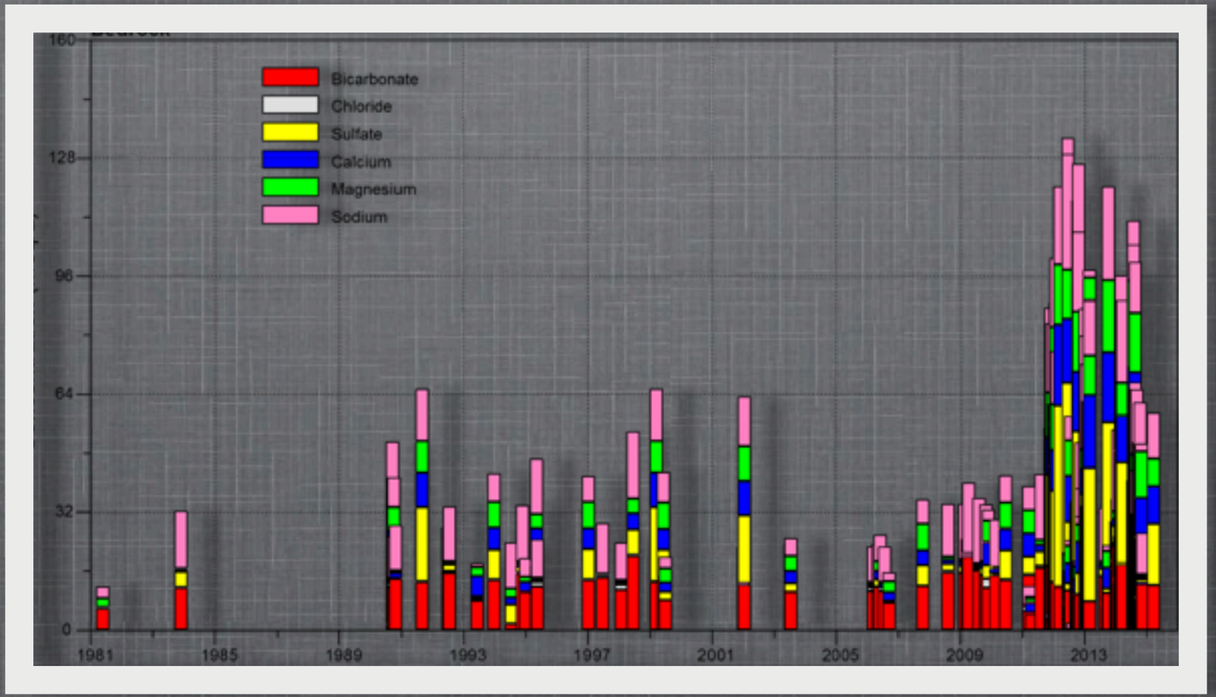
PEACE RIVER REGIONAL DISTRICT
WATER QUALITY BASELINE



PRRD - T8TA

GW Solutions - Interraplan

Chetwynd, Dawson Creek,
Charlie Lake, September 2016

First Nations, thank you for having us on your land.

