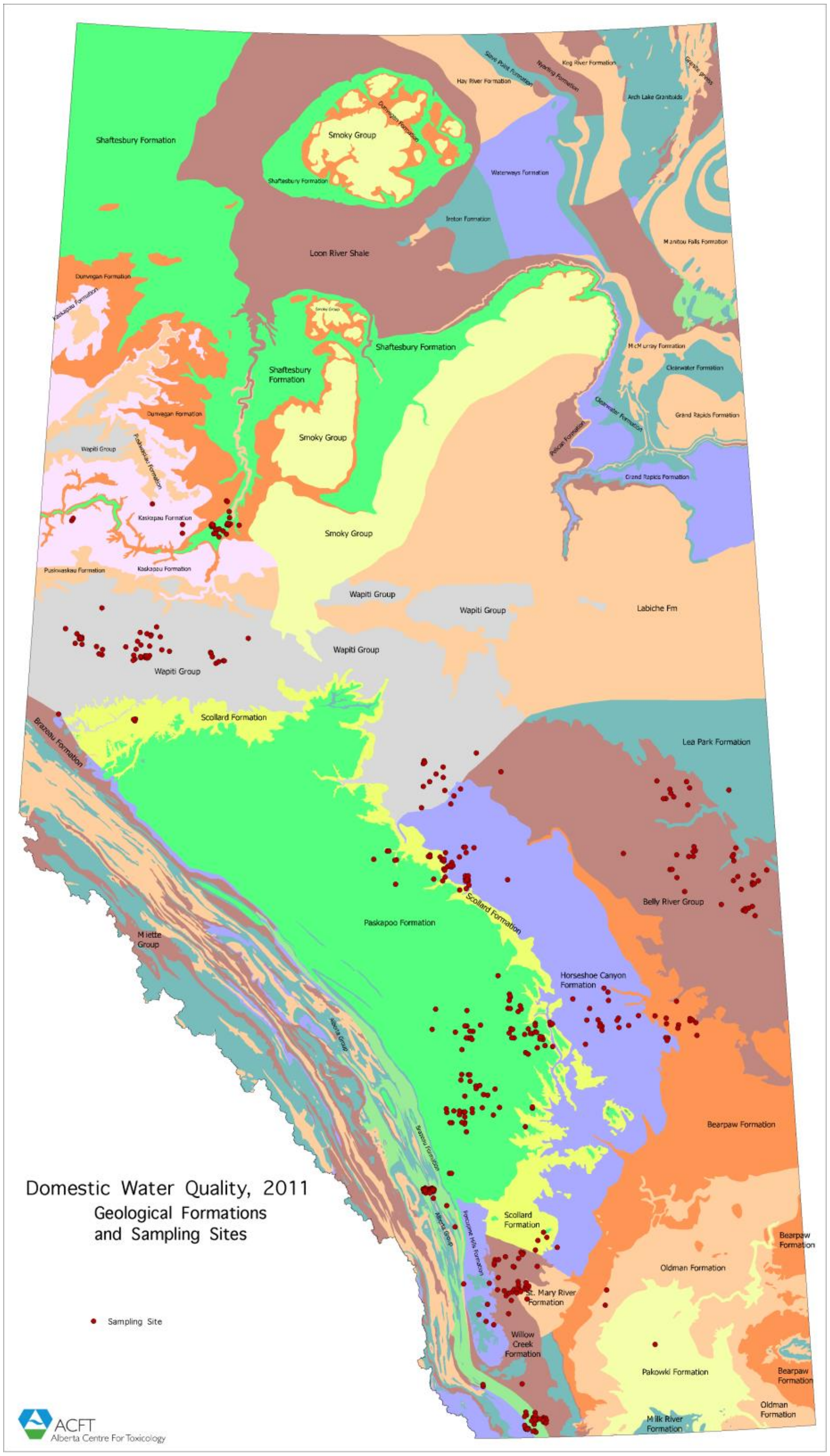


Figure 2 Location of Sampling Sites and Land Formation Types

Types of treatment methods in 205 houses (the paired water samples (before and after treatment) are shown below:

Treatment Method	Number of House	% of Total House
Softener	116	54
Iron filter	68	31
Carbon filter	21	10
Reverse osmosis	61	61
Distiller	17	8
Chlorinator	13	6
Other methods	41	19
1 treatment methods	131	60
2 treatment methods	64	30
3 treatment methods	21	10

There is no universal treatment process that will remove all chemicals from water, although distillation or reverse osmosis will generally remove a substantial fraction (never 100 per cent) of chemicals dissolved in water. Other treatment processes such as softeners or iron filters are designed for removal of specific groups of chemicals, hardness ions in the case of softeners and iron or manganese in the case of iron filters. Such targeted treatment devices may have negligible removal capability for other chemicals. Carbon filters are primarily designed to remove organic chemicals (e.g. pesticides, hydrocarbons), but may adsorb some inorganic chemicals to a minor degree. A chlorinator is primarily to provide disinfection of microbial pathogens and/or to oxidize nuisance chemicals causing taste and odour or iron / manganese to make them less soluble and possible to remove by filtration.

The summary information of raw and treated water samples are listed in Table 1 and 2 for routine testing, Table 3 and 4 for trace element testing, and Table 5 for pesticide testing. The reported detection levels are described as “Limits of Quantitation” (LOQ). The LOQ means the lowest levels of physical parameters and chemicals that can be measured in concentration units using the specified laboratory instruments and analysis methods. The units are mg/L (milligram of chemical per liter of water solution) for all parameters except for conductivity expressed as μS/cm at 25 °C and pH which has no units. The ion balances were within ± five per cent. These units are approximately equivalent to parts per million (ppm, grams of chemical per million grams of water solution).

Alkalinity, pH, conductivity, TDS, bicarbonate, hardness, calcium, sodium, and potassium were detected in all raw samples. Alkalinity, pH, conductivity, TDS, bicarbonate, and hardness were detected in all the treated samples. These findings are as would be expected.

Aluminum, barium, boron, manganese, and zinc were detected in over 80 per cent of the raw water samples. Aluminum, boron, and zinc were detected in over 80 per cent of the treated water samples. Beryllium, mercury and thallium were not detected in any of the raw and treated water samples.

Forty one of out of 42 pesticides were not detected in raw water samples. Clopyralid (herbicide) was detected in one sample.

Table 1 Sample Information in Raw Water – Routine Testing

	Sample Size	% of Reported Detection	Reported Detection Level	Unit
pH	398	100	-3 to 14	no unit
Alkalinity (as $CaCO_3$)	398	100	0.3	mg/L
Electrical Conductivity	398	100	1.87	µS/cm
Total Dissolved Solids	398	100	5.11	mg/L
Hardness (as $CaCO_3$)	398	100	0.66	mg/L
Calcium (as Ca)	398	100	0.1	mg/L
Magnesium (as Mg)	398	99	0.1	mg/L
Potassium (as K)	398	100	0.1	mg/L
Bicarbonate (as $CaCO_3$)	398	100	0*	mg/L
Carbonate (as $CaCO_3$)	398	56	0*	mg/L
Chloride (as Cl)	398	93	1.0	mg/L
Sodium (as Na)	398	100	1.0	mg/L
Sulfate (as SO_4)	398	94	1.0	mg/L
Iron (as Fe)	398	82	0.01	mg/L
Fluoride (as F)	398	93	0.1	mg/L
Nitrate (as N)	398	33	1.0	mg/L
Nitrite-N (as N)	398	7	0.1	mg/L

* value based on the detection limit for total alkalinity of 1ppm.

Table 2 Sample Information in Treated Water – Routine Testing

	Sample Size	% of Reported Detection	Reported Detection Level	Unit
pH	215	100	-3 to 14	no unit
Alkalinity (as $CaCO_3$)	215	100	0.3	mg/L
Electrical Conductivity	215	100	1.87	µS/cm
Total Dissolved Solids	215	100	5.11	mg/L
Hardness (as $CaCO_3$)	215	99	0.66	mg/L
Calcium (as Ca)	215	77	0.1	mg/L
Magnesium (as Mg)	215	64	0.1	mg/L
Potassium	215	82	0.1	mg/L
Bicarbonate (as $CaCO_3$)	215	100	0*	mg/L
Carbonate (as $CaCO_3$)	215	35	0*	mg/L
Chloride	215	79	1.0	mg/L
Sodium	215	94	1.0	mg/L
Sulfate	215	83	1.0	mg/L
Iron	215	37	0.01	mg/L
Fluoride	215	66	0.1	mg/L
Nitrate (as N)	215	31	1.0	mg/L
Nitrite-N (as N)	215	2	0.1	mg/L

* value based on the detection limit for total alkalinity of 1ppm.

Table 3 Sample Information in Raw Water – Trace Element Testing

	Sample Size	% of Samples Reporting Detection	Reported Detection Level	Unit
Aluminum	397	100	0.001	mg/L
Antimony	397	3	0.001	mg/L
Arsenic	397	27	0.001	mg/L
Barium	397	99	0.001	mg/L
Beryllium	397	0	0.001	mg/L
Boron	397	100	0.01	mg/L
Cadmium	397	0.5	0.001	mg/L
Chromium	397	2	0.001	mg/L
Cobalt	397	4.5	0.001	mg/L
Copper	397	75	0.001	mg/L
Lead	397	17	0.001	mg/L
Manganese	397	91	0.001	mg/L
Mercury	397	0.3	0.001	mg/L
Molybdenum	397	63	0.001	mg/L
Nickel	397	22	0.001	mg/L
Selenium	397	16	0.001	mg/L
Silver	397	0	0.001	mg/L
Thallium	397	0	0.001	mg/L
Titanium	397	56	0.001	mg/L
Uranium	397	38	0.001	mg/L
Vanadium	397	0.3	0.001	mg/L
Zinc	397	95	0.0001	mg/L

Table 4 Sample Information in Treated Water - Trace Element Testing

	Sample Size	% of Samples Reporting Detection	Reported Detection Level	Unit
Aluminum	217	100	0.001	mg/L
Antimony	217	2	0.001	mg/L
Arsenic	217	17	0.001	mg/L
Barium	217	59	0.001	mg/L
Beryllium	217	0	0.001	mg/L
Boron	217	99	0.01	mg/L
Cadmium	217	0.5	0.001	mg/L
Chromium	217	0.5	0.001	mg/L
Cobalt	217	1.4	0.001	mg/L
Copper	217	71	0.001	mg/L
Lead	217	13	0.001	mg/L
Manganese	217	55	0.001	mg/L
Mercury	217	0	0.001	mg/L
Molybdenum	217	38	0.001	mg/L
Nickel	217	16	0.001	mg/L
Selenium	217	9	0.001	mg/L
Silver	217	2	0.001	mg/L
Thallium	217	0	0.001	mg/L
Titanium	217	36	0.001	mg/L
Uranium	217	23	0.001	mg/L
Vanadium	217	0.04	0.001	mg/L
Zinc	217	88	0.0001	mg/L

Table 5 Sample Information in Raw Water - Pesticide Testing

	Sample Size	% of Samples Reporting Detection	Reported Detection Level	Unit
2,4-D	80	0	0.005	mg/L
2,4-DB	80	0	0.0075	mg/L
2,4-DP	80	0	0.005	mg/L
bromoxynil	80	0	0.001	mg/L
clopyralid	80	1.3	0.0075	mg/L
dicamba	80	0	0.009	mg/L
diclofop methyl	80	0	0.001	mg/L
Imazamethabenz methyl	80	0	0.005	mg/L
imazethapyr	80	0	0.005	mg/L
MCPA	80	0	0.005	mg/L
MCPB	80	0	0.005	mg/L
MCPP	80	0	0.005	mg/L
2,4-dichlorophenol	80	0	0.0003	mg/L
quinclorac	80	0	0.0075	mg/L
picloram	80	0	0.0075	mg/L
pentachlorophenol	80	0	0.003	mg/L
2,4,6-trichlorophenol	80	0	0.0003	mg/L
2,3,4,6-tetrachlorophenol	80	0	0.0003	mg/L
aldicarb	80	0	0.001	mg/L
aldicarb sulfone	80	0	0.004	mg/L
aldicarb sulfoxide	80	0	0.001	mg/L
atrazine	80	0	0.0005	mg/L
atrazine desethyl	80	0	0.001	mg/L
atrazine desisopropyl	80	0	0.001	mg/L
azinphos methyl	80	0	0.001	mg/L
bendiocarb	80	0	0.004	mg/L
bromacil	80	0	0.001	mg/L
carbaryl	80	0	0.005	mg/L
carbofuran	80	0	0.005	mg/L
chlorpyrifos	80	0	0.0005	mg/L
cyanazine	80	0	0.001	mg/L
diazinon	80	0	0.001	mg/L
dimethoate	80	0	0.001	mg/L
diuron	80	0	0.005	mg/L
malathion	80	0	0.005	mg/L
metolachlor	80	0	0.001	mg/L
metribuzin	80	0	0.005	mg/L
parathion	80	0	0.005	mg/L
phorate	80	0	0.0005	mg/L
simazine	80	0	0.001	mg/L
terbufos	80	0	0.0005	mg/L
trifluralin	80	0	0.0005	mg/L

3.3 Routine Testing

A statistical summary of physical properties and major/minor ions performed in the routine testing for the raw water samples is listed in Table 6. Characteristics for each parameter are discussed in the following sections.

In order to assess the suitability of domestic well water, some cut-off values were recommended by Health Canada (see the relevant documents in the *Guidelines for Canadian Drinking Water Quality*) such as

1. health-based guidelines,
2. aesthetic_quality_based guidelines,
3. optimal levels of fluoride in drinking water for health benefits,
4. classification of water hardness, and
5. taste classification for TDS.

The percentages of the tested raw water samples fitting these cut-off values (under, between or over) are listed in Table 7.

Table 6 Statistical Summary of Major Ions

Parameter*	Type	Mean	Median	Min	Max	SD
pH	Raw	8.3	8.3	7.2	9.4	0.3
	Treated	8.0	8.2	5.9	9.2	0.7
Alkalinity	Raw	503	456	69	1841	222
	Treated	326	333	0.7	1211	269
Electrical Conductivity	Raw	1493	1299	153	7860	879
	Treated	1026	840	2	8390	1091
TDS	Raw	933	774	83	7043	664
	Treated	633	484	1.2	6434	757
Hardness	Raw	226	123	1.35	3580	321
	Treated	93	6	<0.66	2553	226
Calcium	Raw	54	31	0.38	473	66
	Treated	21	1.7	<0.1	323	40
Magnesium	Raw	22	11	<0.1	599	42
	Treated	10	0.4	<0.1	424	33
Bicarbonate	Raw	589	549	84	2185	255
	Treated	385	404	0.9	1341	313
Carbonate	Raw	12	4.8	nd	73	16
	Treated	6	nd	nd	67	12
Chloride	Raw	37	6	<1.0	750	93
	Treated	29	3.3	<1.0	604	81
Sodium	Raw	263	249	2.3	1257	207
	Treated	196	119	<1.0	1794	231
Sulfate	Raw	249	106	<1.0	4301	415
	Treated	168	29	<1.0	3674	386
Potassium	Raw	3.3	1.9	0.3	67	5.0
	Treated	12	1.2	<0.1	617	61
Iron	Raw	0.7	0.06	<0.01	64	3.6
	Treated	0.1	<0.01	<0.01	6.5	0.5
Fluoride	Raw	0.74	0.4	<0.1	5.7	0.9
	Treated	0.34	0.2	<0.1	3.2	0.6
Nitrate-N	Raw	1.8	<1.0	<1.0	81	6.7
	Treated	1.4	<1.0	<1.0	67	6.4
Nitrite-N	Raw	0.02	<0.01	<0.01	3.6	0.2
	Treated	0.01	<0.01	<0.01	1.6	0.1

* Unit for each parameter: see Table 1 and 2. nd=non-detected

Table 7 Guideline Compliances – Major Ions

Parameter	Cut-off Value (mg/L)	Per Cent	Value Definition
Fluoride	> 1.5	15	Above HC – Health
	> 2.4	6.8	Above AENV – Health
	0.7	3.0	Optimal level
	< 0.7	64	Below Optimal level
Nitrate - N	>10	5.3	Above HC – Health
Nitrite - N	>1.0	0.3	Above HC – Health
pH	6.5 – 8.5*	64	Within HC – aesthetic
	8.5 – 9.0	36	causing Moderate alkaline
	<6.5	0	Causing Acid – Corrosive
	>9.0	1.0	Causing Alkaline – scaling
Chloride	> 250	4.0	Above HC – aesthetic
Sodium	> 200	58	Above HC – aesthetic
Sulfate	> 500	15	Above HC – aesthetic
Total Dissolved Solids **	> 500	79	Above HC – aesthetic
	< 300	3.3	Taste – excellent
	300 – 600	29	Taste – good
	600 – 900	28	Taste – fair
	900 – 1200	18	Taste – poor, salty
	>1200	22	Taste-unacceptable
Iron	> 0.3	24	HC – aesthetic
Hardness	≤ 60	42	Soft water
	60 – 20	7.5	Medium hard water
	120 –180	6.3	Hard water
	> 180	44	Vary hard water
	80 – 100	3.0	Optimal level

* no unit; HC -Health = health-based guideline by Health Canada; HC – aesthetic-based guideline by Health Canada; AENV -Health = health-based standard by Alberta Environment; Optimal level = optimal level for dental health.

** Health Canada (1991) **"**The palatability of drinking water has been rated, by panels of tasters, according to TDS level as follows: excellent, less than 300 mg/L; good, between 300 and 600 mg/L; fair, between 600 and 900 mg/L; poor, between 900 and 1200 mg/L; and unacceptable, greater than 1200 mg/L. Rationales are (1) the most important aspect of TDS with respect to drinking water quality is its effect on taste. The palatability of drinking water with a TDS level less than 600 mg/L is generally considered to be good. Drinking water supplies with TDS levels greater than 1200 mg/L are unpalatable to most consumers; (2) concentrations of TDS above 500 mg/L result in excessive scaling in water pipes, water heaters, boilers and household appliances; and (3) an aesthetic objective of ≤ 500 mg/L should ensure palatability and prevent excessive scaling. However, it should be noted that at low levels TDS contributes to the palatability of drinking water. "

3.3.1 pH and Alkalinity

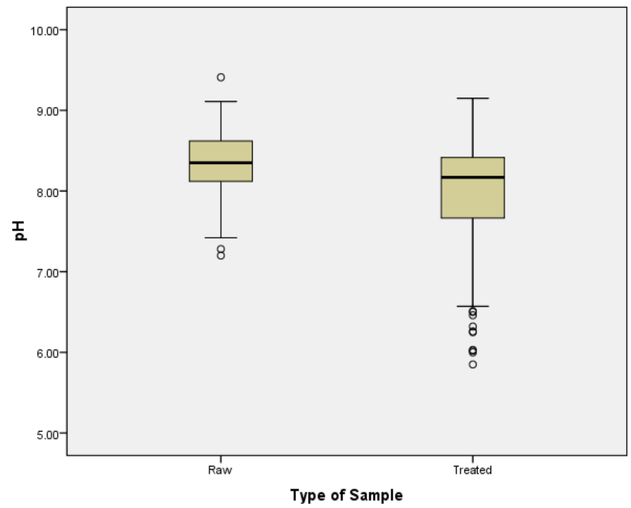
The levels of pH and alkalinity in raw water samples measured in this survey were not significantly different from those measured in the Beaver River Basin (BRB) survey and Alberta Summary study (AH 2013a, 2013b).

	Mean			**Median**		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
pH						
Raw	8.3	8.1	8.4	8.3	8.1	8.4
Treated	8.0	8.1	-	8.2	8.2	-
Alkalinity						
Raw	503	534	513	456	542	488
Treated	326	462	-	333	522	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The distribution and spatial patterns of pH and alkalinity in raw and treated water samples are illustrated in Figure 3, 4, 5, 6, 7, 8. The results are summarized as

1. domestic well water is neutral (6.5 – 8.5 guideline) in 64 per cent of raw well samples,
2. the levels of pH and alkalinity were significantly reduced after water treatment (Figure 3) ($p < 0.001$),
3. the decreased levels of alkalinity after treatment were observed in the 70 houses using reverse osmosis units, distiller or carbon filter,
4. the levels of pH and alkalinity were lower in the Peace River region than other regions (Figure 4) ($p <0.001$),
5. the levels of pH and alkalinity were higher in the Edmonton surrounding and Grande Prairie regions than other regions (Figure 4) ($p <0.001$), and
6. alkalinity is related to hardness of the water because the major source of alkalinity arises from dissolution of $CaCO_3$ in carbonate rocks. The significant reduction of alkalinity levels in some samples may be related to hardness level changes due to treatment.