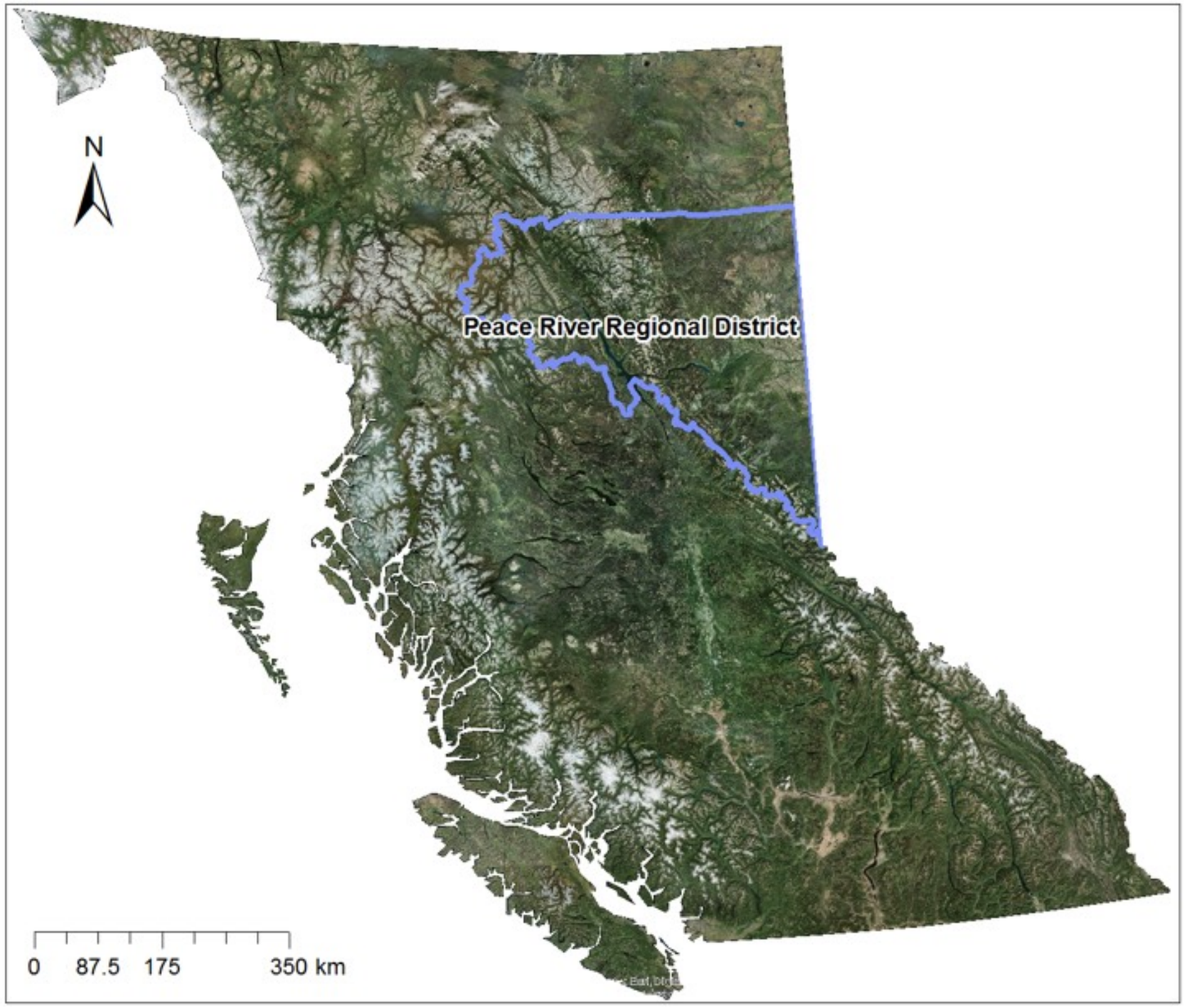
OUTLINE

- Data and Tools
- Surface Water / Groundwater Interaction
  - Regional Context - Human Activities
- Comparison to Guidelines
- Detailed Analyses / Results
  - Scatter, Piper, Mekko Plots, etc.

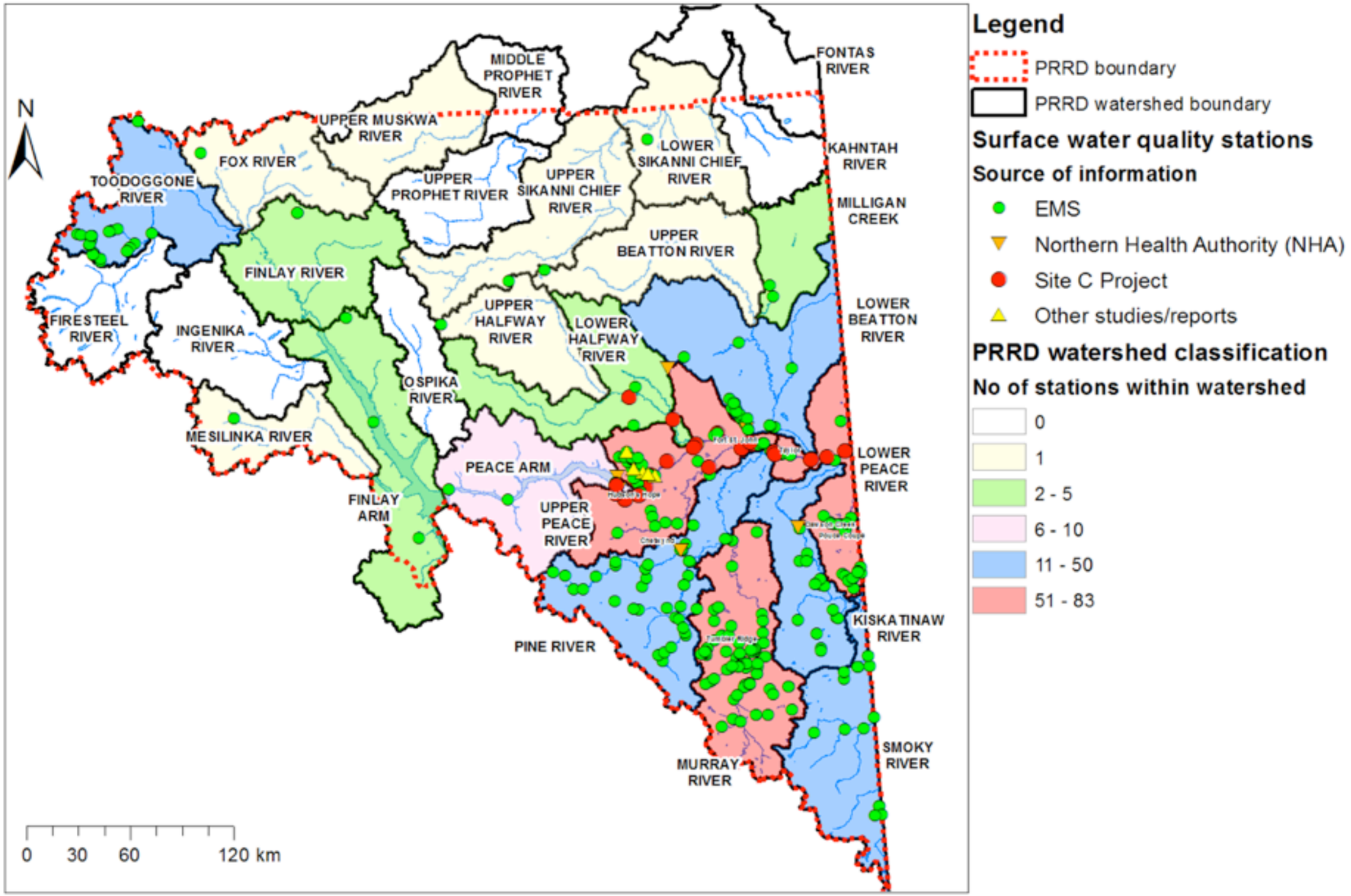
OUTLINE (2)

- Water Quality Index
  - Spatial Visualisation/Comparison
  - Trend Analysis
- Anomalies & Potential Impact on Water Supply
  - Barium in Groundwater
- Conclusions