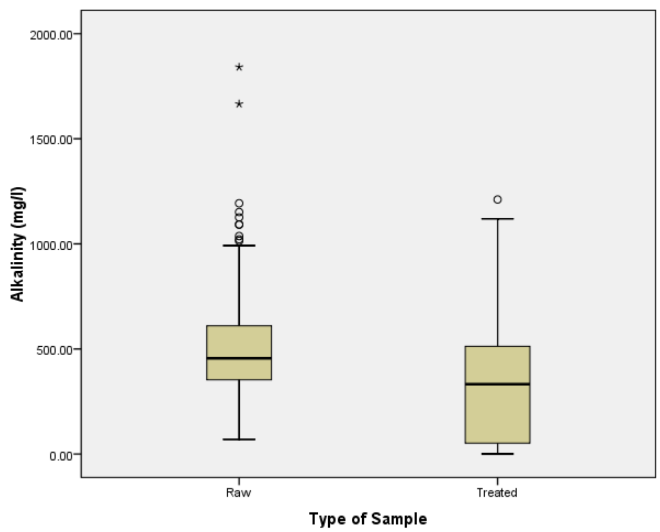


Figure 3 Distribution of pH and Alkalinity in Raw and Treated Water Samples

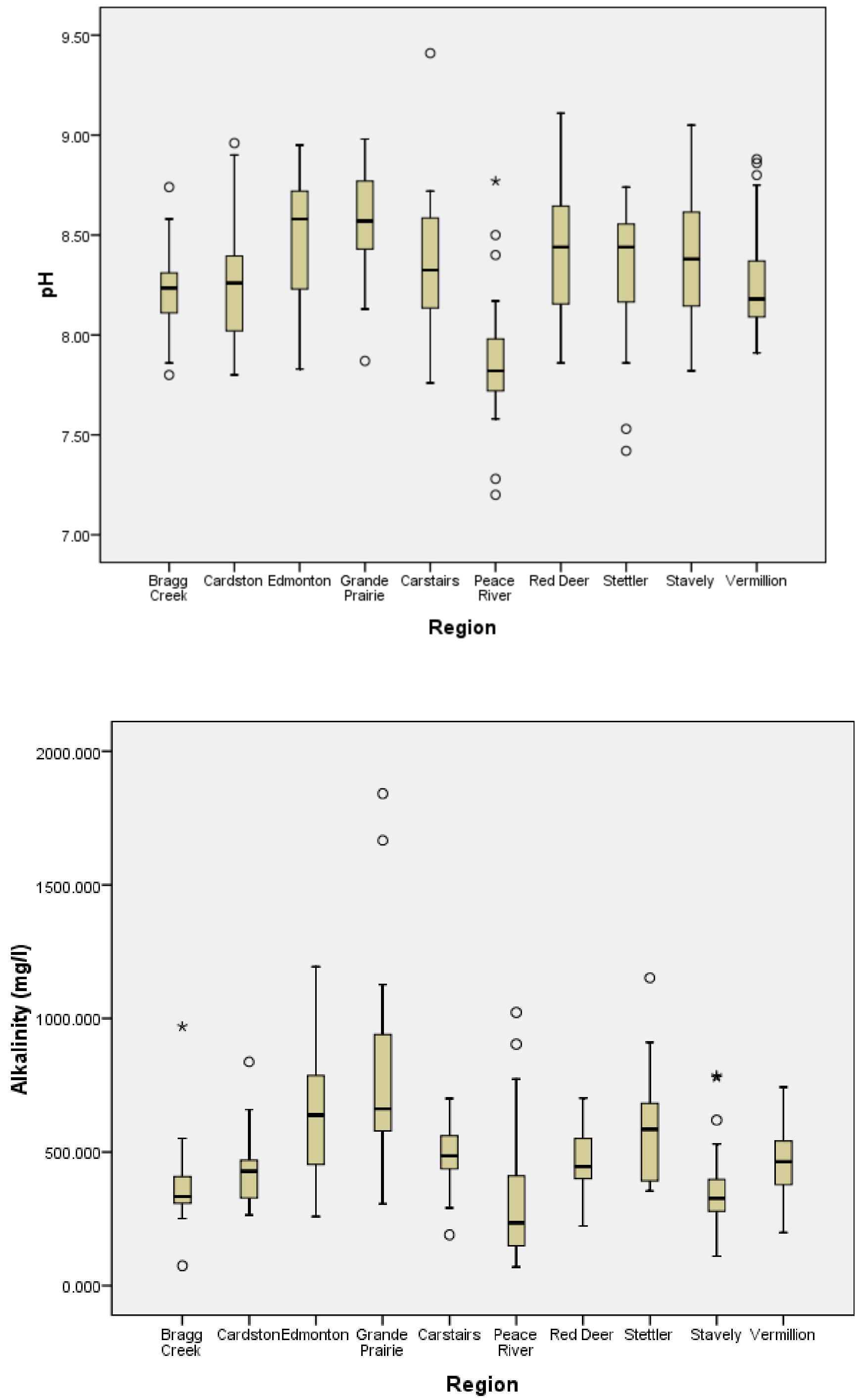


Figure 4 Regional Distribution of pH and Alkalinity in Raw Water

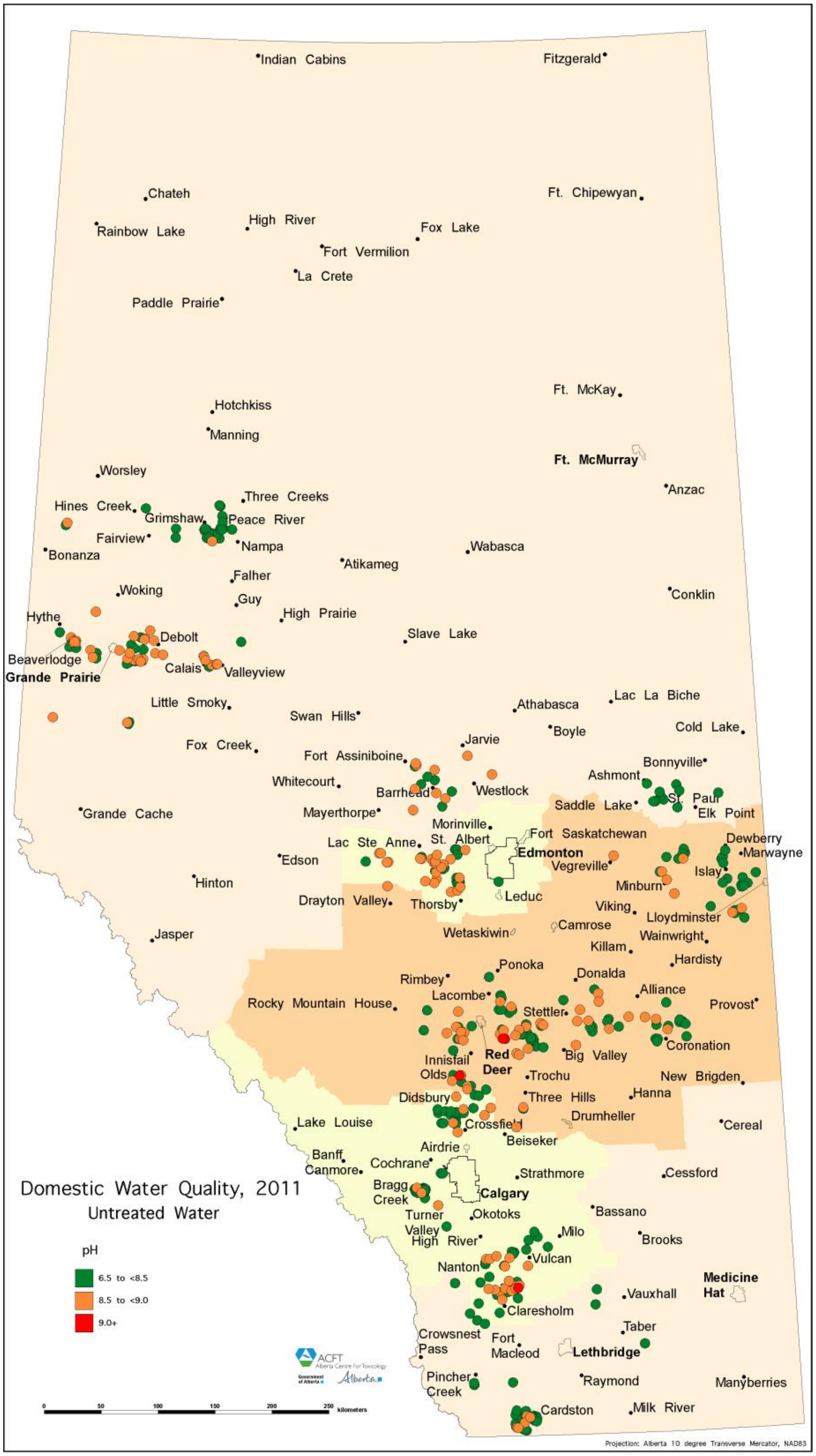


Figure 5 Spatial Patterns with Respect to pH Guideline in Raw Water

Figure 6 Spatial Patterns with Respect to pH Guideline in Treated Water

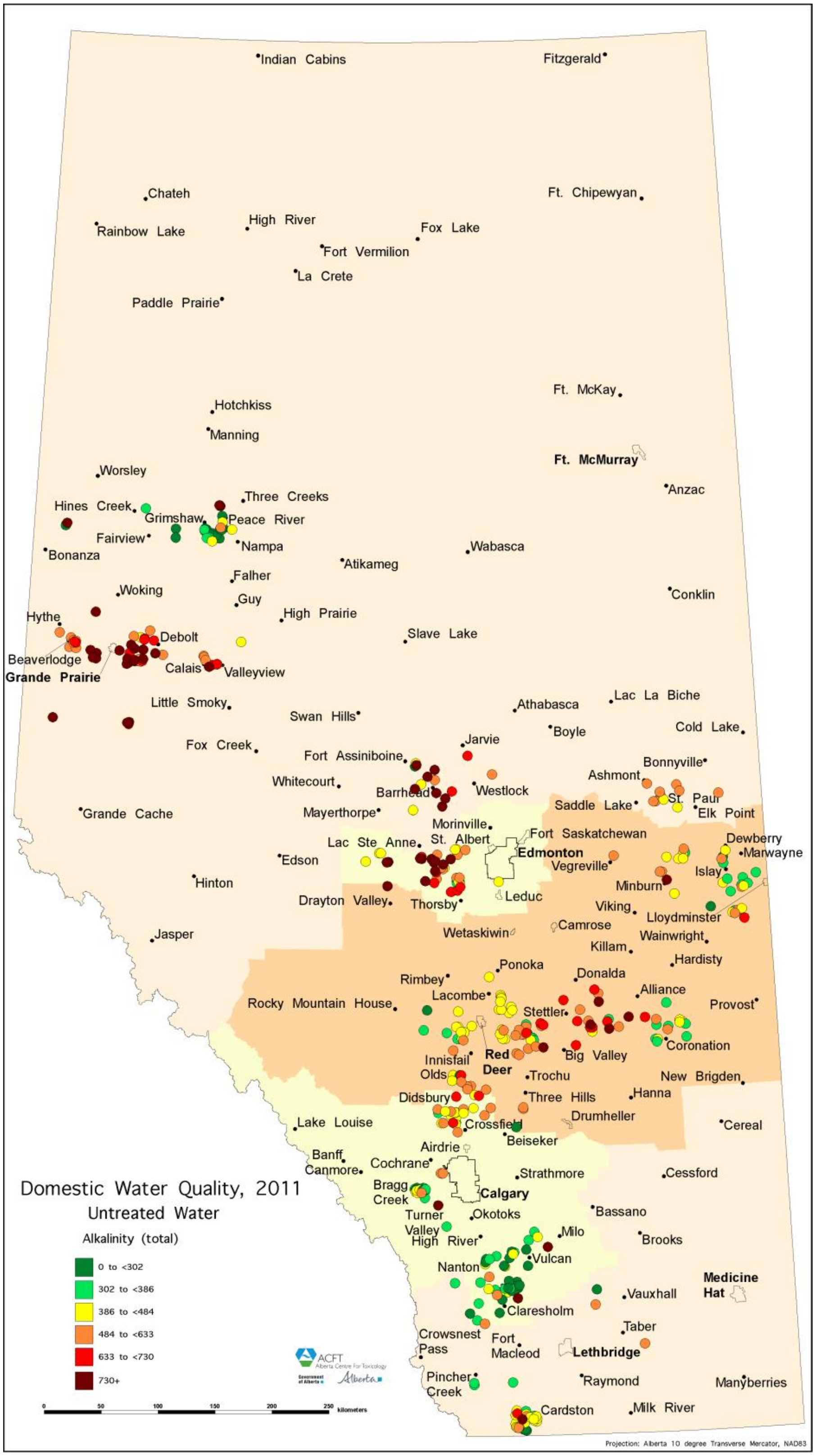


Figure 7 Spatial Patterns of Alkalinity in Raw Water

Figure 8 Spatial Patterns of Alkalinity in Treated Water

3.3.2 Electrical Conductivity and Total Dissolved Solids

The levels of conductivity and total dissolved solids in raw water samples measured in this survey were not significantly different from those measured in the Beaver River Basin (BRB) survey and Alberta Summary study (AH 2013a, 2013b).

	Mean			Median		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Electrical Conductivity						
Raw	1493	1517	1400	1299	1323	1200
Treated	1026	1482	-	840	1354	-
Total Dissolved Solids						
Raw	933	929	866	774	826	729
Treated	633	893	-	484	830	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The overall suitability of domestic well water for human drinking on the basis of taste was found as

Rating	TDS Value	Raw Water	Treated Water
excellent	<300 mg/L	3%	35%
good	300 – 600 mg/L	29%	26%
fair	600 – 900 mg/L	28%	14%
poor	900 – 1,200 mg/L	18%	10%
unacceptable	>1,200 mg/L	22%	13%

The distribution and spatial patterns of conductivity and total dissolved solids in raw and treated water samples are illustrated in Figure 9, 10, 11, 12, 13, 14. The results are summarized as

1. TDS levels exceeded the guideline level of 500 mg/L in 79 per cent of raw water samples and 47 per cent of treated water samples,
2. the levels of conductivity were significantly reduced after water treatment (Figure 9) ($p = 0.03$),
3. the levels of TDS were not significantly reduced after water treatment (Figure 9) ($p = 0.2$),
4. the decreased levels of conductivity and TDS after treatment were observed in 67 houses using reverse osmosis units, distiller or carbon filter,
5. the results indicated that the majority of raw (58 per cent) and treated water (75 per cent) was rated as excellent to fair for human consumption based on taste, and
6. the levels of conductivity and total dissolved solids were not significantly different among regions ($p > 0.05$).

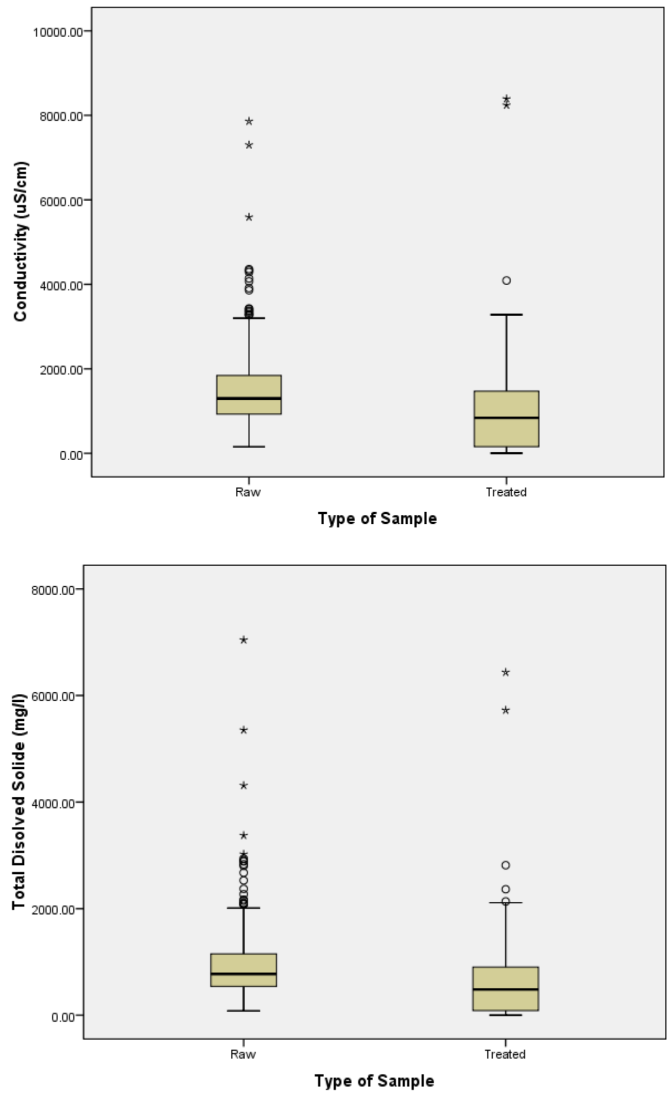


Figure 9 Distribution of Conductivity and TDS in Raw and Treated Water

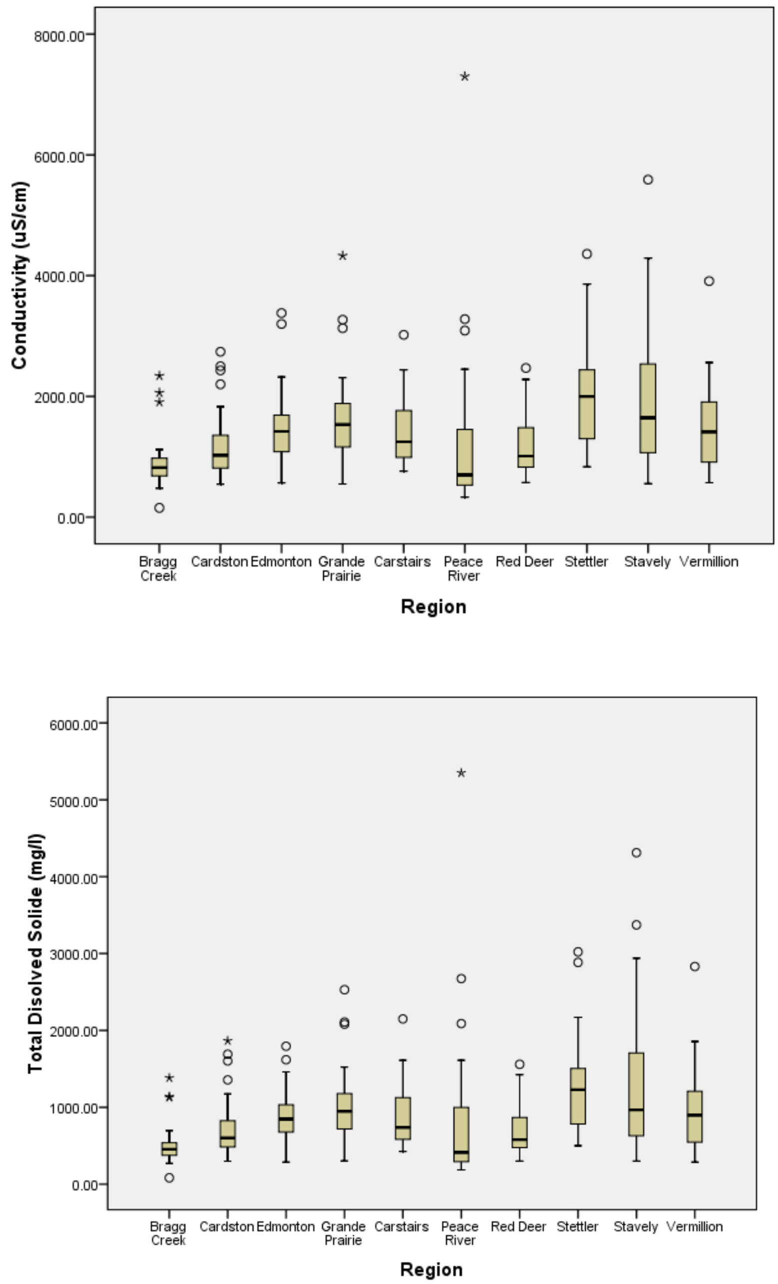


Figure 10 Regional Distribution of Conductivity and TDS in Raw Water

Figure 11 Spatial Patterns of Conductivity in Raw Water

Figure 12 Spatial Patterns of Conductivity in Treated Water

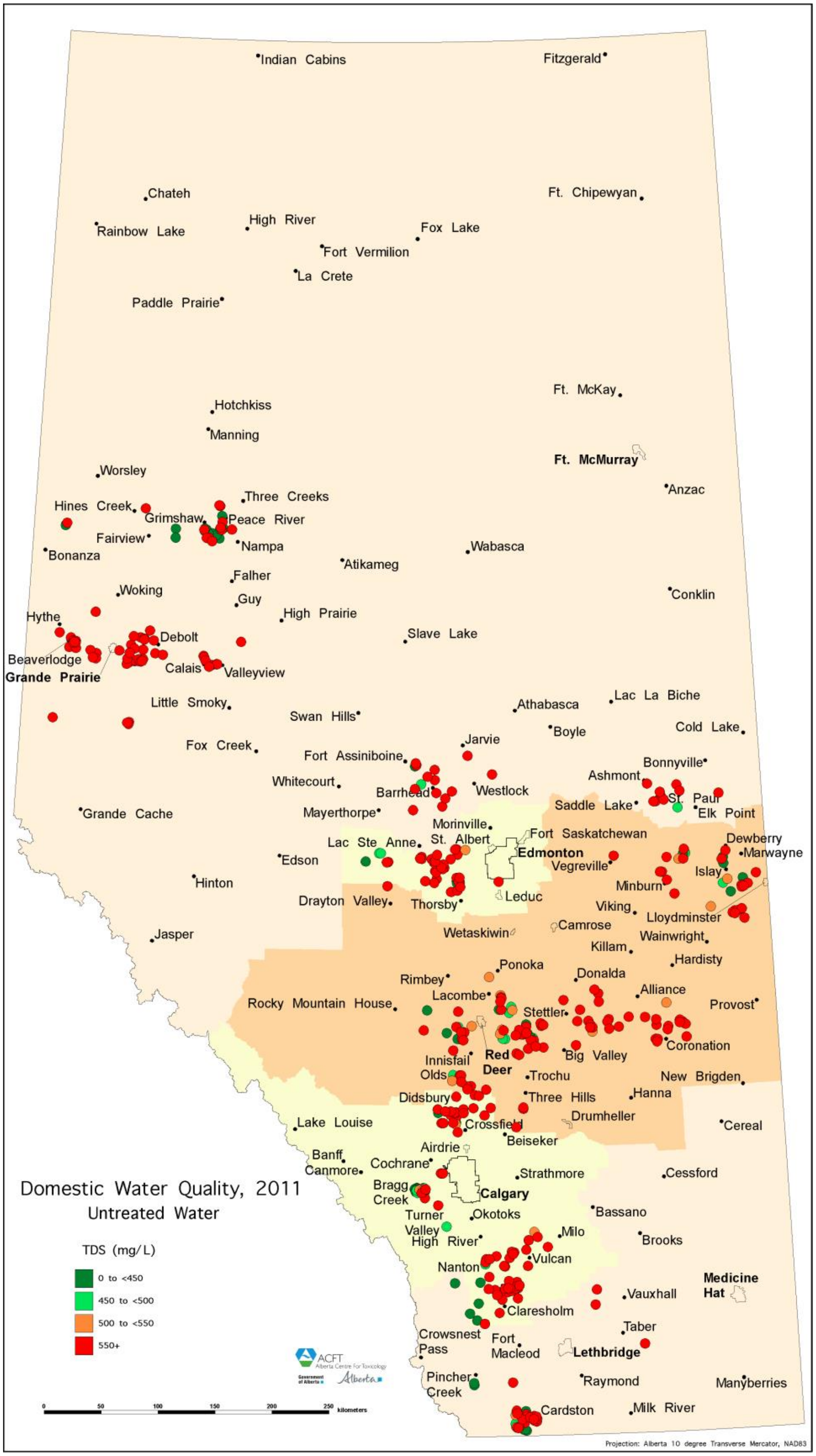


Figure 13 Spatial Patterns with Respect to TDS Guideline in Raw Water

Figure 14 Spatial Patterns with Respect to TDS Guideline in Treated Water

3.3.3 Hardness, Calcium, Magnesium

The median concentrations of hardness, calcium and magnesium in raw water samples measured in this survey were significantly lower than those measured in the Beaver River Basin (BRB) survey and higher than those measured in Alberta summary study (AH 2013a, 2013b).

	Mean			Median		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Hardness						
Raw	226	536	178	123	484	64
Treated	96	88	-	6	12	-
Calcium						
Raw	54	127	43	31	117	17
Treated	21	19	17	1.7	2.6	-
Magnesium						
Raw	22	53	17	11	46	4.5
Treated	10	10	-	0.4	1.1	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

There is no guideline for water hardness in Canada. Public acceptability of the degree of hardness varies greatly from one community to another. Hardness in the water can be classified among four levels (Health Canada 1979):

1. soft at a level less than 60 mg/L (as $CaCO_3$);
2. medium hard at the levels between 60 – 120 mg/L;
3. hard at the levels between 120 – 180 mg/L; and
4. very hard at a level greater than 180 mg/L.