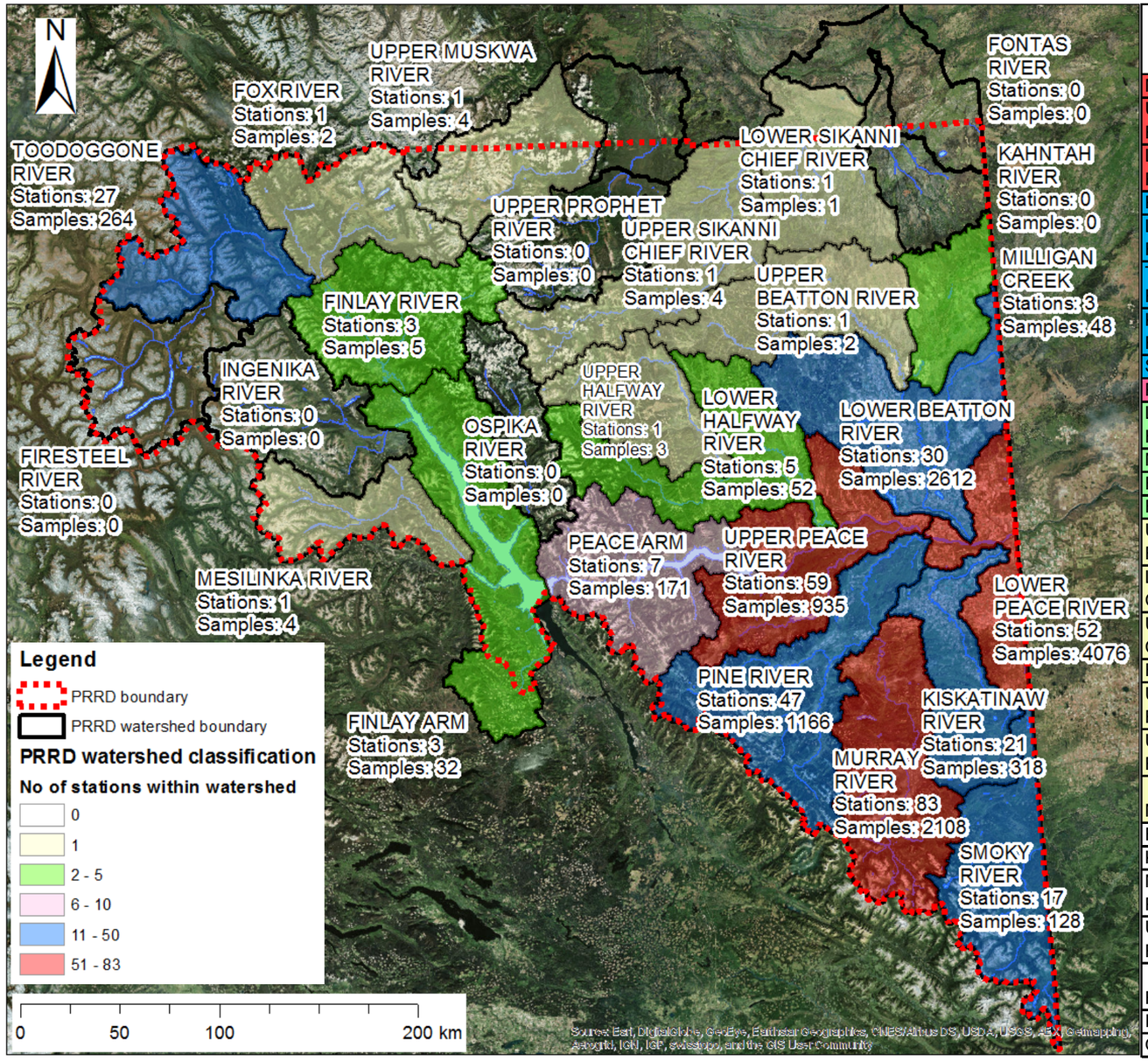
DATA AND TOOLS


N
Peace River Regional District
0 87.5 175 350 km

Surface Water - Data Source



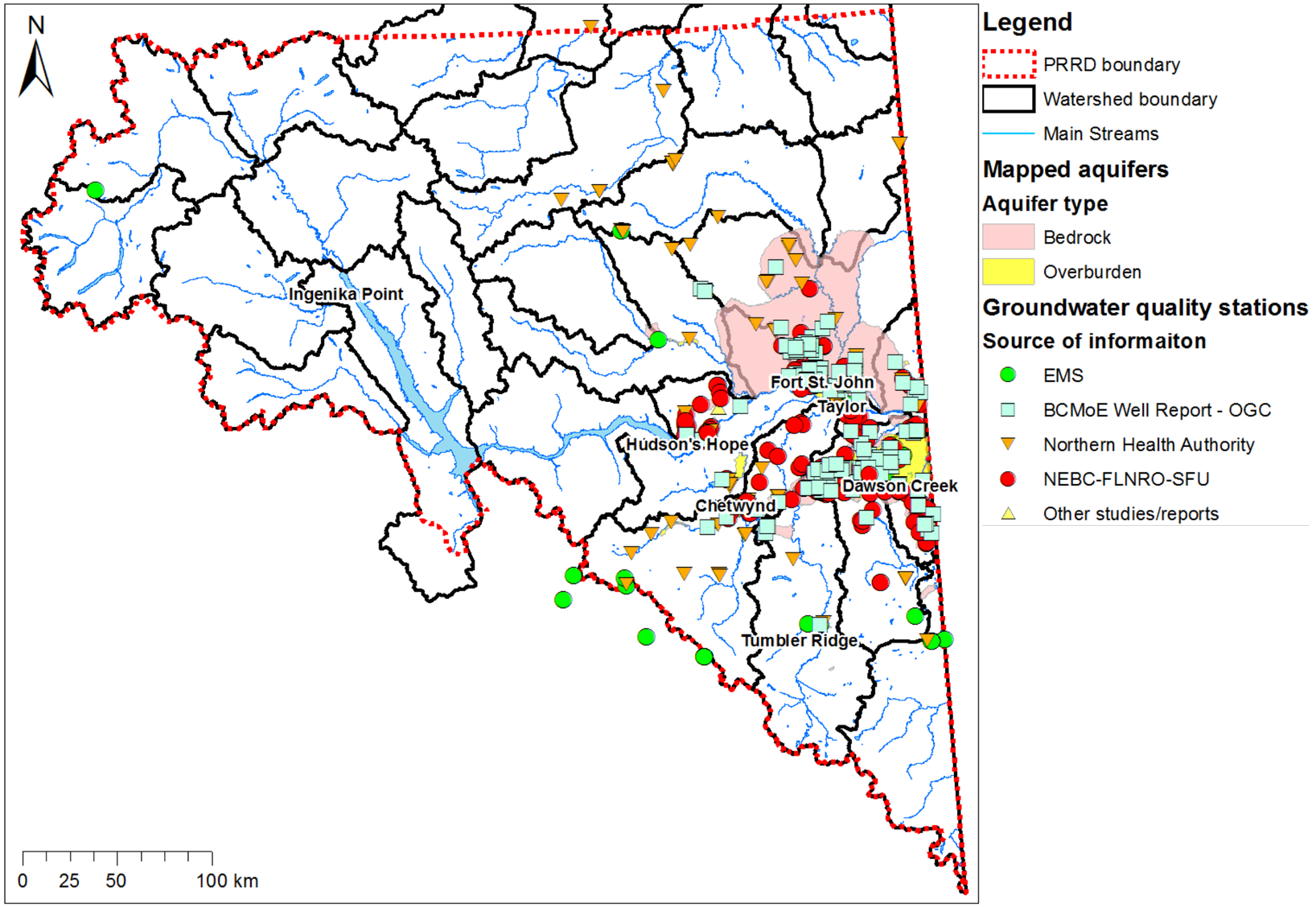
Surface Water - Stations and Samples



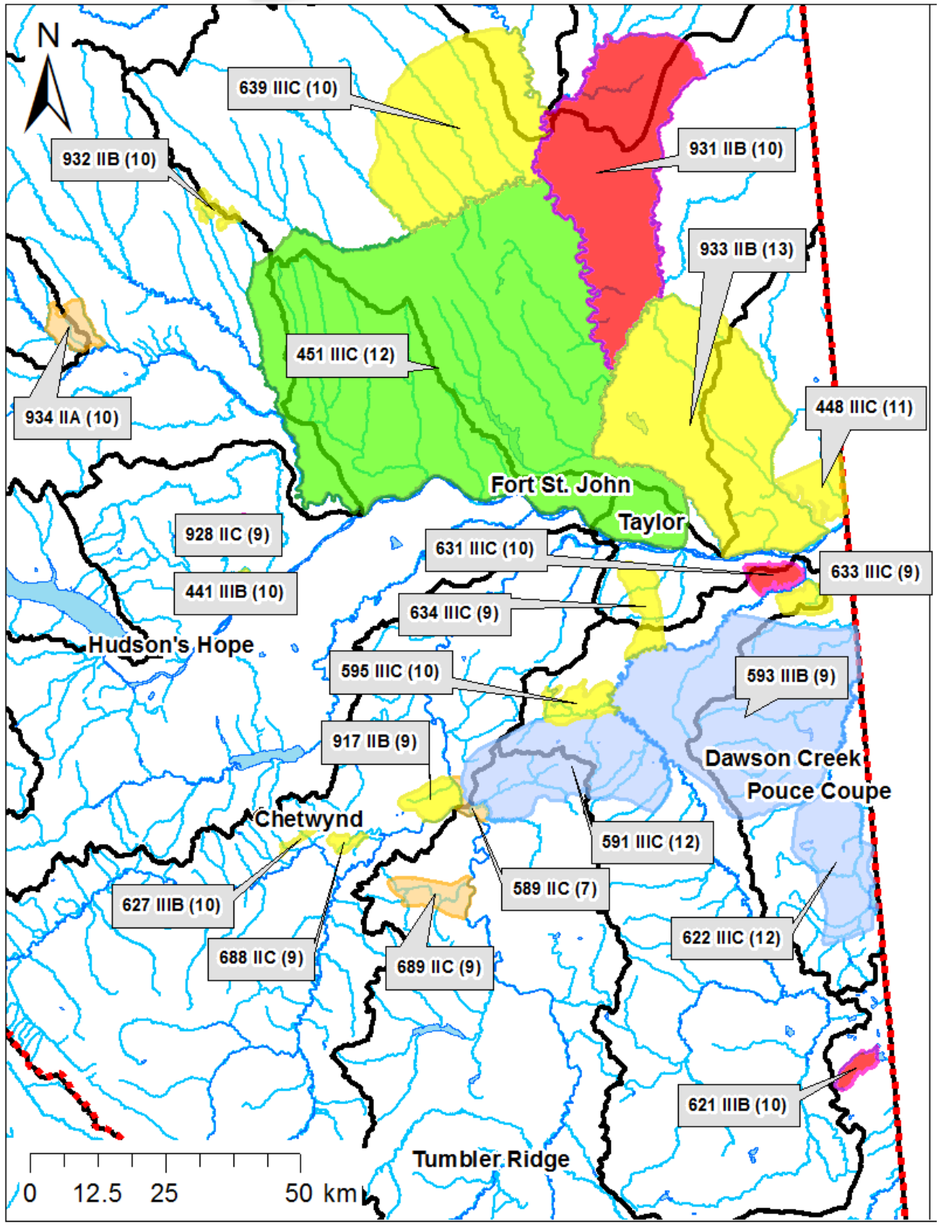
PRRD Watershed	Area (km^2)	% Area compared to PRRD	No of stations	No of samples
MURRAY RIVER	6489.2	5.4%	83	2108
UPPER PEACE RIVER	5736.6	4.8%	59	935
LOWER PEACE RIVER	3268.9	2.7%	52	4076
PINE RIVER	7015.0	5.9%	47	1166
LOWER BEATTON RIVER	7167.8	6.0%	30	2612
TOODOGGONE RIVER	4831.2	4.1%	27	264
KISKATINAW RIVER	4097.9	3.4%	21	318
SMOKY RIVER	5087.7	4.3%	17	128
PEACE ARM	5896.0	4.9%	7	171
LOWER HALFWAY RIVER	5617.9	4.7%	5	52
MILLIGAN CREEK	2635.2	2.2%	3	48
FINLAY RIVER	5504.3	4.6%	3	5
FINLAY ARM	7349.0	6.2%	3	32
UPPER MUSKWA RIVER	4259.4	3.6%	1	4
LOWER SIKANNI CHIEF RIVER	4678.6	3.9%	1	1
UPPER SIKANNI CHIEF RIVER	6419.3	5.4%	1	4
FOX RIVER	4312.2	3.6%	1	2
UPPER BEATTON RIVER	5218.4	4.4%	1	2
UPPER HALFWAY RIVER	3783.8	3.2%	1	3
MESILINKA RIVER	3302.4	2.8%	1	4
FONTAS RIVER	3890.1	3.3%	0	0
KAHNTAH RIVER	2782.4	2.3%	0	0
MIDDLE PROPHET RIVER	2757.5	2.3%	0	0
UPPER PROPHET RIVER	4114.2	3.5%	0	0
FIRESTEEL RIVER	4392.3	3.7%	0	0
INGENIKA RIVER	5330.8	4.5%	0	0
OSPIKA RIVER	2973.1	2.5%	0	0