Rate	Value	Raw Water	Treated Water
soft water	<60 mg/L	42%	72%
Medium hard water	60 – 120 mg/L	7.5%	6.5%
Hard water	120 – 180 mg/L	6.3%	3%
Very hard water	> 180 mg/L	44%	19%
Optimal level of hardness	80 – 100 mg/L	3%	1.4%

The distribution and spatial patterns of hardness, calcium and magnesium in raw and treated water samples are illustrated in Figure 15, 16, 17, 18, 19, 20, 21 and 22. The results are summarized as

1. Water in these regions was soft in 42 per cent of raw water samples and very hard in 44 percent of raw water samples,
2. the levels of hardness, calcium and magnesium were significantly reduced after water treatment (Figure 15) ($p < 0.005$),
3. the decreased levels of hardness, calcium and magnesium after treatment were observed in 125 houses using softeners, reverse osmosis units, distillers or iron filters,

4. the levels of hardness, calcium and magnesium were higher in Bragg Creek, Peace River and Vermillion regions than other regions (Figure 16) (p <0.001),
5. the levels of hardness and calcium were lower in Edmonton surrounding and Grande Prairie regions than other regions (Figure 16) (p <0.001),

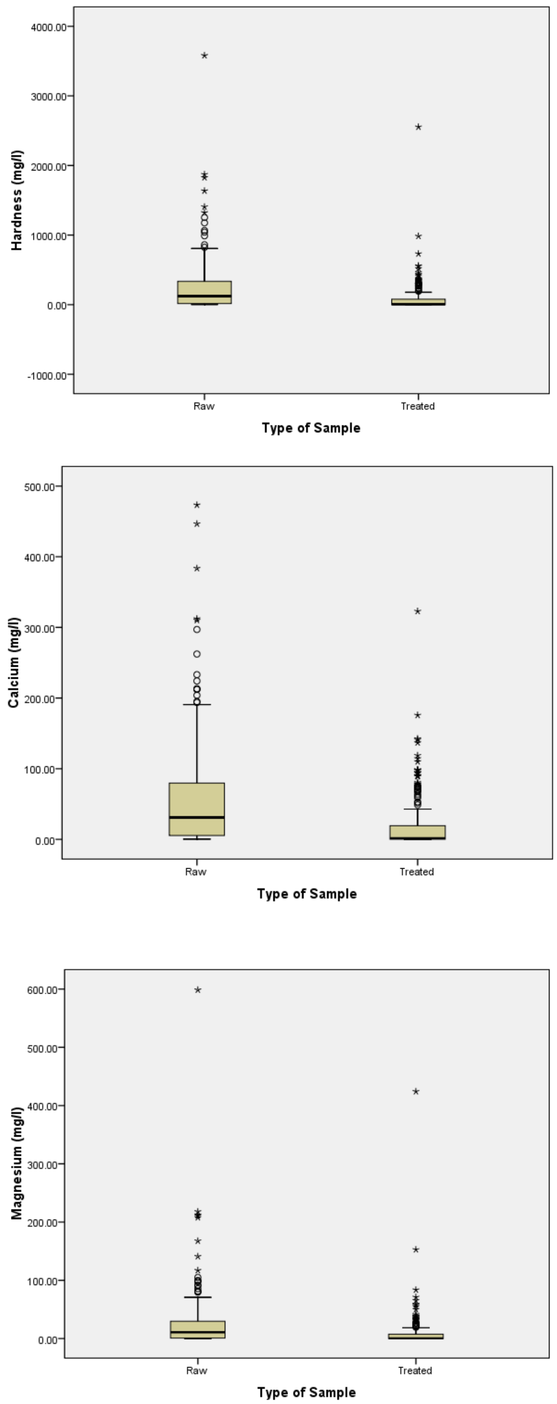


Figure 15 Distribution for Hardness, Calcium and Magnesium in Raw and Treated Water

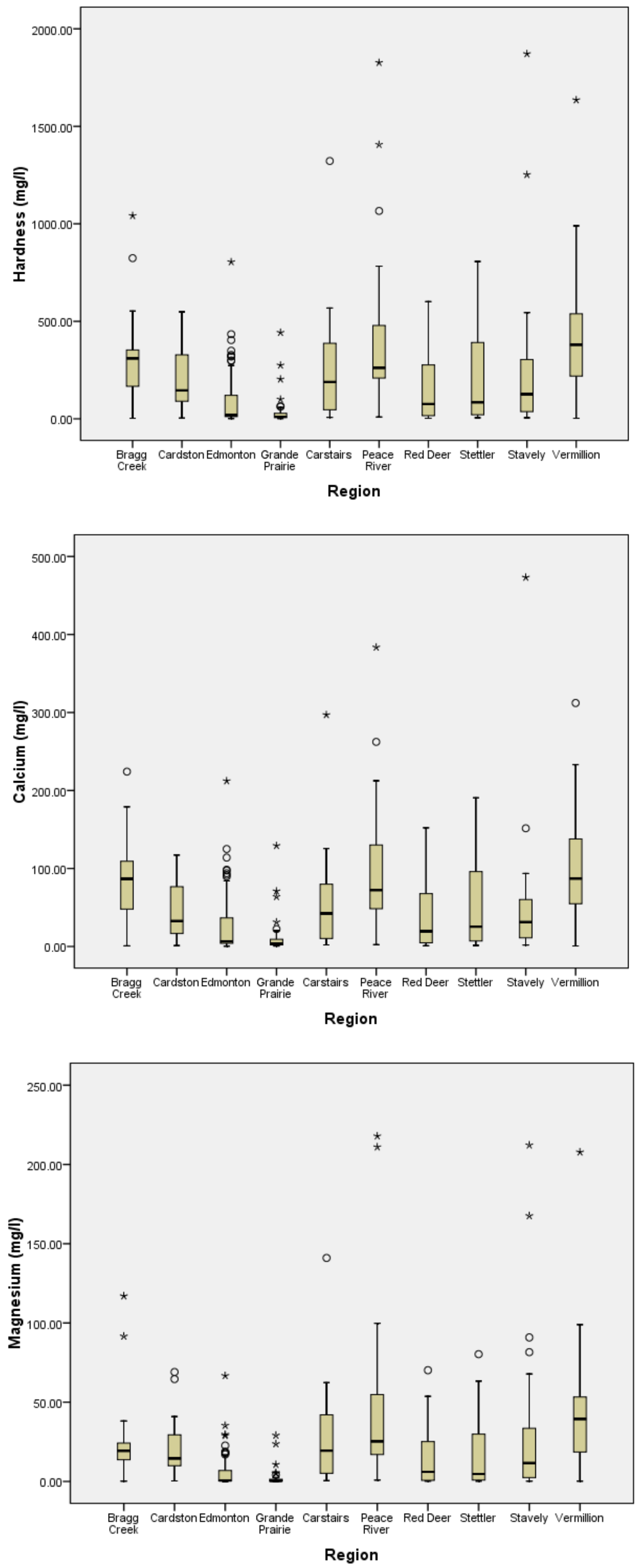


Figure 16 Regional Distribution for Hardness, Calcium and Magnesium in Raw Water

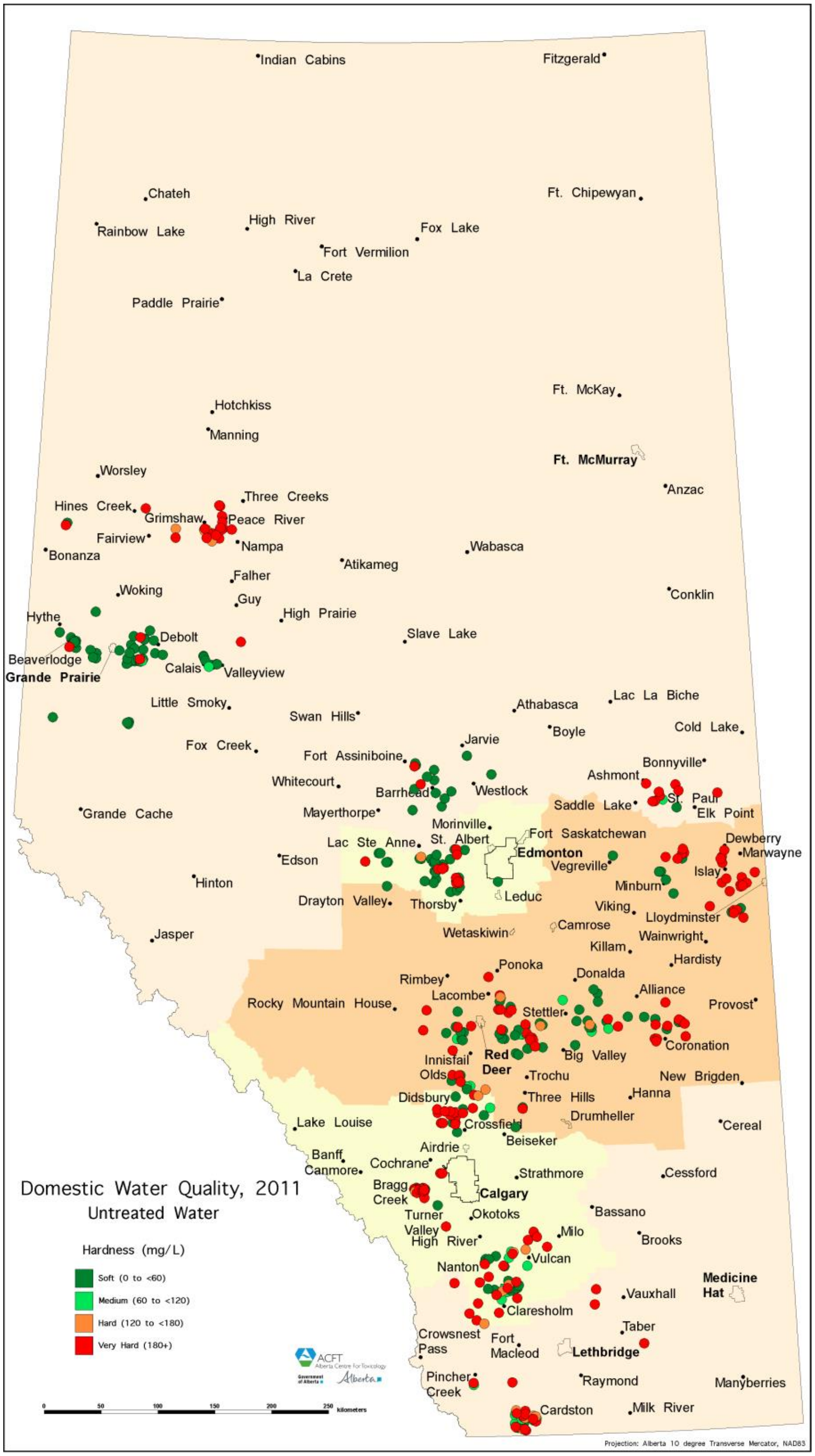


Figure 17 Spatial Patterns of Hardness Classes in Raw Water

Figure 18 Spatial Patterns of Hardness Classes in Treated Water

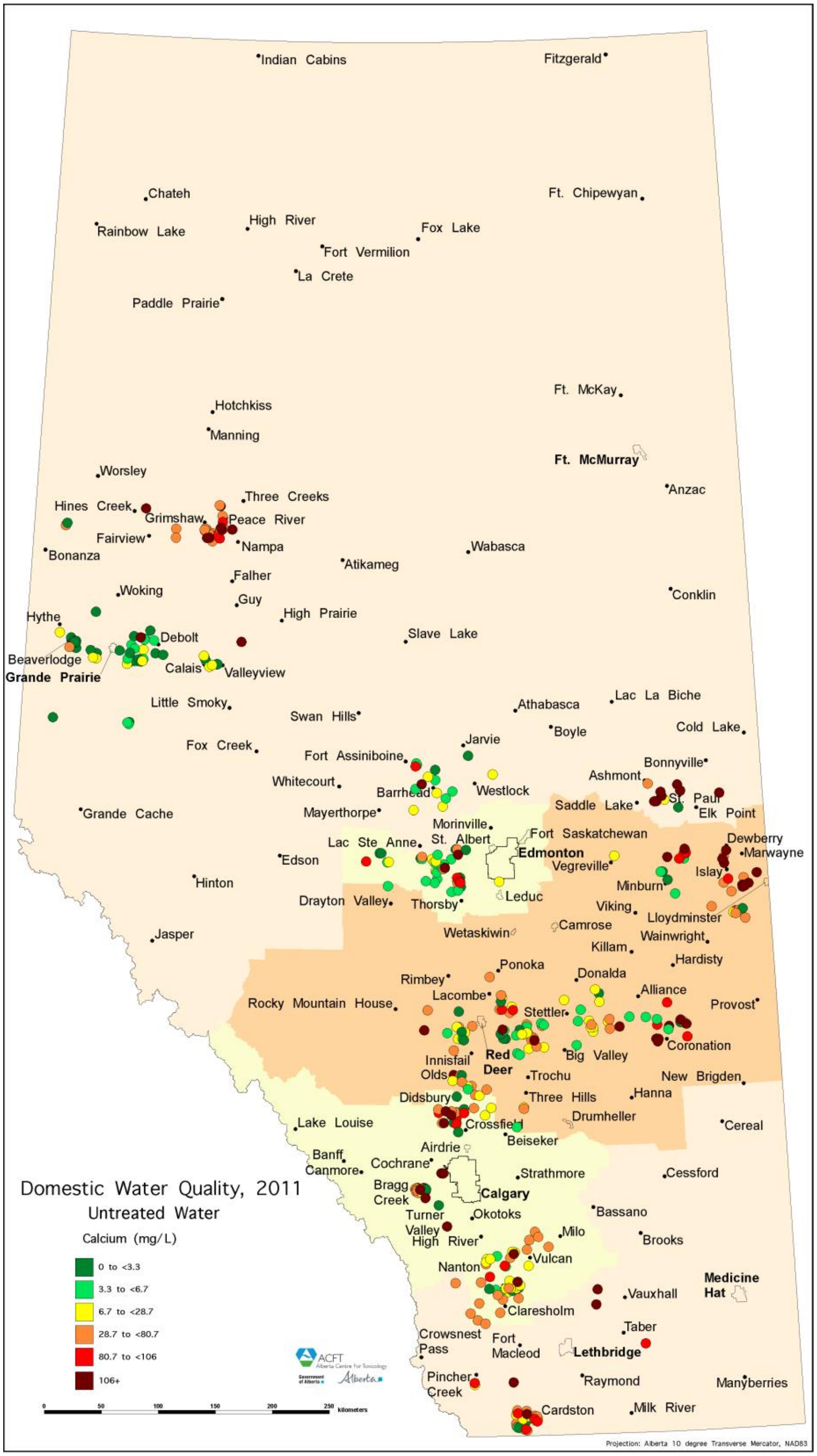


Figure 19 Spatial Patterns of Calcium in Raw Water

Figure 20 Spatial Patterns of Calcium in Treated Water

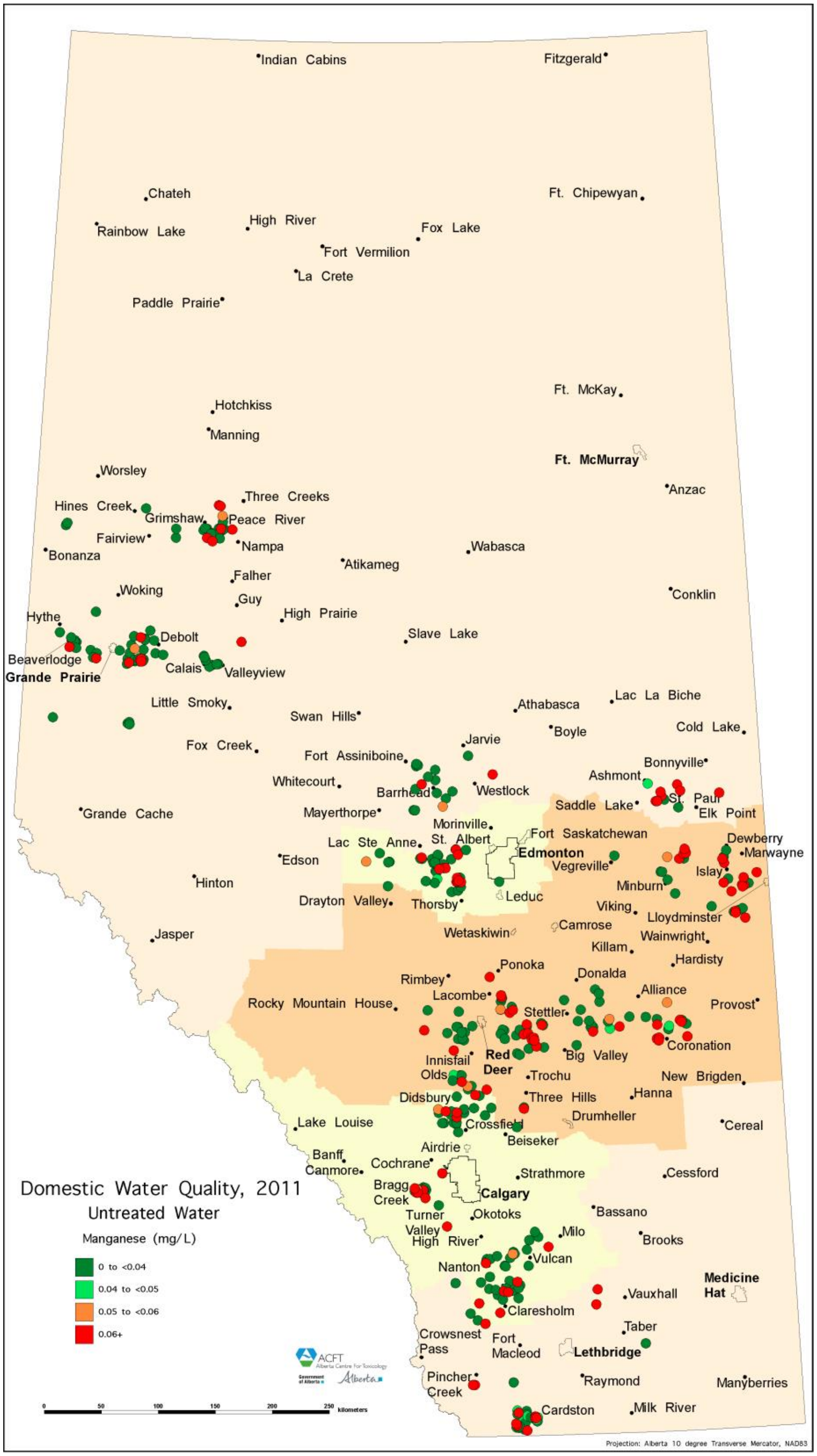


Figure 21 Spatial Patterns of Magnesium in Raw Water

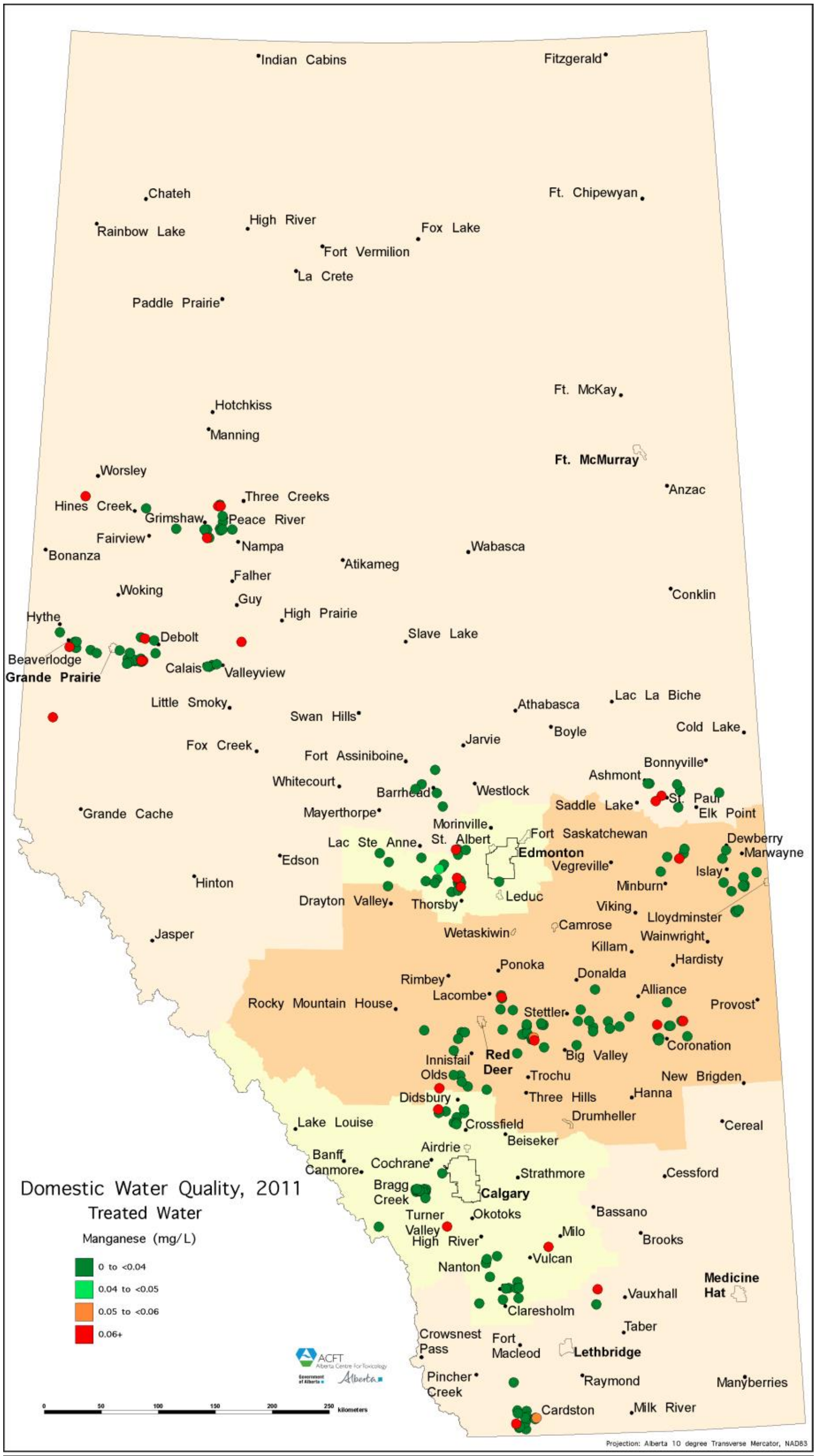


Figure 22 Spatial Patterns of Magnesium in Treated Water

3.3.4 Bicarbonate and Carbonate

The levels of bicarbonate in raw water samples measured in this survey were not significantly different from those measured in the Beaver River Basin (BRB) survey and Alberta summary study (AH 2013a, 2013b). The levels of carbonate in raw water samples measured in this survey were higher than those measured in the Beaver River Basin (BRB) survey, but not significantly different from Alberta summary study (AH 2013a, 2013b).