11935 samples

Groundwater - Data Source



Groundwater - Bedrock Wells



PRRD boundary

Watershed boundary

Main Streams

Bedrock aquifer

Number of water quality stations

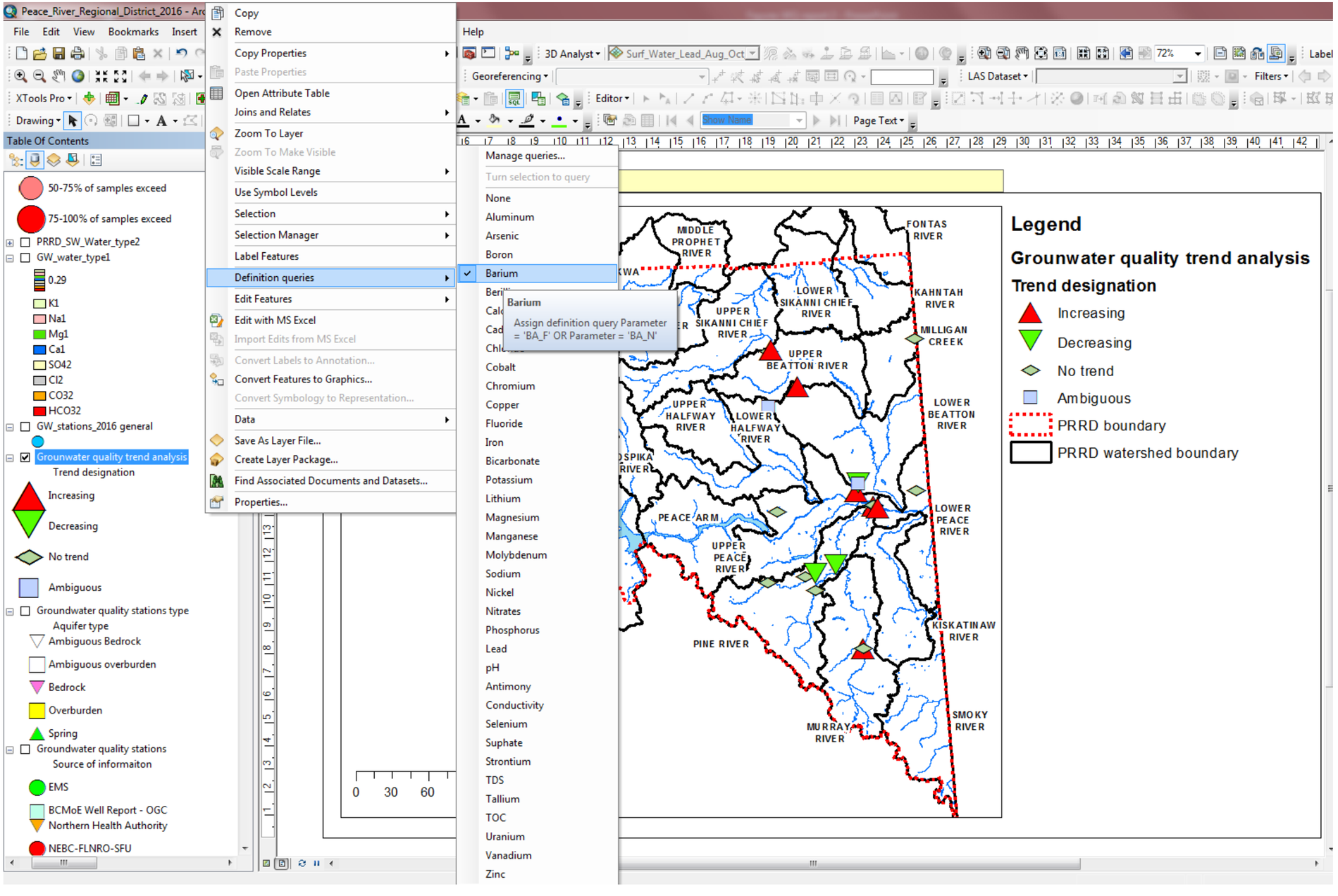
- 0
- 1-2
- 3-10
- 11-30
- 30-85

Aquifer name	No of stations	No of samples	Sampling start date	Sampling end date
451 IIIC (12)	85	113	Mar, 1943	Oct, 2014
591 IIIC (12)	28	41	Jan, 1965	Mar, 2015
593 IIIB (9)	26	40	Aug, 1964	Jul, 2014
622 IIIC (12)	16	23	Oct, 1963	Oct, 2014
933 IIB (13)	9	9	Jan, 1965	Oct, 2014
633 IIIC (9)	8	10	Jan, 1965	Mar, 2014
932 IIB (10)	7	7	Jan, 1970	Oct, 2012
634 IIIC (9)	6	7	Jan, 1965	Oct, 2014
639 IIIC (10)	6	7	Jul, 1994	May, 2014
627 IIIB (10)	4	24	Jun, 1980	Aug, 2014
917 IIB (9)	4	6	Jan, 1965	Jun, 2006
595 IIIC (10)	4	5	Jan, 1969	Dec, 2011
688 IIC (9)	3	9	Jan, 1969	Nov, 2014
441 IIIB (10)	3	5	Feb, 2013	Nov, 2014
448 IIIC (11)	3	3	Jan, 1965	Aug, 2014
689 IIC (9)	2	2	Jan, 1969	Sep, 1981
589 IIC (7)	1	1	Jan, 2013	Jan, 2013
934 IIA (10)	1	1	Feb, 2014	Feb, 2014
Undefined bedrock	52	127	Jan, 1969	Nov, 2014