	Mean			**Median**		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Bicarbonate						
Raw	589	650	598	549	661	570
Treated	385	556	-	404	633	-
			Carbonate			
Raw	12	0.7	12	4.8	nd	7.2
Treated	6	3.7	-	nd	nd	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The distribution and spatial patterns of bicarbonate and carbonate in raw and treated water samples are illustrated in Figure 23, 24, 25, 26, 27 and 28. The results are summarized as

1. the levels of bicarbonate and carbonate were significantly reduced after water treatment (figure 23) ($p < 0.001$),
2. decreased levels of bicarbonate and carbonate after treatment were observed in the 70 houses using reverse osmosis units, distillers or carbon filters,
3. the levels of bicarbonate and carbonate were lower in the Peace River region than other regions (Figure 24) ($p <0.001$), and
4. the levels of bicarbonate and carbonate were higher in the Edmonton surrounding and Grande Prairie regions than other regions (Figure 24) ($p <0.001$),

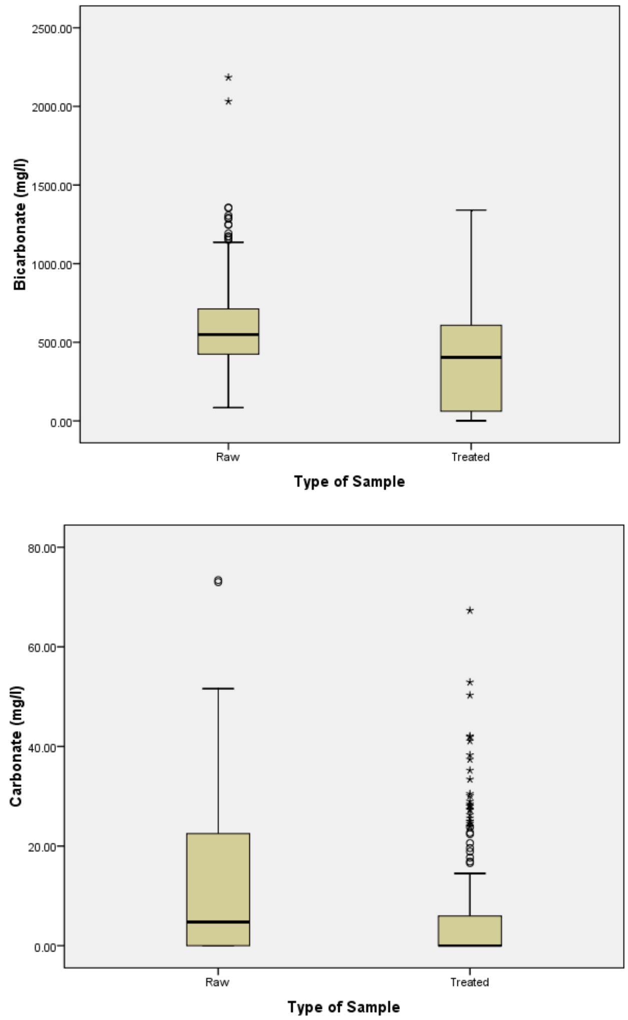


Figure 23 Distribution of Bicarbonate and Carbonate in Raw and Treated Water

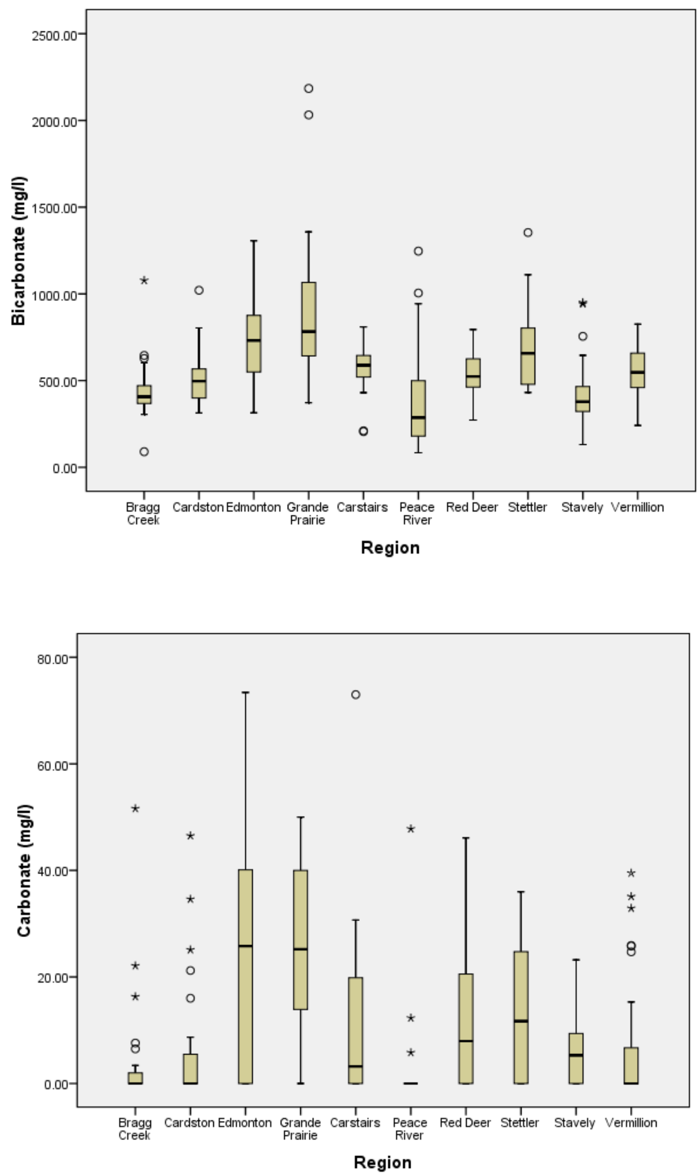


Figure 24 Regional Distribution of Bicarbonate and Carbonate in Raw Water

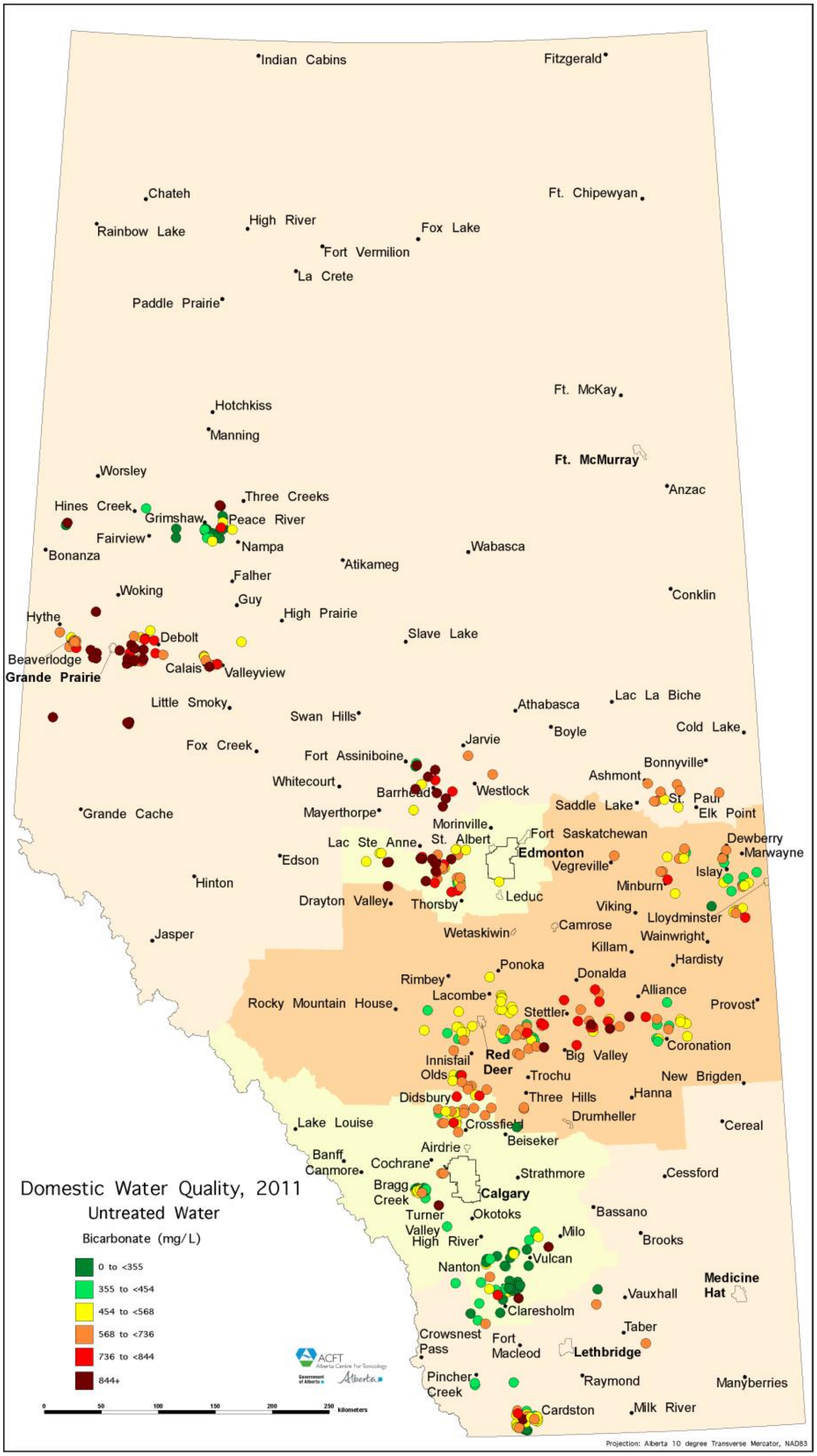


Figure 25 Spatial Patterns of Bicarbonate in Raw Water

Figure 26 Spatial Patterns of Bicarbonate in Treated Water

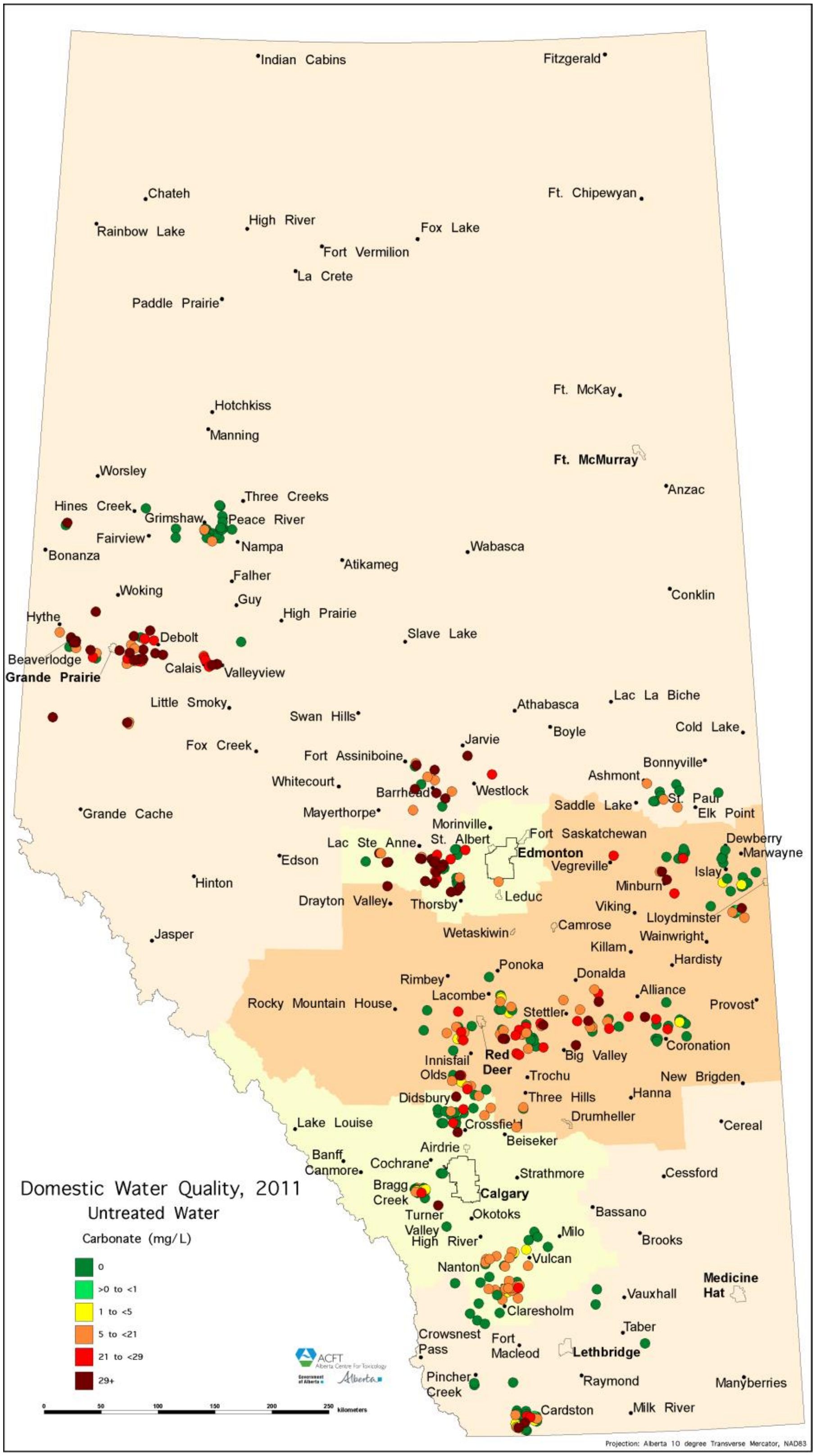


Figure 27 Spatial Patterns of Carbonate in Raw Water

Figure 28 Spatial Patterns of Carbonate in Treated Water

3.3.5 Sodium

The levels of sodium in raw water samples measured in this survey were higher than those measured in the Beaver River Basin (BRB) survey, but not significantly different from the Alberta summary study (AH 2013a, 2013b).

	Mean			**Median**		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Sodium						
Raw	263	136	265	249	190	250
Treated	196	230	-	119	109	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The distribution and spatial patterns of sodium in raw and treated water samples are illustrated in Figure 29, 30, 31 and 32. The results are summarized as

1. sodium levels exceeded the guideline level of 200 mg/L in 58 per cent of raw water samples and 37 per cent of treated water samples,
2. the levels of sodium were not significantly reduced after water treatment in all overall raw water samples (Figure 29) ($p = 0.4$) because the increased levels or decreased levels of sodium occurred in some houses,
3. the increased levels of sodium after treatment were observed in the 42 houses using softeners, as would be expected because ion exchange softeners typically exchange sodium for calcium, thereby increasing sodium.
4. the levels of sodium were lower in the Peace River region than other regions (Figure 30) ($p <0.05$), and
5. the levels of sodium were higher in the Edmonton surrounding and Grande Prairie regions than other regions (Figure 30) ($p <0.001$).

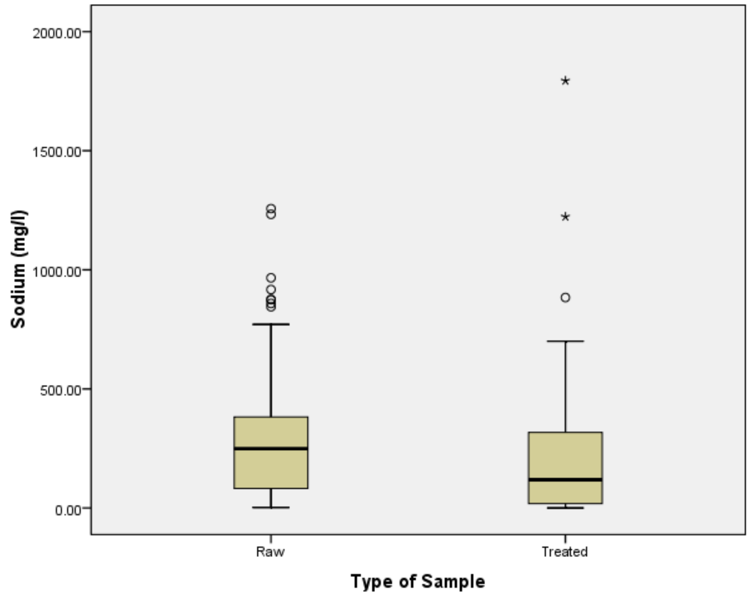


Figure 29 Distribution of Sodium in Raw and Treated Water

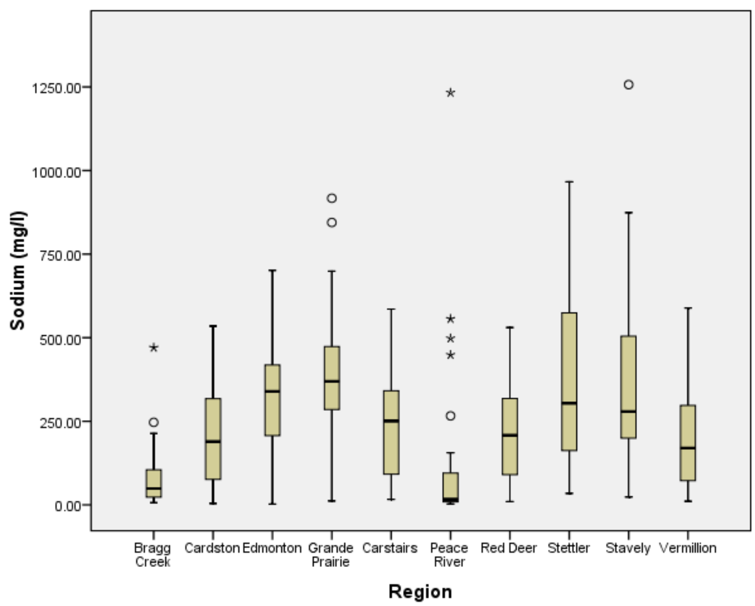


Figure 30 Regional Distribution of Sodium in Raw Water

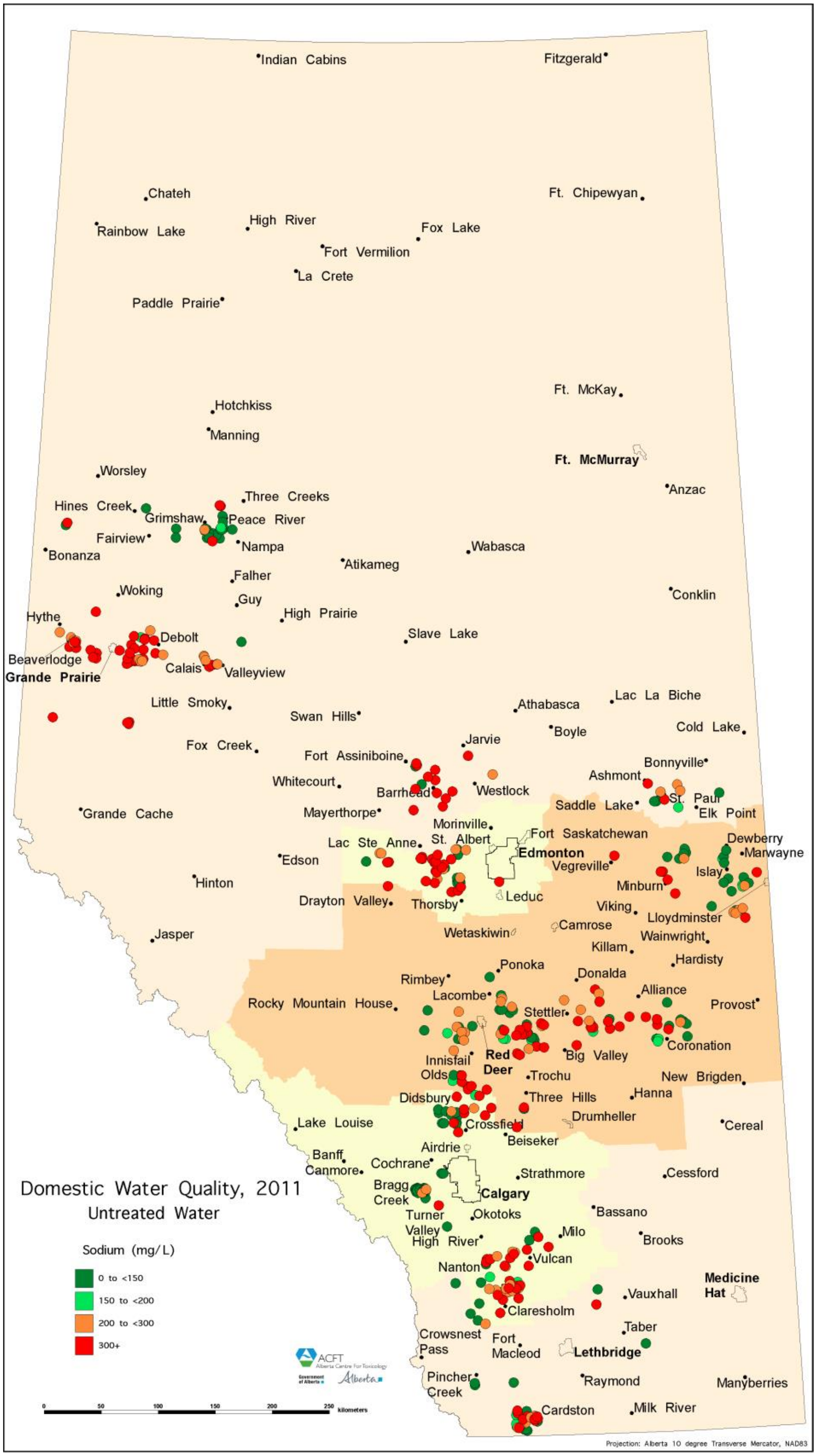


Figure 31 Spatial Patterns with Respect to Sodium Guideline in Raw Water

Figure 32 Spatial Patterns with Respect to Sodium Guideline in Treated Water

3.3.6 Chloride

The levels of chloride in raw water samples measured in this survey were lower than those measured in the Beaver River Basin (BRB) survey, but not significantly different from Alberta summary study (AH 201a, 2013b).

	Mean			Median		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Chloride						
Raw	37	86	39	6	17	4.8
Treated	29	69	-	3.3	14	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The distribution and spatial patterns of chloride in raw and treated water samples are illustrated in Figure 33, 34, 35 and 36. The results are summarized as

1. chloride levels exceeded the guideline level of 250 mg/L in 4 per cent of raw water samples and 3 per cent of treated water samples,
2. the levels of chloride were not significantly reduced after water treatment in all overall raw water samples (Figure 33) (p = 0.3), and
3. the levels of chloride were not significantly different among regions (Figure 34) (p =0.08).

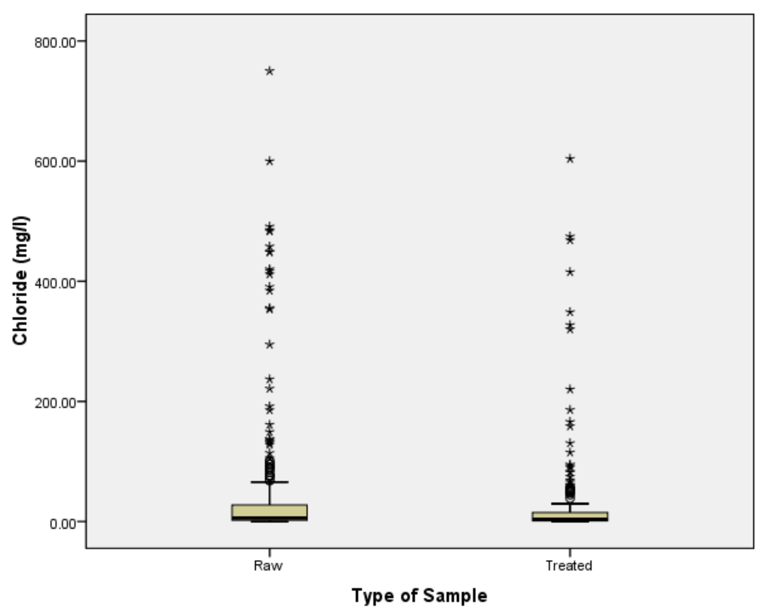


Figure 33 Distribution of Chloride in Raw and Treated Water

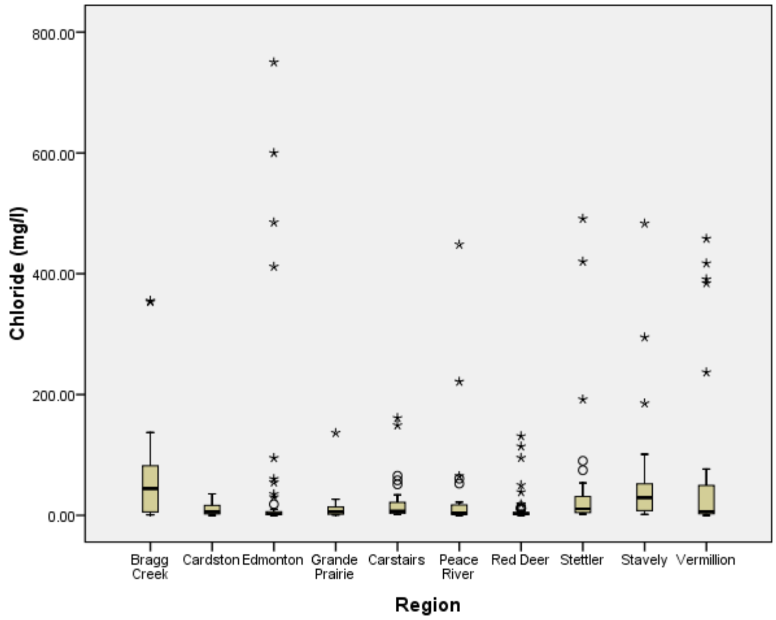


Figure 34 Regional Distribution of Chloride in Raw Water

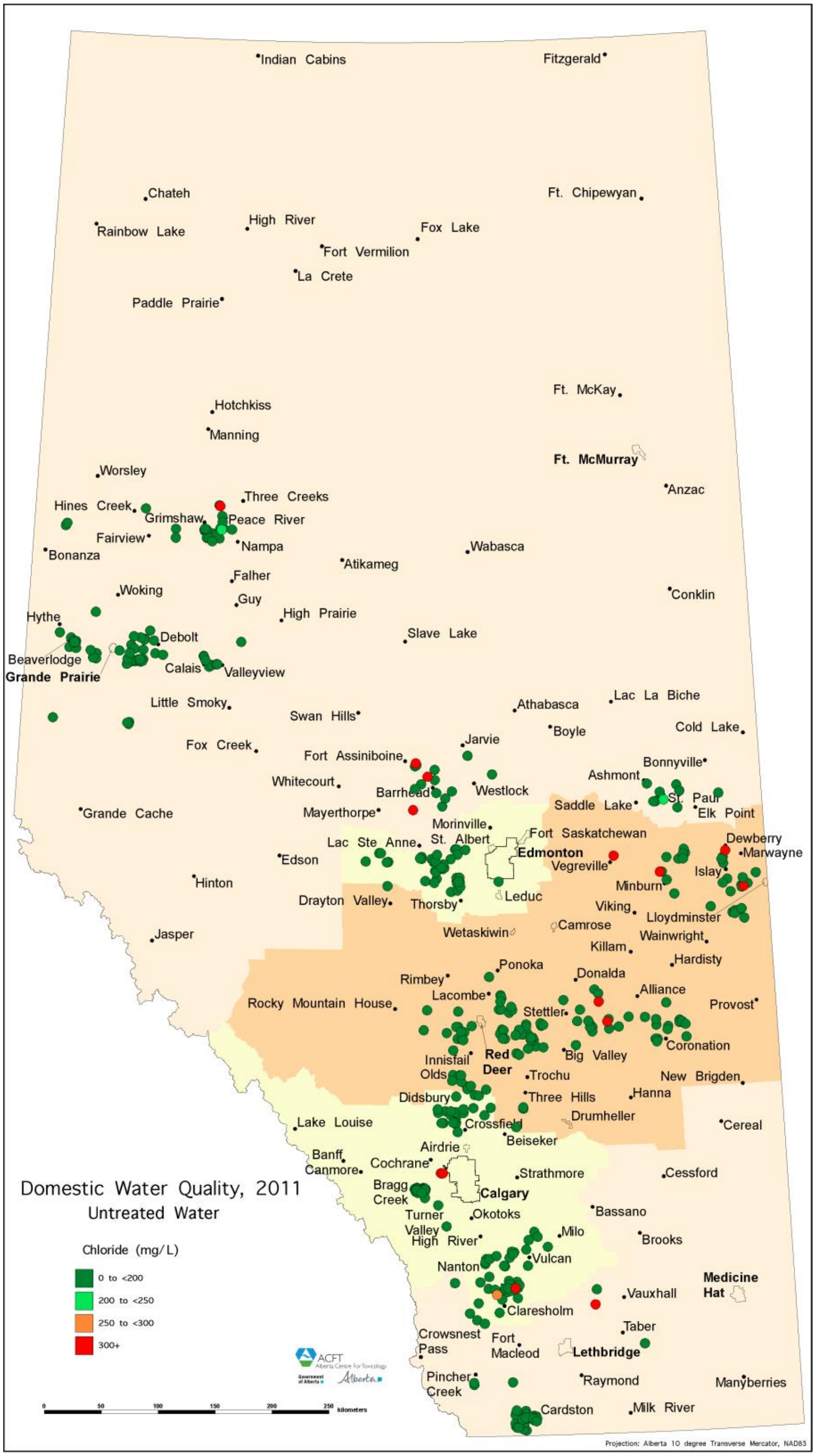


Figure 35 Spatial Patterns with Respect to Chloride Guideline in Raw Water

Figure 36 Spatial Patterns with Respect to Chloride Guideline in Treated Water

3.3.7 Sulfate

The levels of sulfate in raw water samples measured in this survey were not significantly different from those measured in the Beaver River Basin (BRB) survey and Alberta summary study (AH 2013a, 2013b).

	Mean			Median		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Sulfate						
Raw	249	199	188	106	109	70
Treated	168	179	-	29	91	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The distribution and spatial patterns of sulfate in raw and treated water samples are illustrated in Figure 37, 38, 39 and 40. The results are summarized as

1. sulfate levels exceeded the guideline level of 500 mg/L in 15 per cent of raw water samples and 9 per cent of treated water samples,
2. the levels of sulfate were significantly reduced after water treatment in all overall raw water samples (Figure 37) ($p < 0.02$), and
3. the levels of sulfate were higher than those in the Stettler and Stavely regions than other regions (Figure 38) ($p < 0.001$).

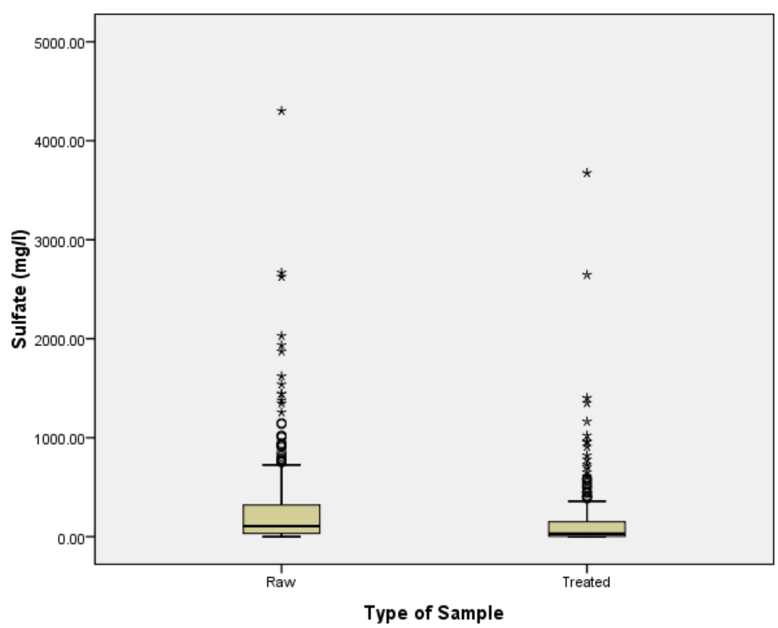


Figure 37 Distribution of Sulfate in Raw and Treated Water

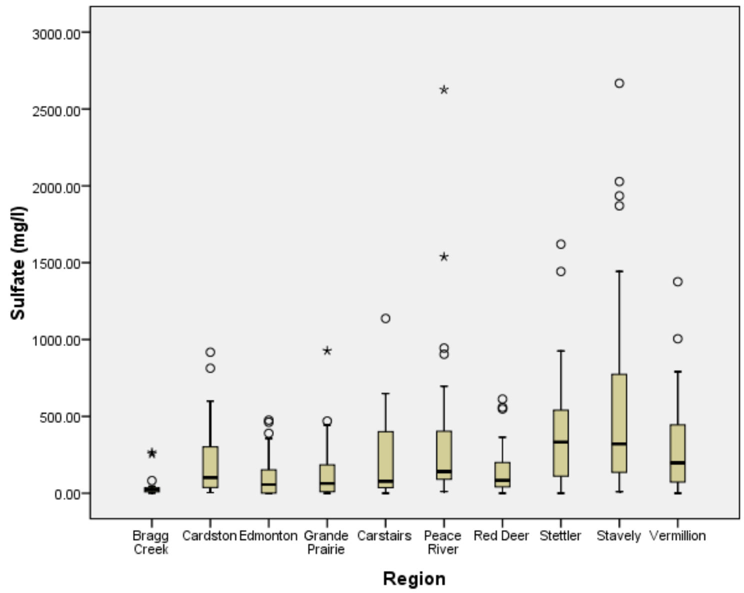


Figure 38 Regional Distribution of Sulfate in Raw Water

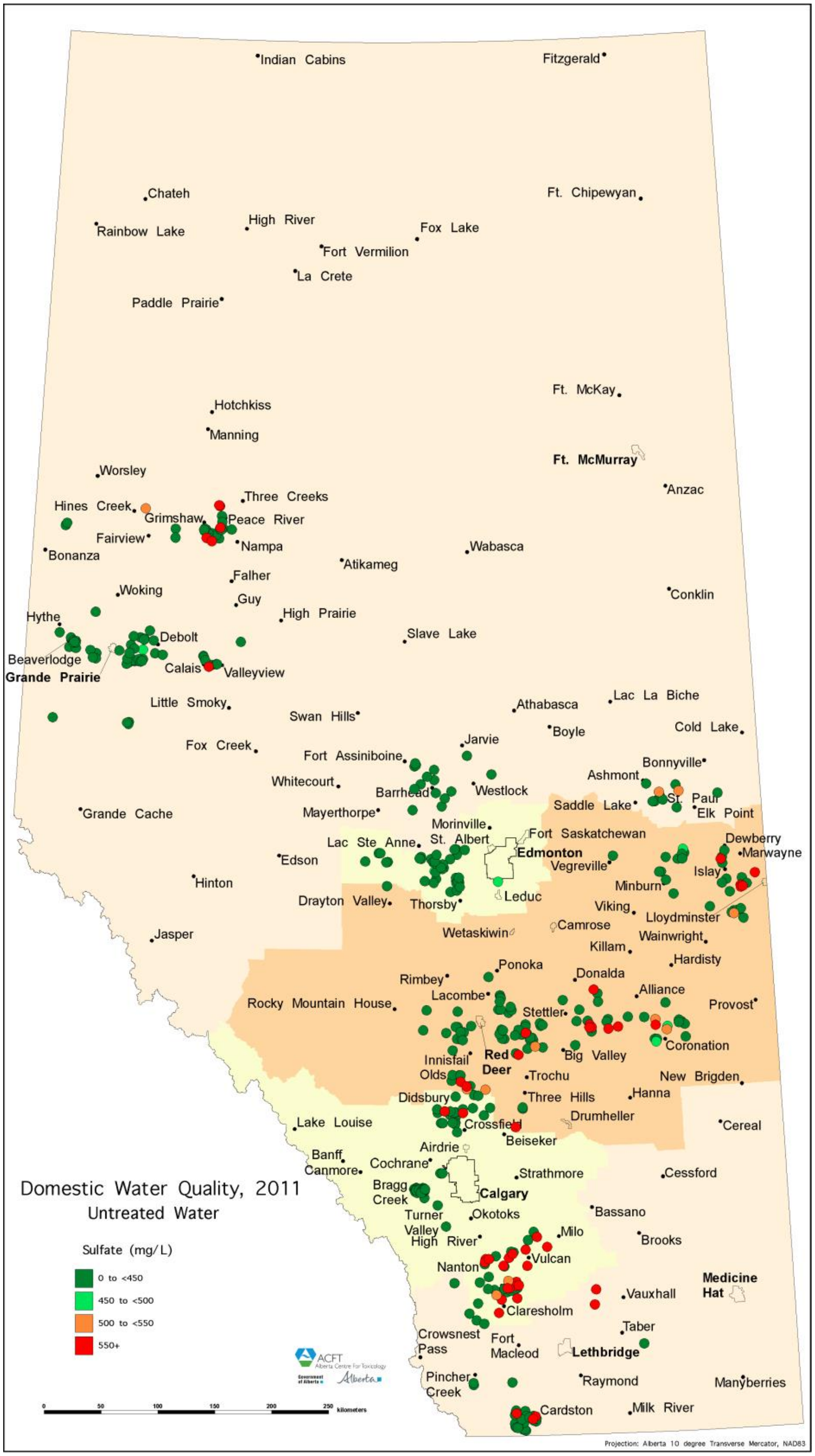


Figure 39 Spatial Patterns with Respect to Sulfate Guideline in Raw Water

Figure 40 Spatial Patterns with Respect to Sulfate Guideline in Treated Water

3.3.8 Potassium

The levels of potassium in raw water samples measured in this survey were lower than those measured in the Beaver River Basin (BRB) survey, but not significantly different from the Alberta summary study (AH 2013a, 2013b).

	Mean			**Median**		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Potassium						
Raw	3.3	5.4	4.9	1.9	5.0	1.9
Treated	12	107	-	1.2	3.5	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The distribution and spatial patterns of potassium in raw and treated water samples are illustrated in Figure 41, 42, 43 and 44. The results are summarized as

1. overall, the average level of potassium was significantly increased in raw water samples after water treatment (Figure 41) ($p < 0.01$), but the median of potassium was decreased because of the large increased sodium levels in some houses, which also had large increases in sodium because of ion exchange softeners.
2. the increased levels of potassium after treatment were observed in the 42 houses using softeners, and
3. the levels of potassium were higher in the Peace River region than other regions (Figure 42) ($p <0.001$).

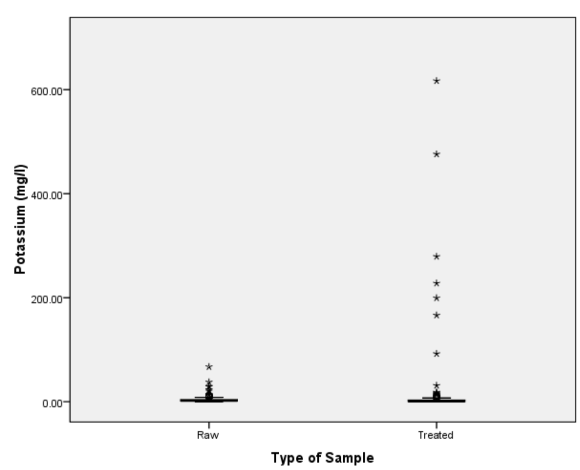


Figure 41 Distribution of Potassium in Raw and Treated Water

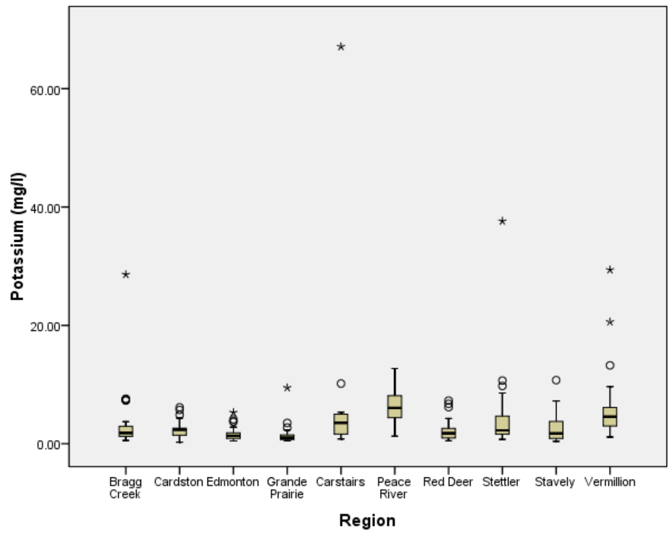


Figure 42 Regional Distribution of Potassium in Raw Water

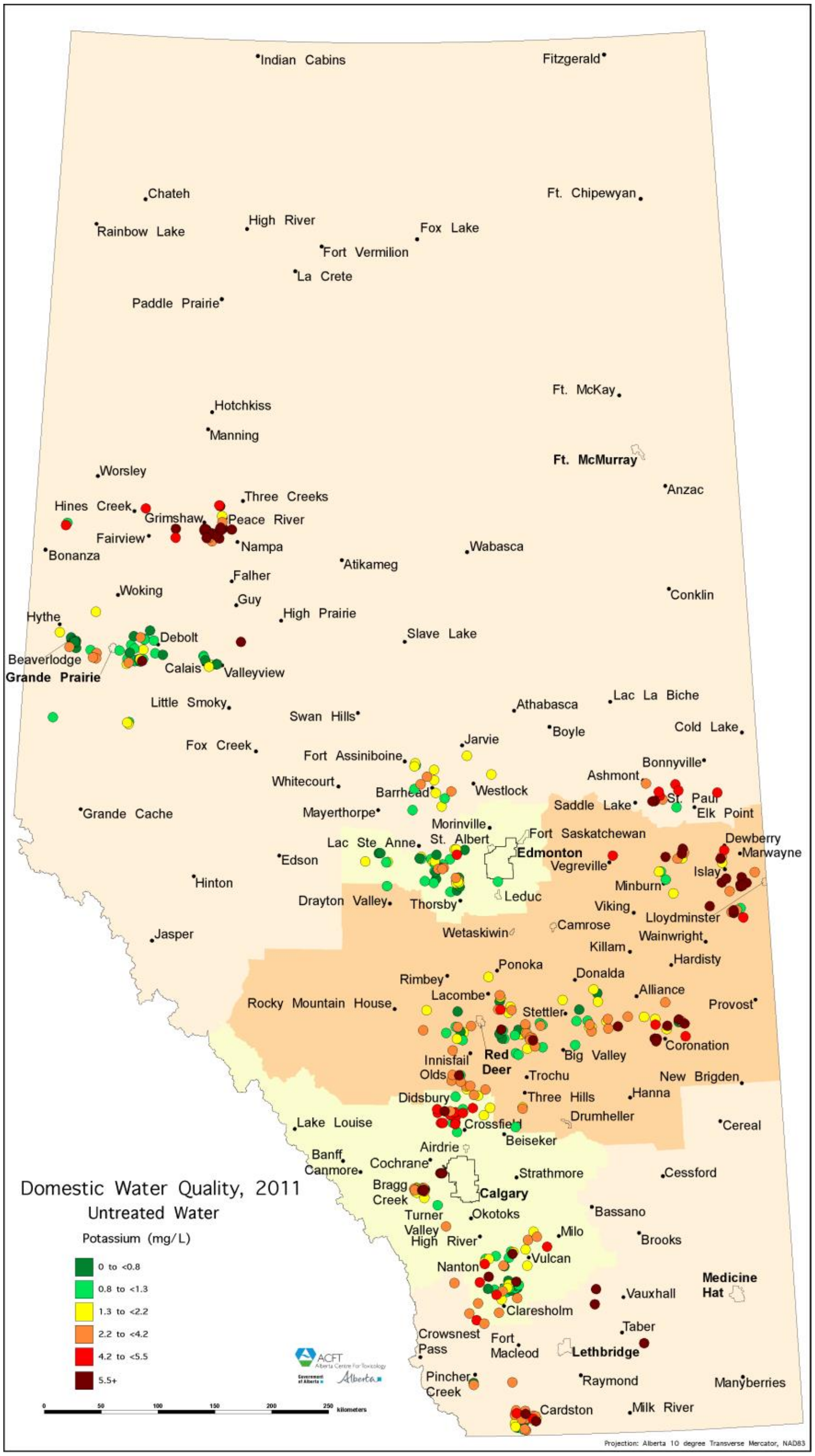


Figure 43 Spatial Patterns of Potassium in Raw Water

Figure 44 Spatial Patterns of Potassium in Treated Water

3.3.9 Iron

The levels of iron in raw water samples measured in this survey were lower than those measured in the Beaver River Basin (BRB) survey, but not significantly different from the Alberta summary study (AH 2013a, 2013b).

	Mean			**Median**		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Iron						
Raw	0.66	2.0	0.5	0.06	1.0	0.06
Treated	0.09	0.09	-	<0.01	0.04	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The distribution and spatial patterns of iron in raw and treated water samples are illustrated in Figure 45, 46, 47 and 48. The results are summarized as

1. iron levels exceeded the guideline level of 0.3 mg/L in 24 per cent of raw water samples and 5.5 per cent of treated water samples,
2. overall, the levels of iron were significantly reduced in raw water samples after water treatment (Figure 45) ($p < 0.02$),
3. the levels of iron were similar in all study regions (Figure 46), and
4. treated water at greater than 0.3 mg/L (5.5%) indicates ineffective treatment for iron.

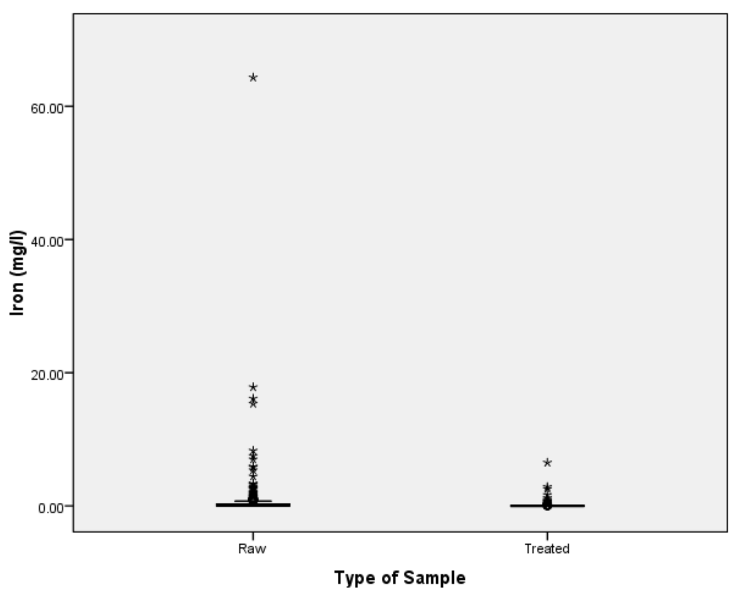


Figure 45 Distribution of Iron in Raw and Treated Water

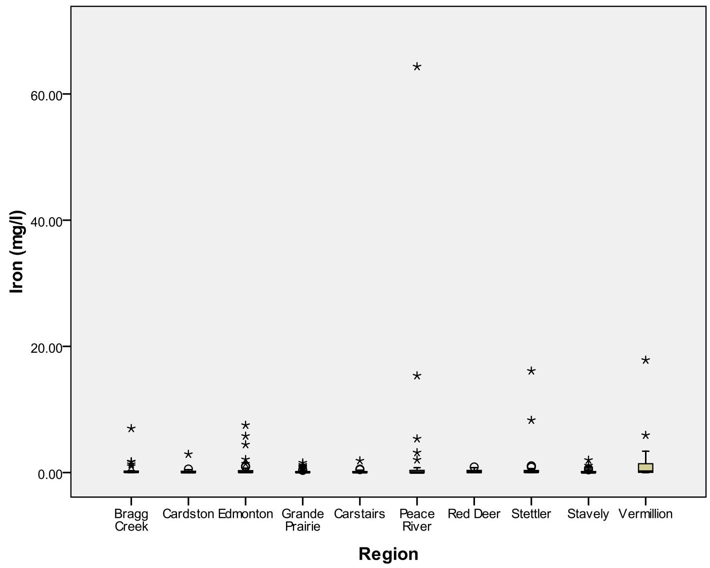


Figure 46 Regional Distribution of Iron in Raw Water

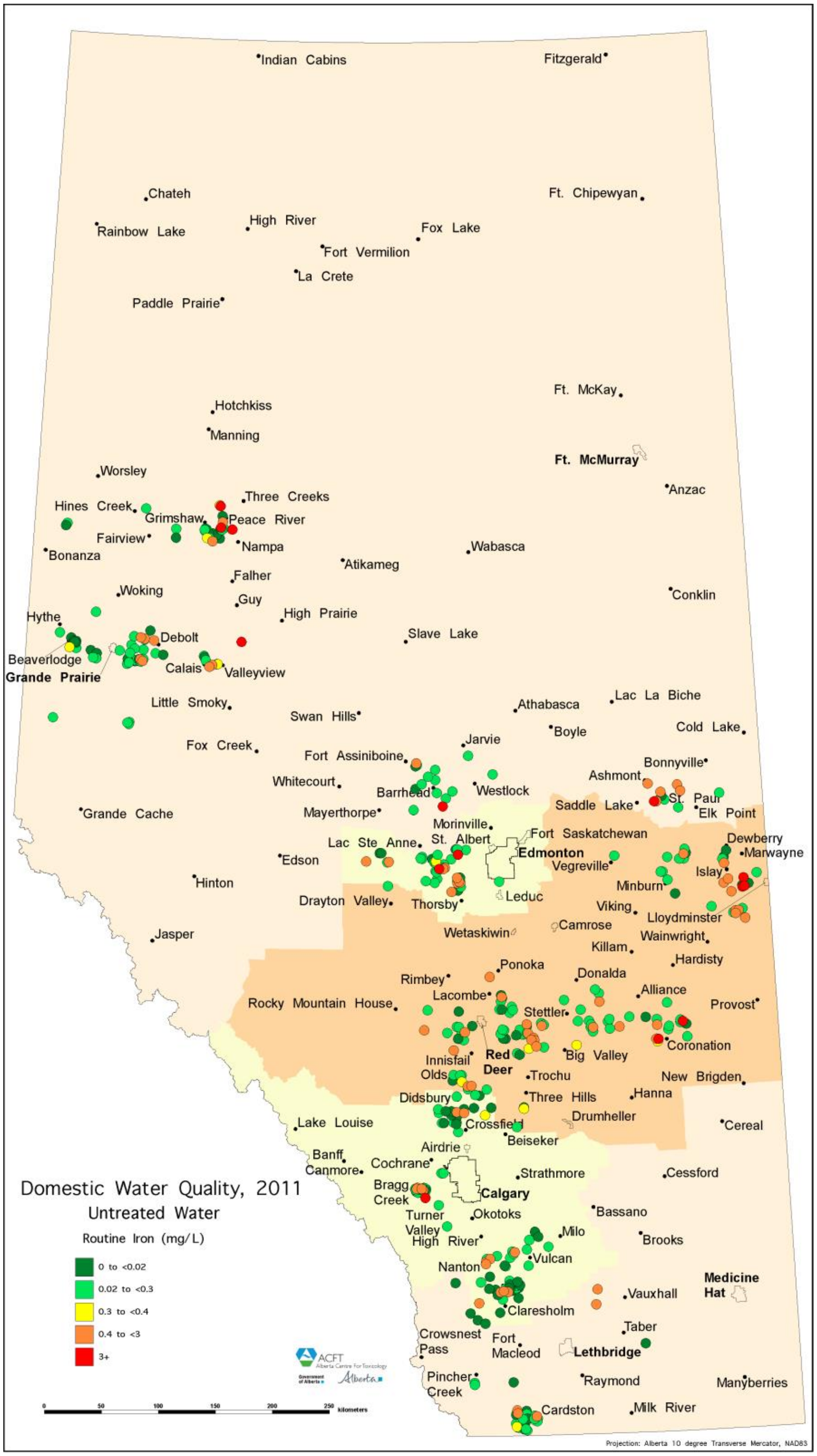


Figure 47 Spatial Patterns of Iron in Raw Water

Figure 48 Spatial Patterns of Iron in Treated Water

3.3.10 Fluoride

The levels of fluoride in raw water samples measured in this survey were higher than those measured in the Beaver River Basin (BRB) survey, but not significantly different from the Alberta summary study (AH 2013a, 2013b).

	Mean			Median		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Fuoride						
Raw	0.7	0.3	0.7	0.4	0.2	0.3
Treated	0.4	0.2	-	0.2	0.2	-

*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The distribution and spatial patterns of fluoride in raw and treated water samples are illustrated in Figure 49, 50, 51 and 52. The results are summarized as

1. fluoride levels exceeded the Health Canada guideline level of 1.5 mg/L in 15 per cent of raw water samples and the Alberta Standard of 2.4 mg/L in 6.8 per cent of raw water samples,
2. fluoride levels were within an optimal level for dental health (0.7 mg/L) in 3 per cent of raw water samples,
3. fluoride levels were less than an optimal level for dental health (0.7 mg/L) in 64 per cent of raw water samples,
4. overall, the levels of fluoride were significantly reduced in raw water samples after water treatment (Figure 49) ($p < 0.001$),
5. the levels of fluoride were lower in the Bragg Creek, Peace River and Vermillion regions (Figure 50) ($p < 0.01$), and
6. higher fluoride levels (that is, greater than 2.4 mg/L) may cause mottling of dental enamel in consumers.

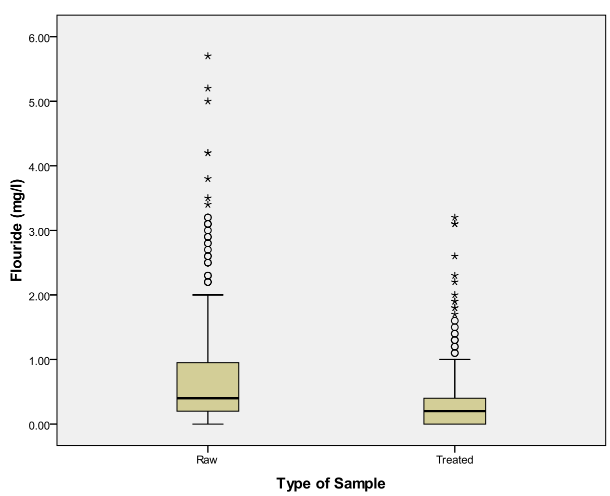


Figure 49 Distribution of Fluoride in Raw and Treated Water

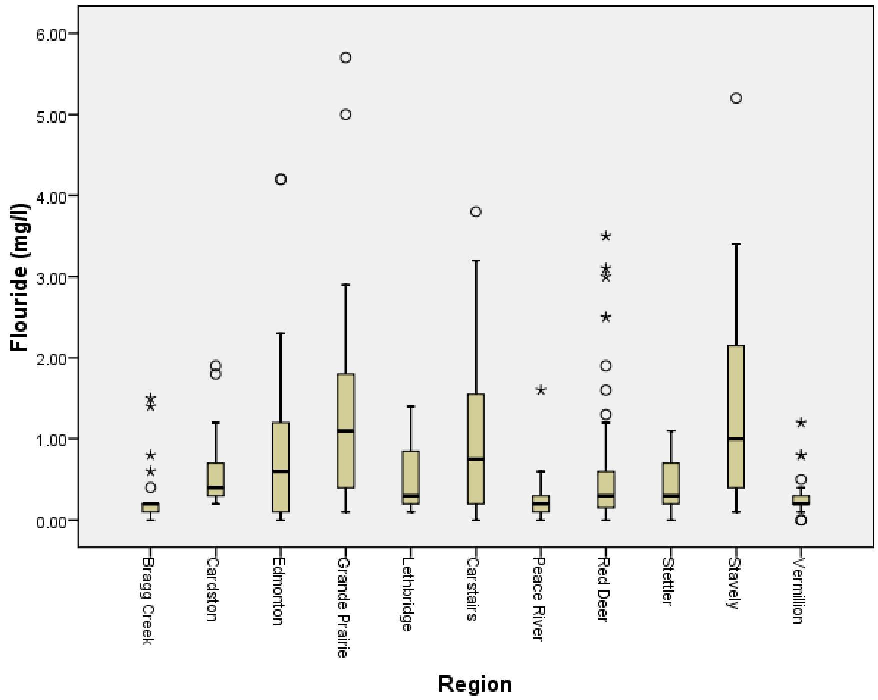


Figure 50 Regional Distribution of Fluoride in Raw Water

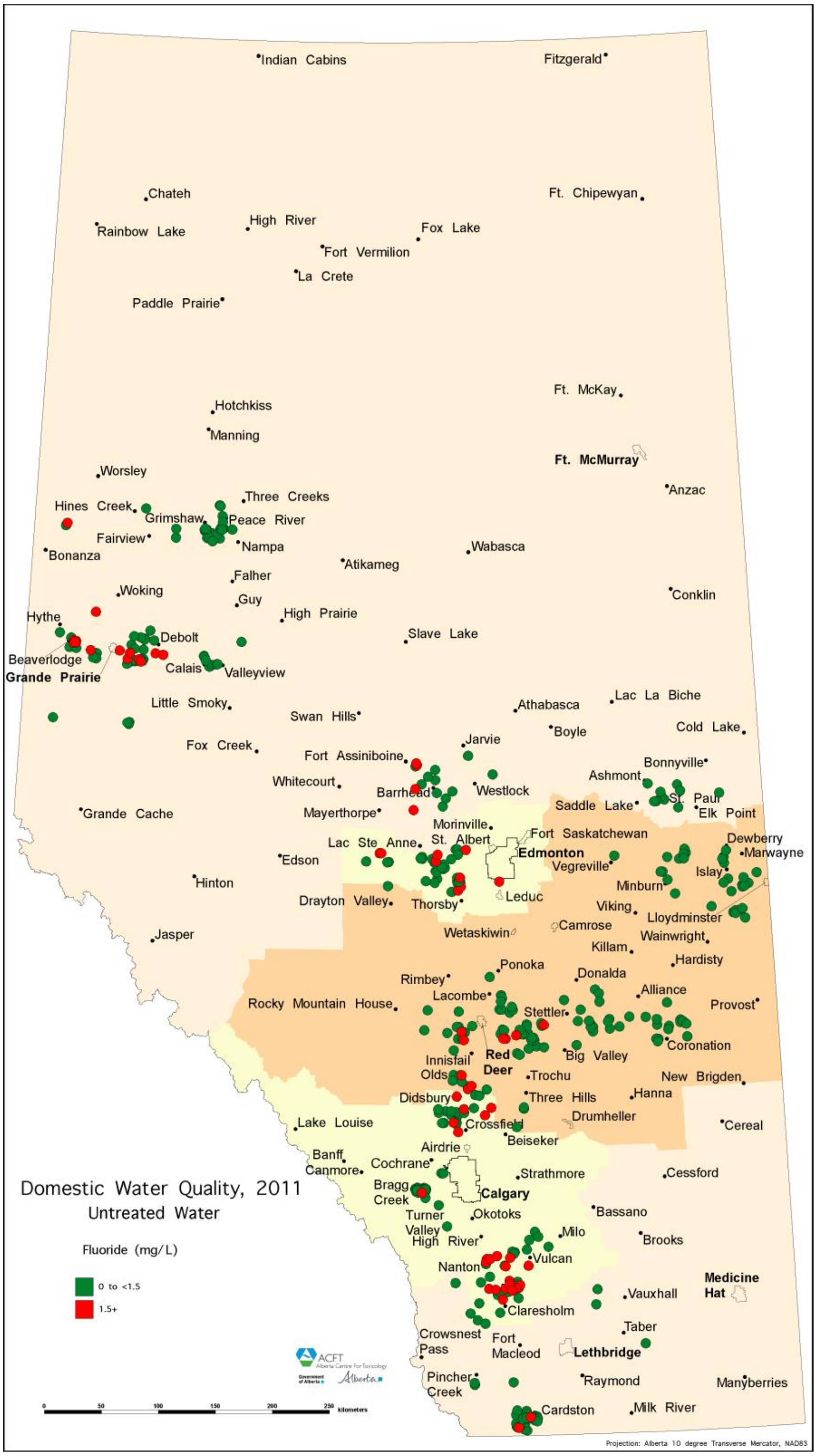


Figure 51 Spatial Patterns of Fluoride in Raw Water

Figure 52 Spatial Patterns of Fluoride in Treated Water

3.3.11 Nitrate and Nitrite

The levels of nitrate/nitrite in raw water samples measured in this survey were higher than those measured in the Beaver River Basin (BRB) survey, but not significantly different from the Alberta summary study (AH 2013a, 2013b).

	Mean			**Median**		
	Current	**BRB***	**Alberta****	**Current**	**BRB***	**Alberta****
Nitrate						
Raw	1.8	1.5	1.2	<1.0	<1.0	<1.0
Treated	1.4	1.4	-	<1.0	<1.0	-
Nitrite						
Raw	0.02	0.1	0.07	<0.1	<0.1	<0.1
Treated	0.01	<0.1	-	<0.1	<0.1	-

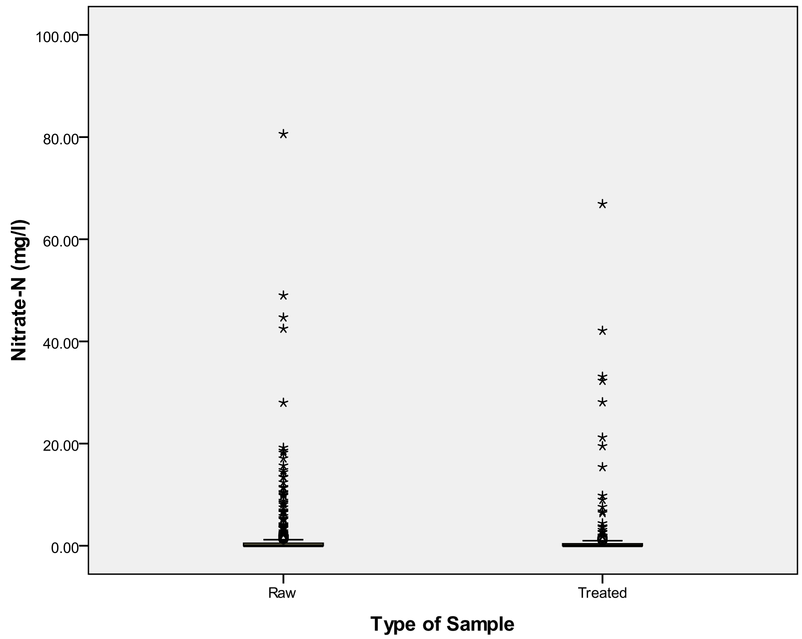
*Alberta Domestic Well Water Quality Monitoring – Beaver River Basin 2009
**Alberta Domestic Well Water Quality Monitoring – 2002-2008

The distribution and spatial patterns of nitrate/nitrite in raw and treated water samples are illustrated in Figure 53, 54, 55, 56, 57 and 58. The results are

1. nitrate levels exceeded the guideline level of 10 mg/L (NO_3-N) in 24 per cent of raw water samples and 5.5 per cent of treated water samples,
2. overall, the levels of nitrate/nitrite were not significantly reduced in raw water samples after water treatment (Figure 53) ($p > 0.05$),
3. the relative higher levels were observed in Lethbridge (3 samples), and
4. nitrate levels exceeding the guideline in 21 wells (see table below) were not correlated with well depth, distance to septic tanks and animal pens, and
5. Alberta Government regulations for setback distances for wells from contamination sources range from 10m to 100m (AG 2013).

House	**Nitrate** mg/L	**Well Depth** (meter)	**Distance to Septic Tank** (meter)	**Distance to Animal Pen** meter
SV-034	80	15	18	14
SV-018	49	46	213	18
NC-010	45	34	4	61
ST-009	43	12	100	30
LB-001	33	n/a	20	No
SV-035	28	15	76	107
LB-003	20	n/a	6	No
ST-018	19	12	46	No
NC-020	18	24	16	33
SV-008	17	30	98	No
SV-028	17	37	61	152
PR-019	16	n/a	61	400
SV-022	15	43	366	366
SV-026	14	37	23	152
CA-026	14	31	49	49
RD-015	13	24	24	300
PR-004	12	13	24	No
VM-006	12	16	60	No

House	Nitrate mg/L	Well Depth (meter)	Distance to Septic Tank (meter)	Distance to Animal Pen meter
NC-007	11	25	33	66
CA-001	10.5	n/a	328	164
CA-005	10.3	n/a	33	33



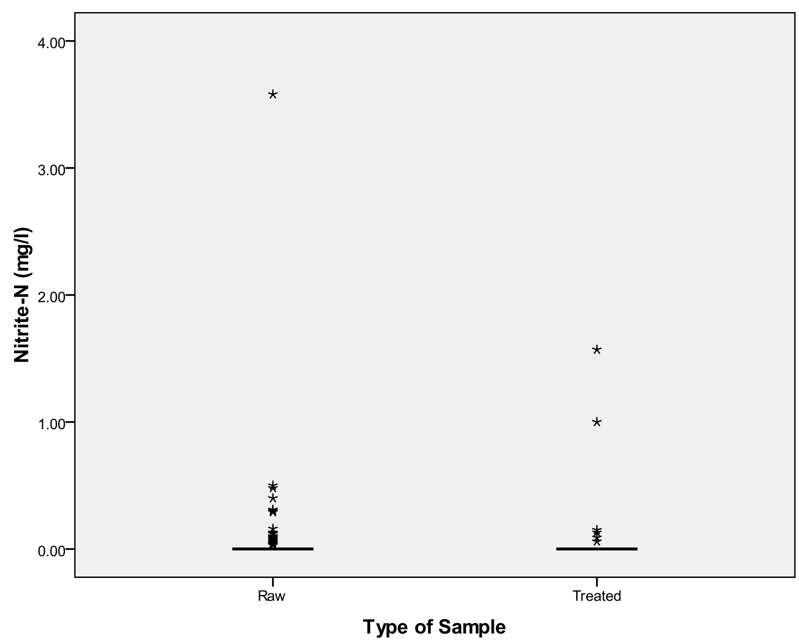
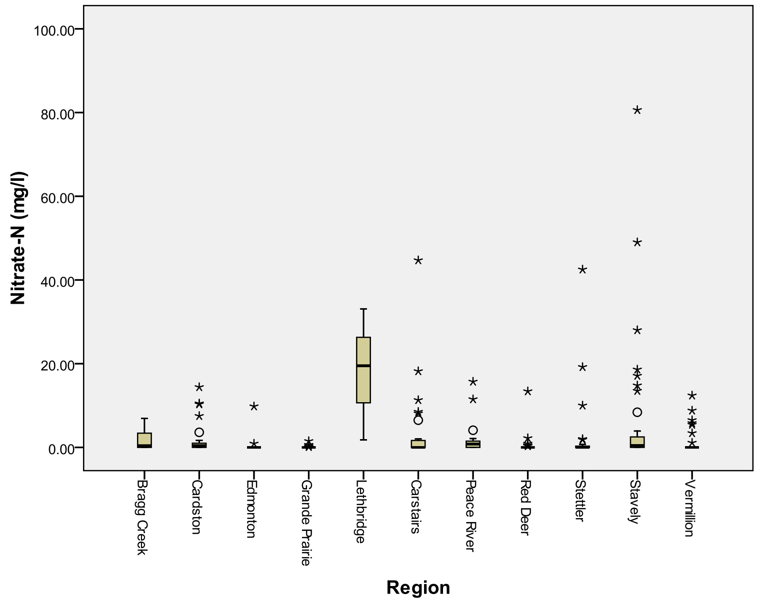


Figure 53 Distribution of Nitrate and Nitrite in Raw and Treated Water



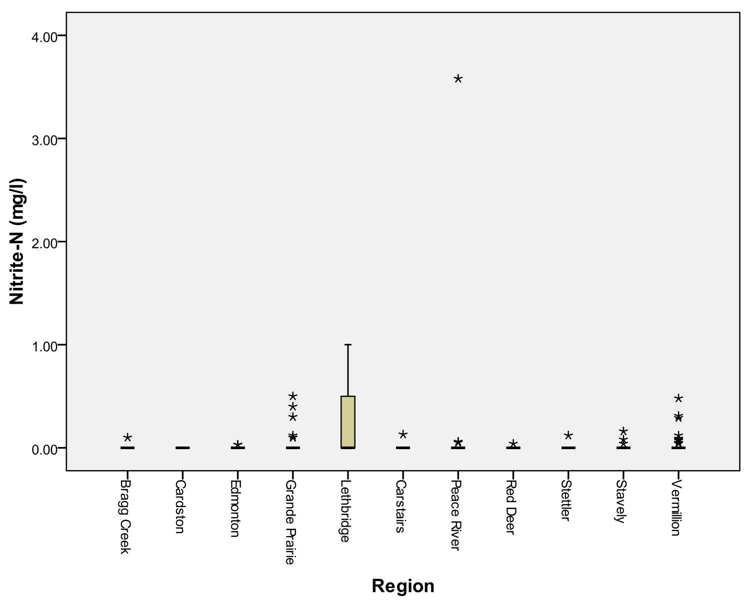


Figure 54 Regional Distribution of Nitrate/Nitrite in Raw Water

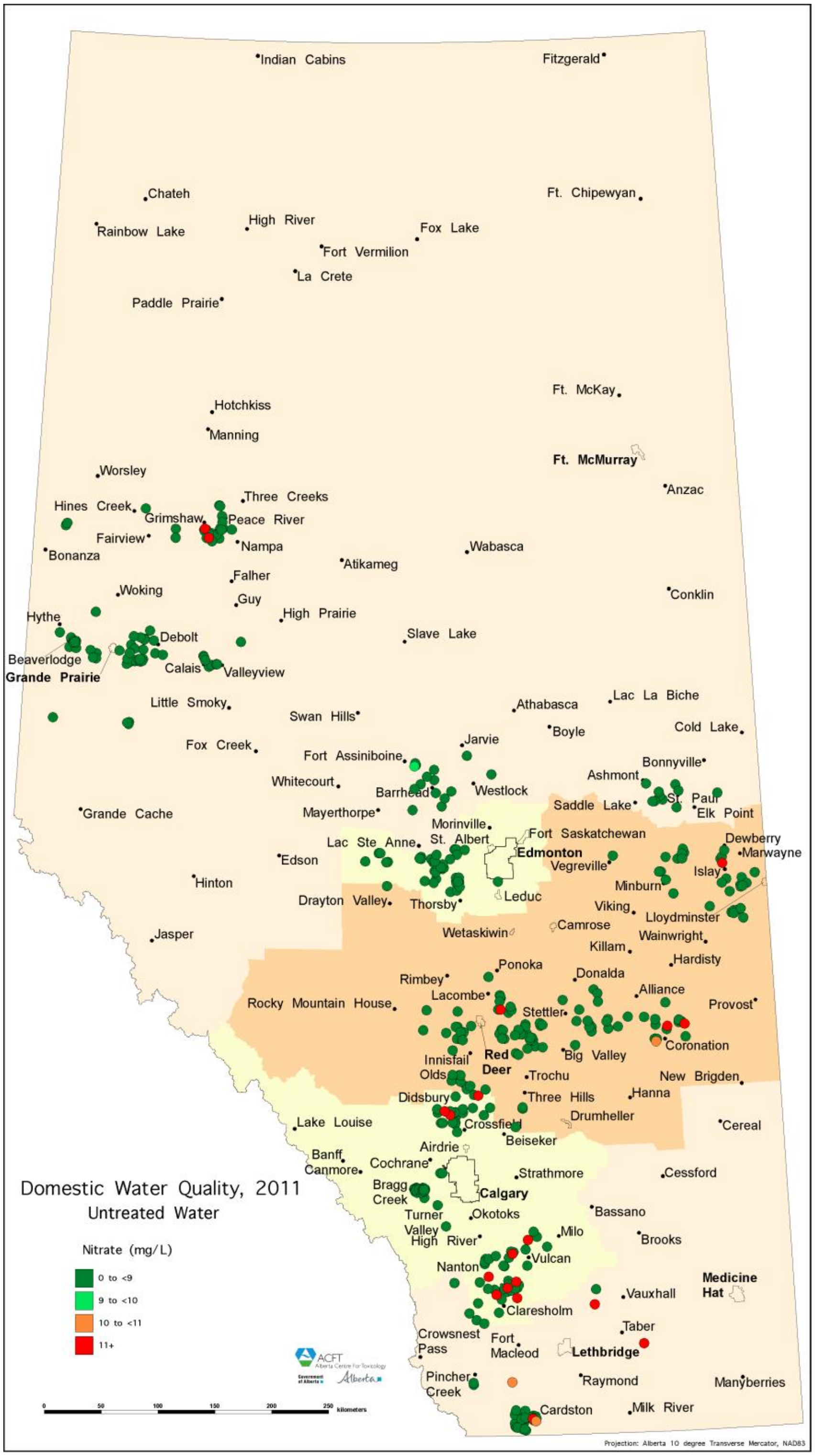


Figure 55 Spatial Patterns of Nitrate in Raw Water

Figure 56 Spatial Patterns of Nitrate in Treated Water

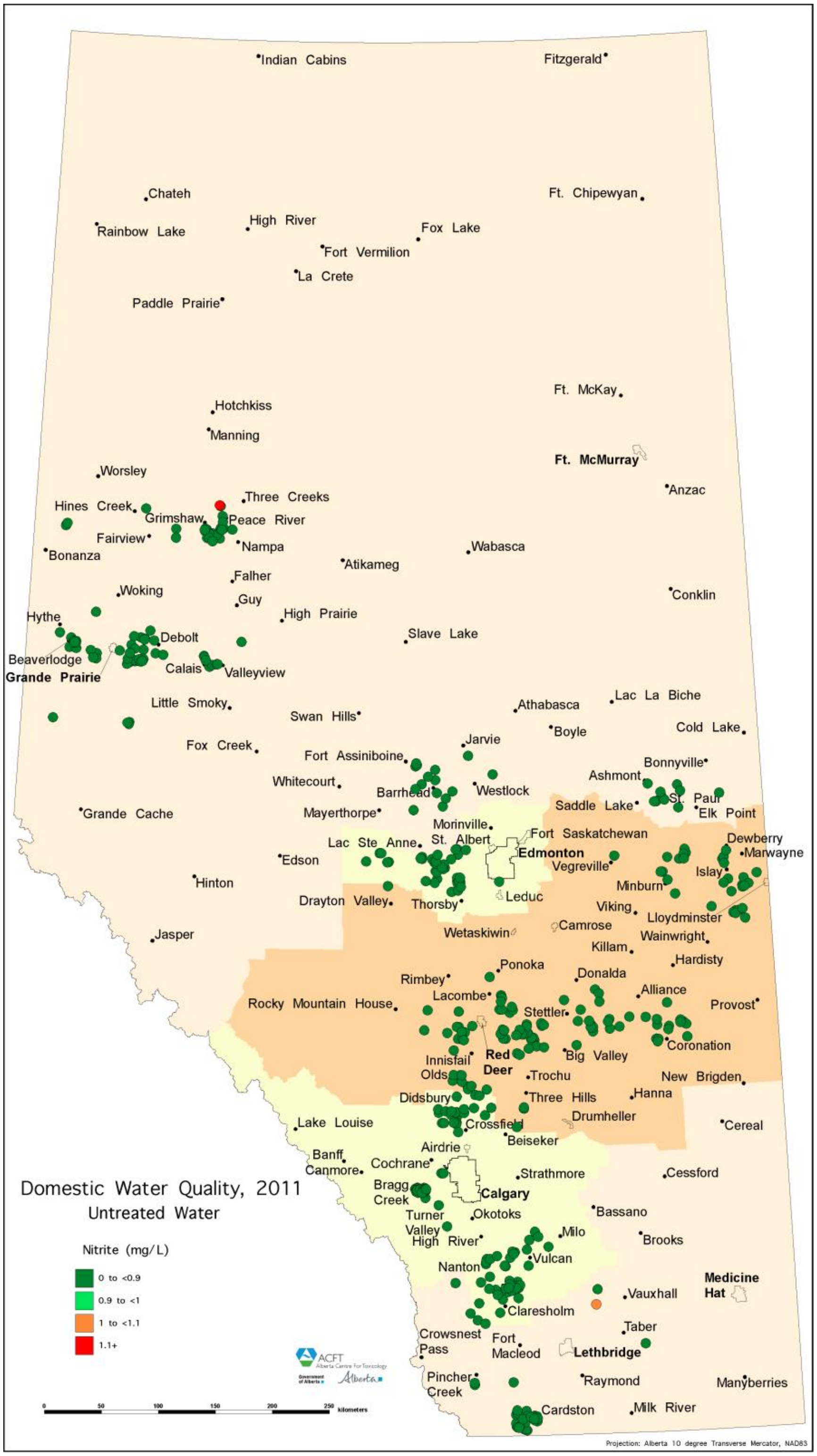


Figure 57 Spatial Patterns of Nitrite in Raw Water

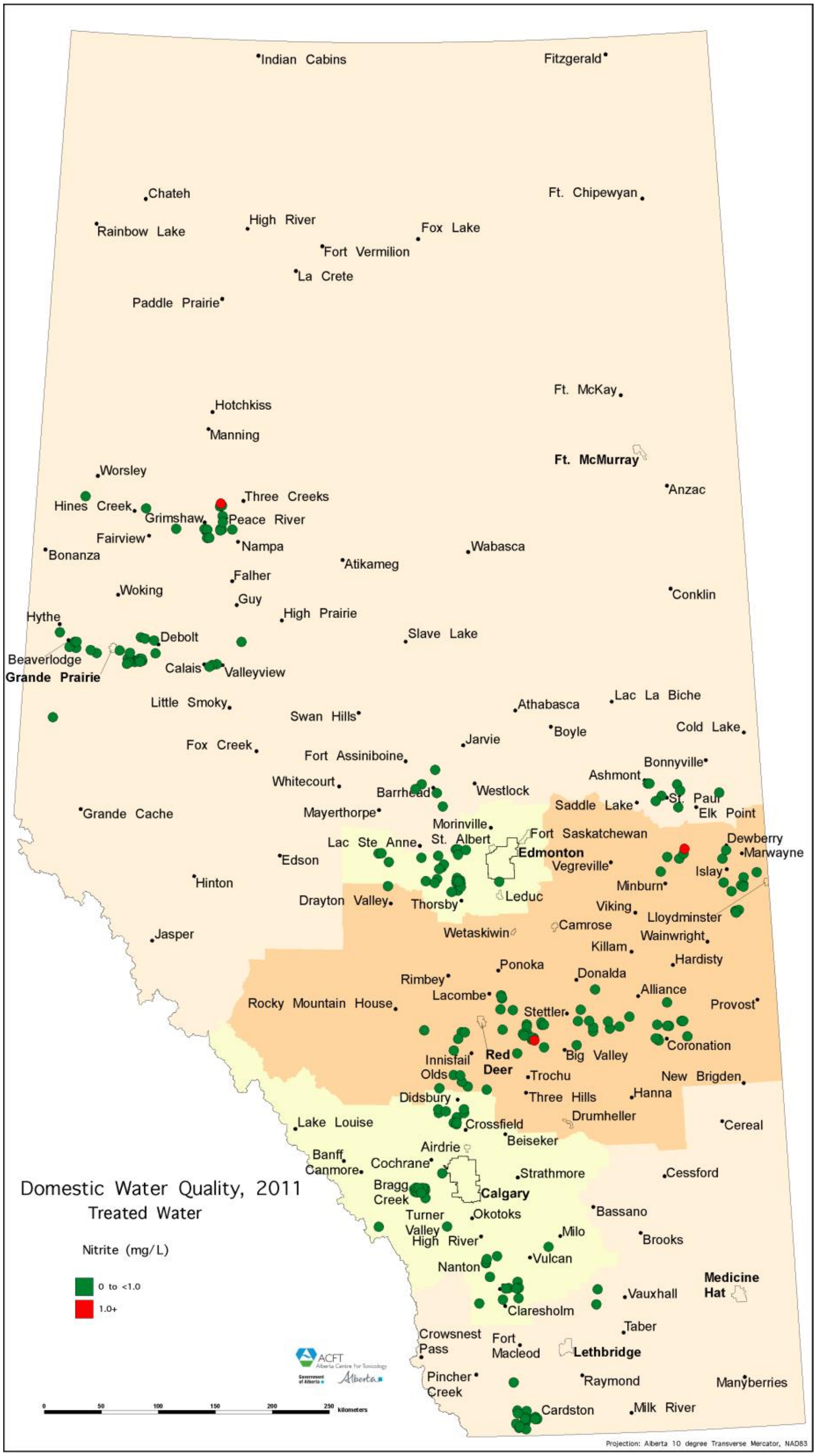


Figure 58 Spatial Patterns of Nitrite in Treated Water

Nitrate/nitrite levels in well water often indicate the impact of agricultural activities (Forrest et al. 2006). Geological characteristics also could influence nitrate levels in groundwater. Alberta Environment and Sustainable Resource Development conducted groundwater survey in regions related to agricultural activities in Alberta. Among 128 well water samples, nitrate levels exceeded the guideline in 2 shallow well water samples collected from nearby Lethbridge region. One well has been impacted by a nearby septic system and the other is likely to be natural (geologic nitrate) (AESRD http://environment.alberta.ca/02884.html).

Another indicator is the presence of bacteria in domestic well water.

The bacteriological test was conducted in the regions of Bragg Creek, Edmonton, Carstairs, and Stavely. The average of presence of E. Coli in well water was 14 per cent. The regions with high agricultural activities like Bragg Creek, Edmonton, Carstairs, and Stavely showed a higher per cent of E. Coli presence level than the region of Edmonton. Presence levels of bacteria were not correlated with nitrate levels among the regions. Water intended from human consumption should have no detection of E. Coli which serves as a precautionary indicator of the presence of fecal contamination and associated waterborne disease risk.

Region	**Sample Size**	**Absent**	**Present**	**Per Cent**
Bragg Creek	30	25	5	17
Edmonton	57	53	4	7
Carstairs	31	27	4	13
Stavely	44	37	7	16
Total	**162**	**142**	**20**	**14**

3.3.12 Summary

Domestic well water quality at a province level and the Beaver River Basin (BRB) region were assessed by Alberta Health in 2010 (AH 2013a, 2013b). The comparison of the median levels of physical properties and chemical parameters in raw water samples among three surveys is showed in Table 8.

Table 8 Comparison of Medians of Physical and Chemical Parameters

Parameter*	**Median in the BRB (mg/L)**	**Median in Alberta (mg/L)**	**Median in this study (mg/L)**
pH	8.1	8.4	8.3
Alkalinity	542	488	456
Electrical Conductivity	1,323	1,200	1,299
Total Dissolved Solids	826	729	774
Hardness	484	64	123
Calcium	117	17	31
Magnesium	46	4.5	11
Bicarbonate	661	570	549
Carbonate	0	7.6	4.8
Chloride	17	4.8	6
Sodium	85	250	249
Sulfate	109	70	106
Potassium	5.0	1.9	1.9
Iron	1.0	0.06	0.06
Fluoride	0.2	0.3	0.4
Nitrate-N	<1.0	<1.0	<1.0
Nitrite-N	<0.1	<0.1	<0.1

* Unit for each parameter: see Table 1.

As compared to the parameters across Alberta, raw domestic water quality in the selected region has its own characteristic:

1. overall water quality measured by using the suitability indicators of pH, alkalinity, conductivity and TDS was similar to the provincial average;
2. sulfate was higher than the provincial average level;
3. hardness of water was classified as “very hard water” in some regions and “soft” in other regions, while hardness of water was classified as “medium hard water or hard water” for the provincial average;
4. the levels of fluoride were similar to those across Alberta;
5. the nitrate levels exceeding the health-based guideline were observed in certain regions, particularly in the Southern Alberta;
6. 55 per cent of private well owners treated raw domestic well water for household use including for human consumption; and
7. after treatment, a significant reduction of levels of pH, alkalinity, conductivity, hardness, calcium, magnesium, carbonate, bicarbonate, sulfate, iron and fluoride was generally found.

3.4 Trace Element Testing

A statistical summary of results of trace element testing is listed in Table 9. Maximum Acceptable Concentrations (MAC) for some trace elements in drinking water have been proposed by Health Canada (2009). In cases where no guidelines have been specified, the World Health Organization drinking water guidelines were referenced (WHO 2011). The guidelines included health-based and aesthetic-quality-based guidelines. The percentages of the tested domestic well water samples with the values less than the guidelines are listed in Table 10.

The summary of the results of trace element testing is that

1. the levels of beryllium, mercury and thallium were not detected (less than 0.001 mg/L) in any raw or treated water samples;
2. the levels of antimony, boron, copper, mercury, nickel, and zinc were under the guideline values in any raw or treated water samples;
3. the levels of aluminum, arsenic, barium, cadmium, chromium, lead, molybdenum, selenium, and uranium were under the guideline values in 93 to 99 per cent of raw or treated water samples;
4. changes of trace element levels before and after water treatment were not significant for aluminum, antimony, arsenic, beryllium, boron, cobalt, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, uranium and zinc ($p > 0.05$);
5. after water treatment, a significant reduction ($p < 0.05$) of levels of barium (Figure 59/60), manganese (Figure 61/62) and titanium (Figure 63/64) were found; and
6. the levels of manganese were under the guideline value in 69 per cent of raw water samples and 87 per cent of treated water samples. Manganese often occurs together with iron in groundwater and the high levels of manganese can impart an unpleasant tastes and cause black or brown colour and staining in plumbing fixtures. The treatment methods for removing iron can also remove manganese efficiently.

Table 9 Statistical Summary of Trace Elements

Parameter	Type	Mean mg/L	Median mg/L	Min mg/L	Max mg/L	Percentile (mg/L)			
						10	**25**	**75**	**90**
Aluminum	Raw	0.020	0.007	0.003	0.783	0.004	0.006	0.010	0.014
	Treated	0.011	0.007	0.004	0.264	0.004	0.006	0.009	0.020
Antimony	Raw	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001
Arsenic	Raw	0.002	<0.001	<0.001	0.081	<0.001	<0.001	0.001	0.006
	Treated	0.002	0.002	<0.001	0.088	<0.001	<0.001	<0.001	0.003
Barium	Raw	0.110	0.044	<0.001	2.524	0.008	0.017	0.110	0.262
	Treated	0.048	0.002	<0.001	0.328	<0.001	<0.001	0.027	0.130
Boron	Raw	0.303	0.210	0.020	2.300	0.050	0.100	0.355	0.676
	Treated	0.279	0.160	<0.01	3.150	0.028	0.060	0.320	0.630
Cadmium	Raw	<0.001	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001
Chromium	Raw	<0.001	<0.001	<0.001	0.008	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	Raw	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	0.001
	Treated	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001
Copper	Raw	0.034	0.004	<0.001	6.088	<0.001	<0.001	0.013	0.042
	Treated	0.028	0.003	<0.001	0.777	<0.001	0.001	0.014	0.047
Lead	Raw	0.001	<0.001	<0.001	0.089	<0.001	<0.001	<0.001	0.002
	Treated	<0.001	<0.001	<0.001	0.058	<0.001	<0.001	<0.001	0.002
Manganese	Raw	0.094	0.013	<0.001	1.742	0.001	0.004	0.071	0.245
	Treated	0.037	0.002	<0.001	1.283	<0.001	<0.001	0.007	0.093
Molybdenum	Raw	0.006	0.002	<0.001	0.252	<0.001	<0.001	0.005	0.011
	Treated	0.004	<0.001	<0.001	0.232	<0.001	<0.001	0.002	0.005
Nickel	Raw	<0.001	<0.001	<0.001	0.015	<0.001	<0.001	0.001	0.002
	Treated	<0.001	<0.001	<0.001	0.033	<0.001	<0.001	<0.001	0.001
Selenium	Raw	<0.001	<0.001	<0.001	0.027	<0.001	<0.001	<0.001	0.002
	Treated	<0.001	<0.001	<0.001	0.017	<0.001	<0.001	<0.001	<0.001
Silver	Raw	<0.001	<0.001	<0.001	0.027	<0.001	<0.001	<0.001	0.002
	Treated	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	<0.001	<0.001
Titanium	Raw	0.003	0.001	<0.001	0.063	<0.001	<0.001	0.002	0.003
	Treated	0.001	<0.001	<0.001	0.033	<0.001	<0.001	0.001	0.001
Uranium	Raw	0.004	<0.001	<0.001	0.327	<0.001	<0.001	0.002	0.003
	Treated	0.003	<0.001	<0.001	0.306	<0.001	<0.001	0.001	0.001
Vanadium	Raw	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	<0.001
	Treated	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	Raw	0.069	0.010	<0.001	3.543	0.001	0.003	0.030	0.008
	Treated	0.034	0.005	<0.0001	1.633	<0.0001	0.002	0.018	0.065

Table 10 Guideline Compliance – Trace Elements

Parameter	Guideline Value (mg/L)	% under Guideline Before / After Treatment	Guideline – Source/type
Aluminum	0.1	97 / 99	HC- operation
Antimony	0.006	100 / 100	HC - health
Arsenic	0.01	93 / 95	HC - health
Barium	1.0	99 / 100	HC - health
Boron	5.0	100 / 100	HC - health
Cadmium	0.005	99.7 / 100	HC - health
Chromium	0.05	100 / 100	HC - health
Copper	≤ 1.0	99.7 / 100	HC - aesthetic-quality
Lead	0.01	99.7 / 98.6	HC - health
Manganese	≤ 0.05	68.8 / 87	HC - aesthetic-quality
Mercury	0.001	100 / 100	HC - health
Molybdenum	0.07	98.7 / 99	WHO - health
Nickel	0.07	100 / 100	WHO- health
Selenium	0.01	98 / 99.5	HC - health
Uranium	0.02	97 / 98.6	HC - health
Zinc	≤ 5.0	100 / 100	HC - aesthetic-quality

HC = Guidelines for Canadian Drinking Water Quality (Health Canada 2008), WHO = World Health Organization Guidelines for Drinking-water Quality, 3rd edition (WHO 2008)
*This value was in the 3rd edition of the WHO Guidelines for Drinking-water Quality, but it was dropped from the 4th edition in 2011.

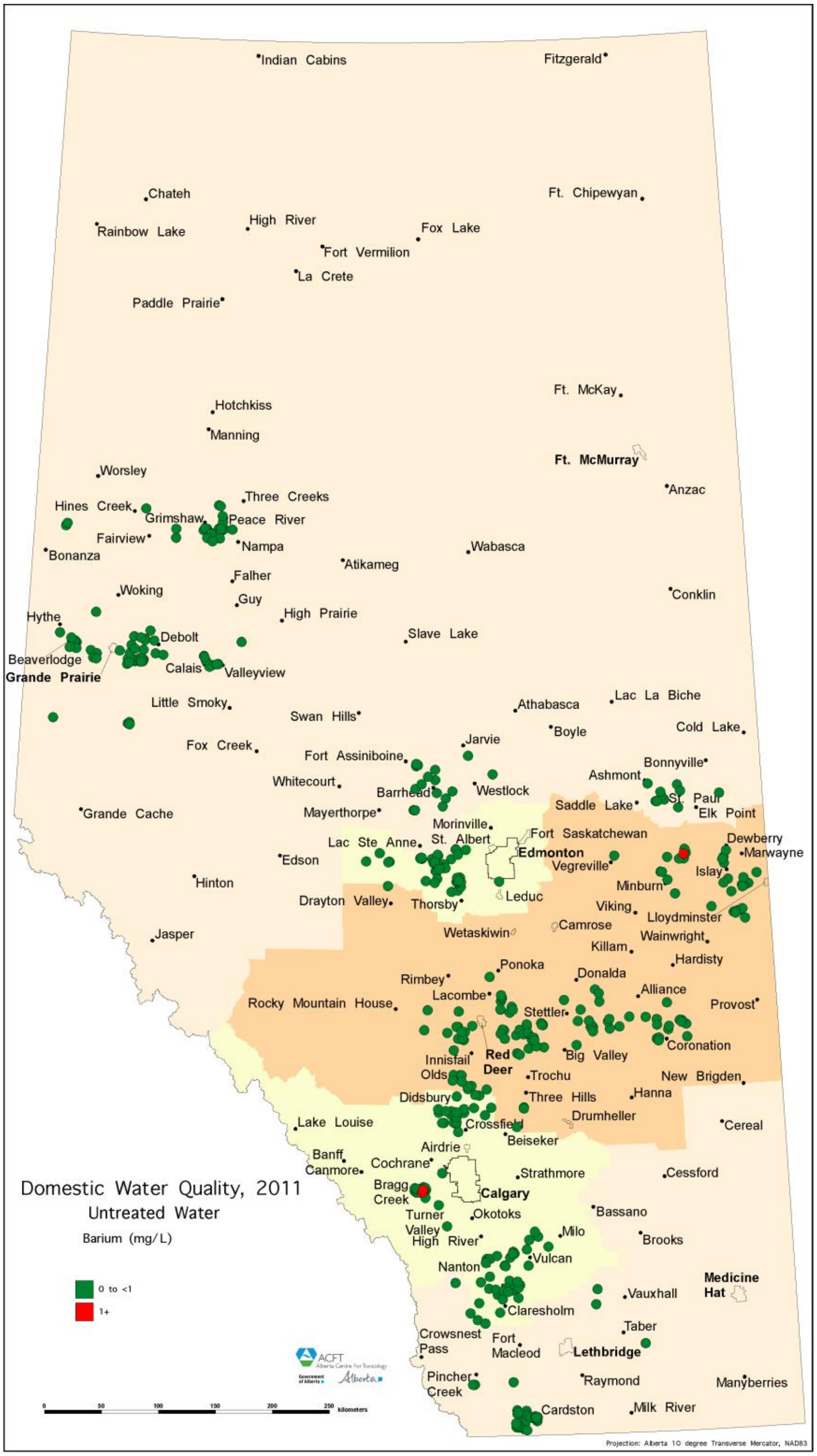


Figure 59 Distribution of Barium in Raw Water

Figure 60 Distribution of Barium in Treated Water

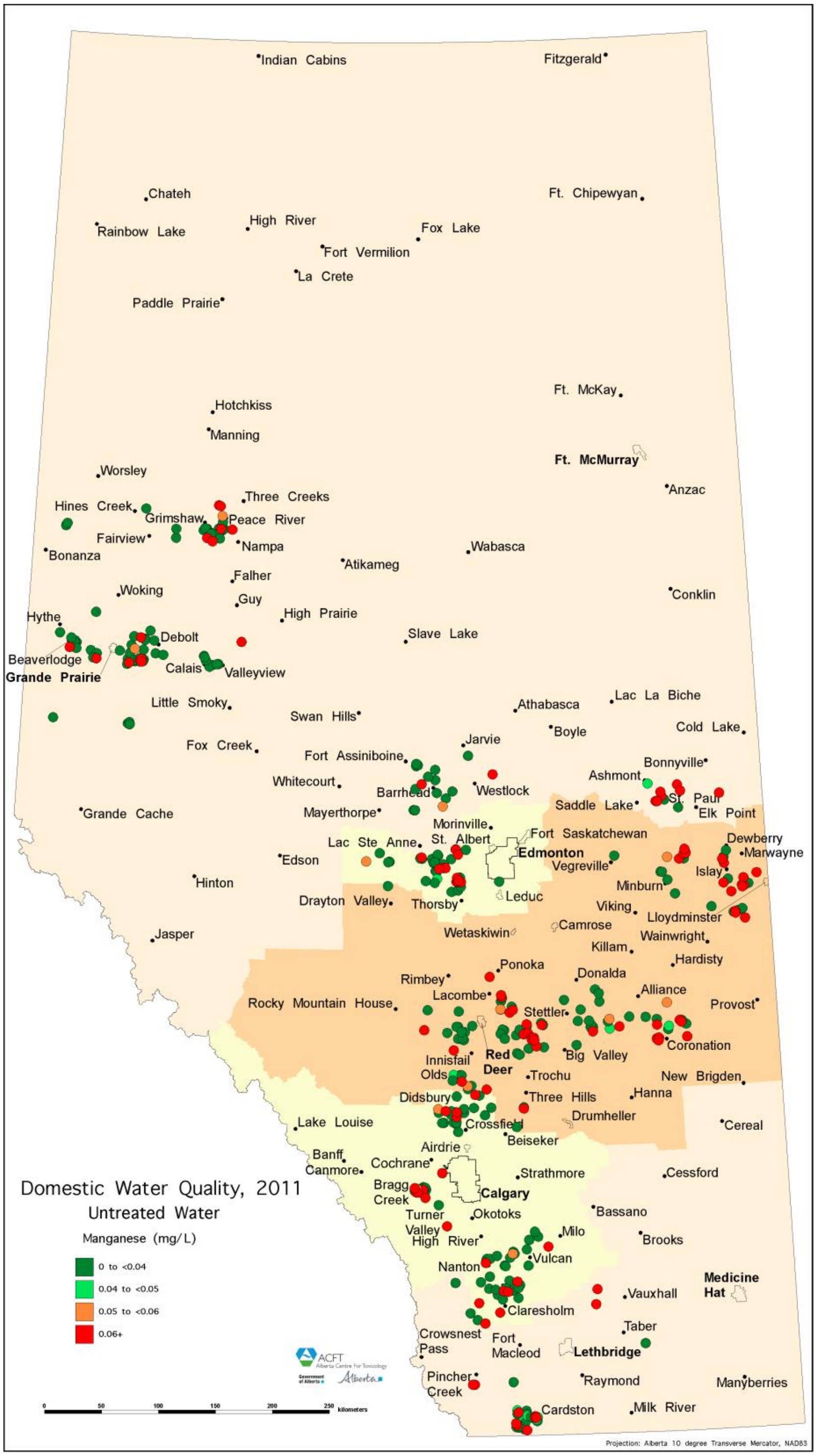


Figure 61 Distribution of Manganese in Raw Water

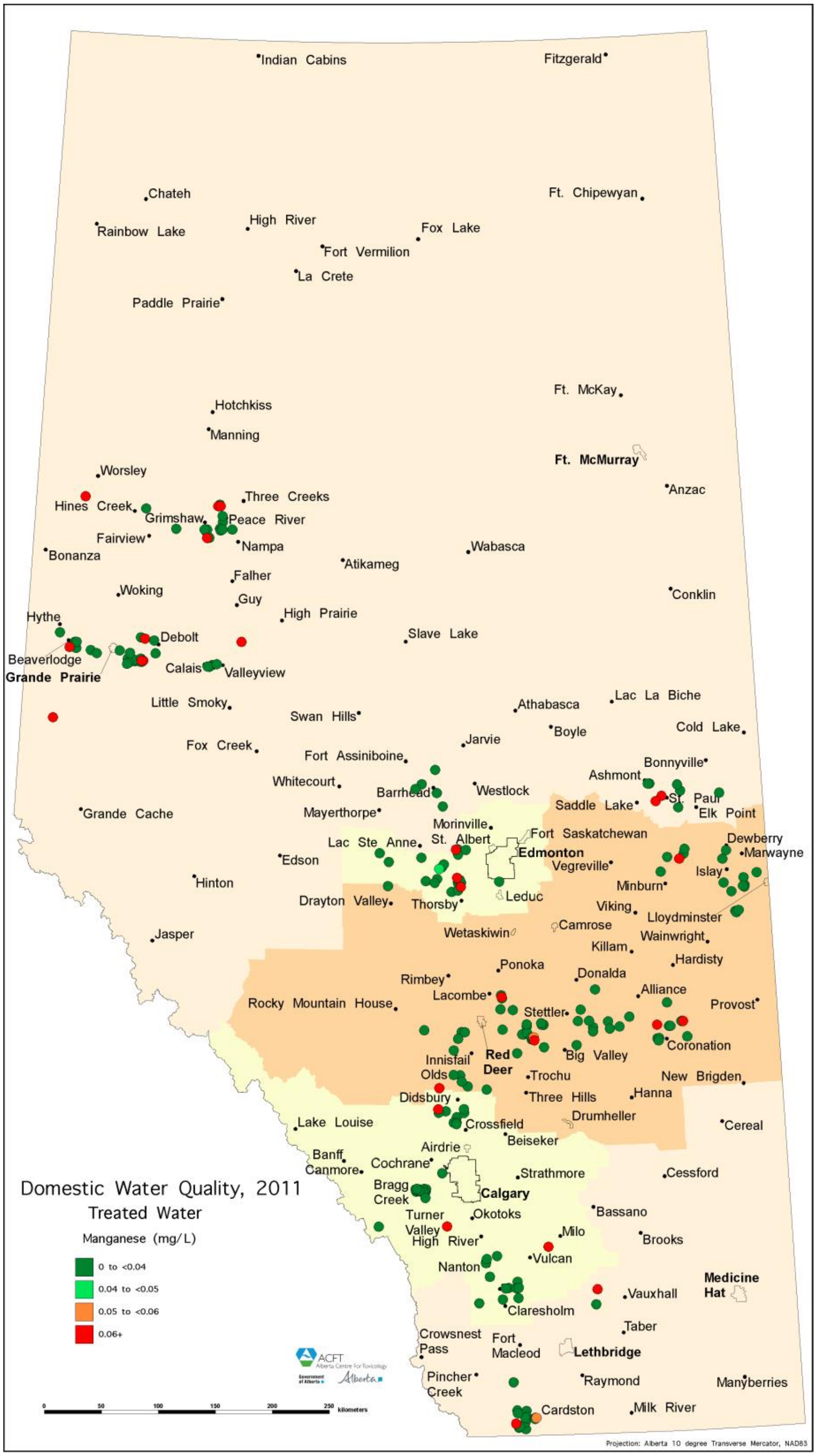


Figure 62 Distribution of Manganese in Treated Water

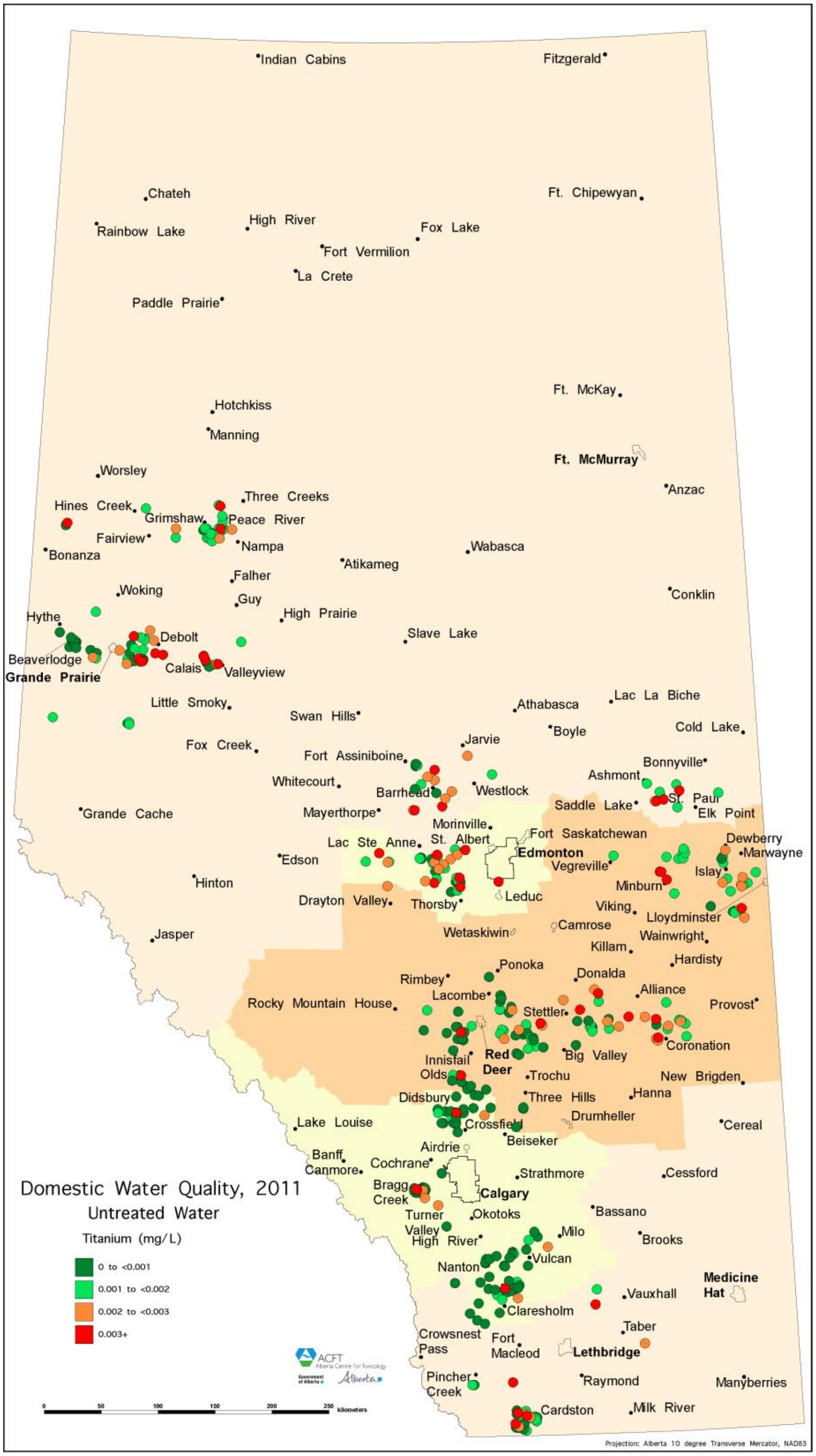


Figure 63 Distribution of Titanium in Raw Water

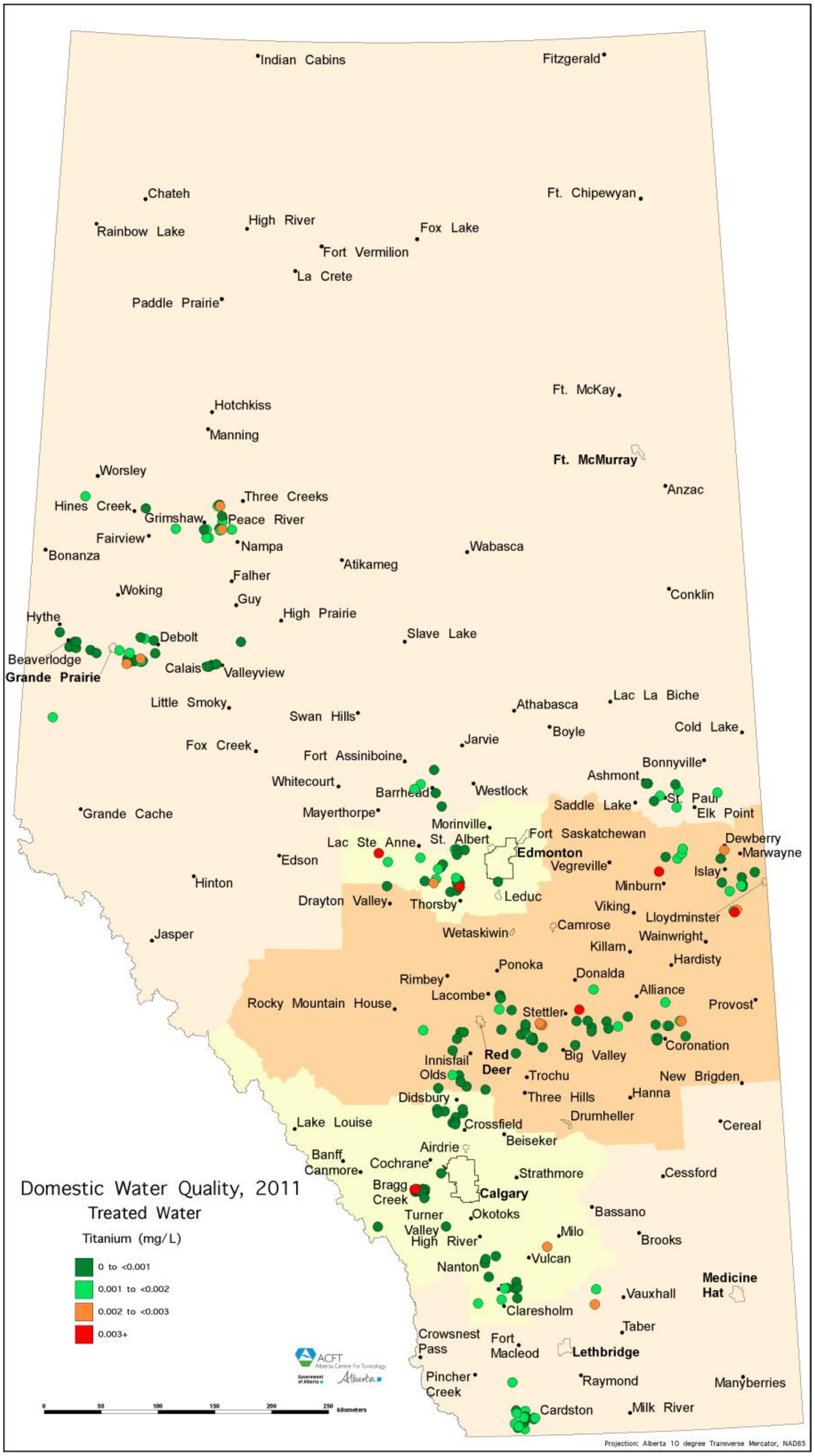


Figure 64 Distribution of Titanium in Treated Water

3.5 Arsenic Speciation and Treatment Effectiveness

In order to assess the effectiveness of treatment for removing arsenic from raw water, arsenic species AsIII and AsV were analyzed in 301 paired raw-treated well samples collected in the Beaver River Basin survey and the current survey. The concentrations of arsenic species in water before and after the treatment were compared to gain information on the effectiveness of various treatment methods (Table 11). AsIII and AsV levels were significantly reduced after treatment by using distillers, softener + RO, softener + iron filter, or softener + RO + iron filter. AsIII levels were significantly reduced after treatment by using RO.

Table 11 Arsenic Species Levels and Treatment Methods

Level (mg/L)	N	As III Raw ($\times10^{-3}$)	As III Treated ($\times10^{-3}$)	p value†	As V Raw ($\times10^{-3}$)	As V Treated ($\times10^{-3}$)	p value†
Overall combined							
mean	303	4.30	2.74		1.88	1.20	
median	303	0.19	<0.001	**<0.001**	0.26	0.12	**<0.001**
Distiller							
mean	10	0.48	<0.001		0.38	0.04	
median	10	0.12	<0.001	**0.016**	0.17	<0.001	**0.016**
Reverse Osmosis (RO)							
mean	15	0.49	0.06		2.22	0.32	
median	15	<0.001	<0.001	**0.016**	0.10	0.12	1.0
Iron Filter (IF)							
mean	22	1.94	0.86		0.76	0.65	
median	22	0.12	<0.001	0.23	0.07	0.10	0.77
Softener							
mean	98	6.79	5.41		2.17	1.76	
median	98	0.25	0.23	0.60	0.50	0.24	0.0003
Carbon Filter							
mean	4	0.81	0.09		0.15	0.12	
median	4	<0.001	<0.001	1.0	0.05	0.13	1.0
RO + IF							
mean	6	1.20	0.02		0.27	0.33	
median	6	0.25	<0.001	0.25	0.21	<0.001	1.0
Softener + IF							
mean	44	7.02	4.19		4.06	2.78	
median	44	3.26	0.29	**0.004**	1.58	0.82	**0.047**
Softener + RO							
mean	24	2.59	0.06		1.54	0.37	
median	24	0.15	<0.001	**<0.001**	0.15	<0.001	**0.013**
Softener + RO + IF							
mean	15	6.96	0.67		1.29	1.03	
median	15	0.17	<0.001	**0.004**	0.36	<0.001	**0.022**

* a total of 303 raw-treated paired wells, and there were additional treated tap water samples collected in four houses. † nonparametric test (sign test)

3.6 Water Consumption Patterns

A total of 397 participants provided the information on the well water consumption and well water use pattern. The information is summarized in Table 12. Over 90 per cent of well owners used well water for cooking, washing food, brushing teeth, bathing and showering, and laundry. Eighty per cent of well owners used well water for human consumption. Total fluid consumption was 2.6 L/d per person and total well water consumption was 1.8 L/d per person.

Table 12 Summary of Water Consumption Patterns

Activity	This Study	Beaver River Basin Study
consumed cold tap water from the kitchen tap	80%	70%
consumed cold tap water from the kitchen tap plus cold bottled water	13%	32%
used tap water for drinking	80%	70%
used tap water for cooking	98%	95%
used tap water for washing food	94%	96%
used tap water for making beverages	84%	70%
used tap water for brushing teeth	94%	95%
used the water in house for laundry and bathing/showering	94%	93%
an average volume of total fluid consumption (tap water, bottled water, beverages, soup etc.)	2.6 L/d	3.2 L/d
an average volume of water consumption	1.8 L/d	2.0 L/d

3.7 Reported Water Quality Issues and Well Maintenance

Questionnaires on reported well water quality issues and well maintenance were completed for each participant. The results are summarized in Table 13. Seventy two per cent of owners complained about the well water quality issues in terms of colour, smell and taste. Forty six per cent of owners used shock chlorination. The average distance from wells to septic tanks, animal pens and fertilizer storages were over 60 meters. In some cases these distances were substantially smaller (i.e. only 2 to 6 m).

Table 13 Reported Well Water Quality Issues

Question	Yes # participant	% of participant	Description
Do you have any well water quality issues?	286	72	sulphur odor, rust, hardness, color, salt taste,
Has there been recent flooding or high water around the well?	18	5	
Was the well shock chlorinated?	183	46	
At what depth is your screen set?	122	31	Mean = 48 m Range: 6 – 115 m
At what depth is your pump set?	238	60	Mean = 36 m Range: 2 – 140 m
Distance from septic tank/field/ discharge	356	90	Mean = 98 m Range: 5 – 1,600 m
Distance from manure storage	27	7	Mean = 259 m Range: 23 – 1,600 m
Distance from animal pens	198	50	Mean = 115 m Range: 2 – 1,600 m
Distance from fuel storage	172	43	Mean = 78 m Range: 3 – 457 m
Distance from fertilizer storage	13	3	Mean = 360 m Range: 91 – 488 m

4. CONCLUSIONS

The major findings are summarized below:

1. overall water quality measured by using the indicators of pH, alkalinity, conductivity and total dissolved solids was similar to the provincial average level;
2. sulfate was relatively higher than the provincial average level;
3. hardness of water was classified as “very hard water” in some regions and “soft water” in other regions;
4. the levels of fluoride were similar to those elsewhere in Alberta;
5. the nitrate levels exceeding the health-based guideline were observed in certain regions, particularly in the Southern Alberta;
6. fifty five per cent of private well owners treated raw water for house use including human consumption;
7. the levels of aluminum, arsenic, barium, cadmium, chromium, lead, molybdenum, selenium, and uranium were under the guideline values in 93 per cent in raw water; and
8. after treatment, a significant reduction of levels of alkalinity, conductivity, hardness, calcium, magnesium, carbonate, bicarbonate, sulfate, iron, fluoride, barium, manganese and titanium was found.

5. RECOMMENDATIONS

The findings suggest recommendations as:

1. private well owners continue to contact Alberta Health Services to test the well water quality regularly, and
2. local public health officers in Alberta Health Services will routinely discuss well water quality, testing schedule, testing results, treatment methods, well maintenance, well protection and health concerns with private well owners.

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