430 samples

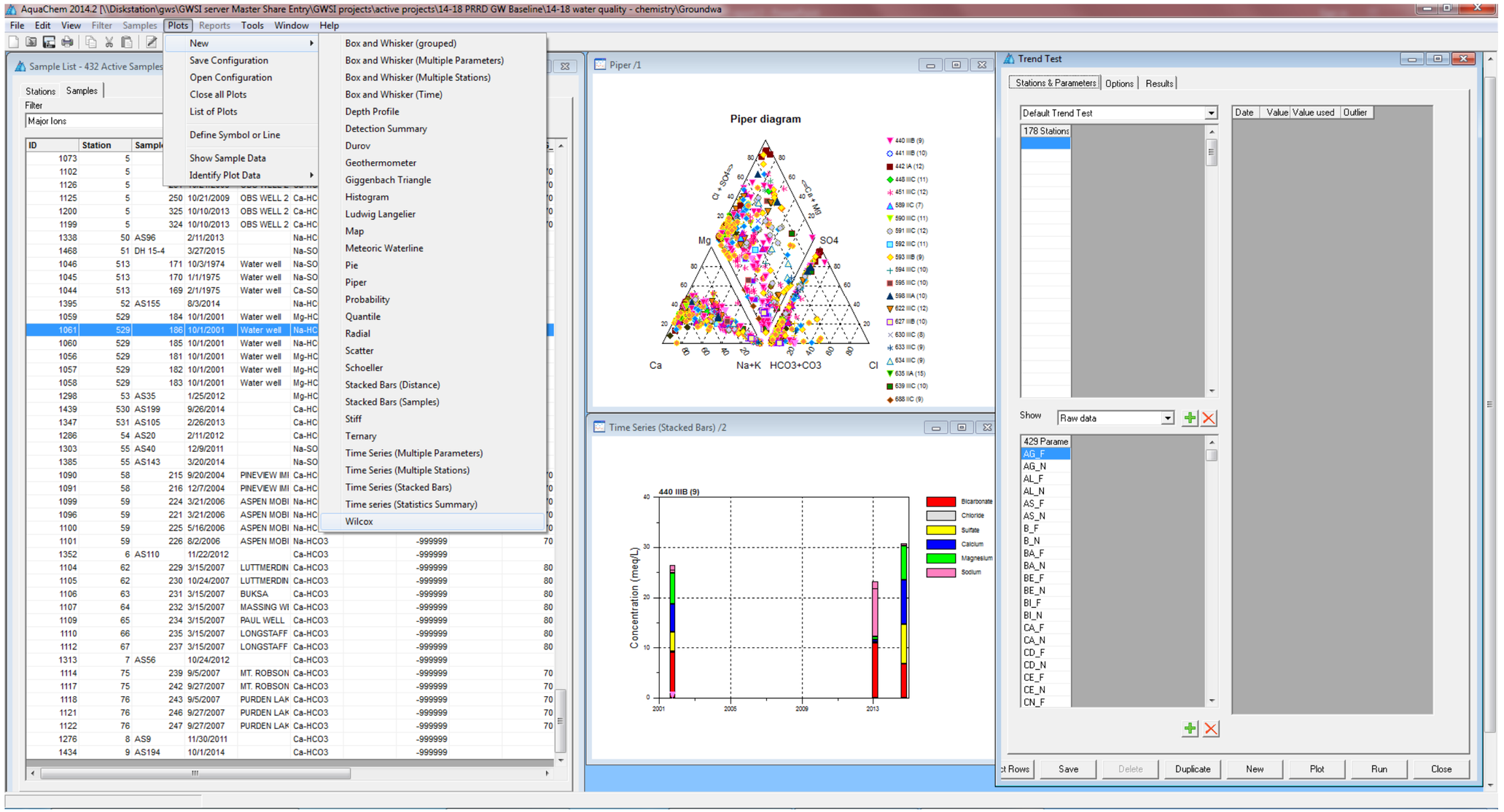
GIS Database platform data analysis and presentation

Example showing the groundwater quality trend analysis and result for Barium

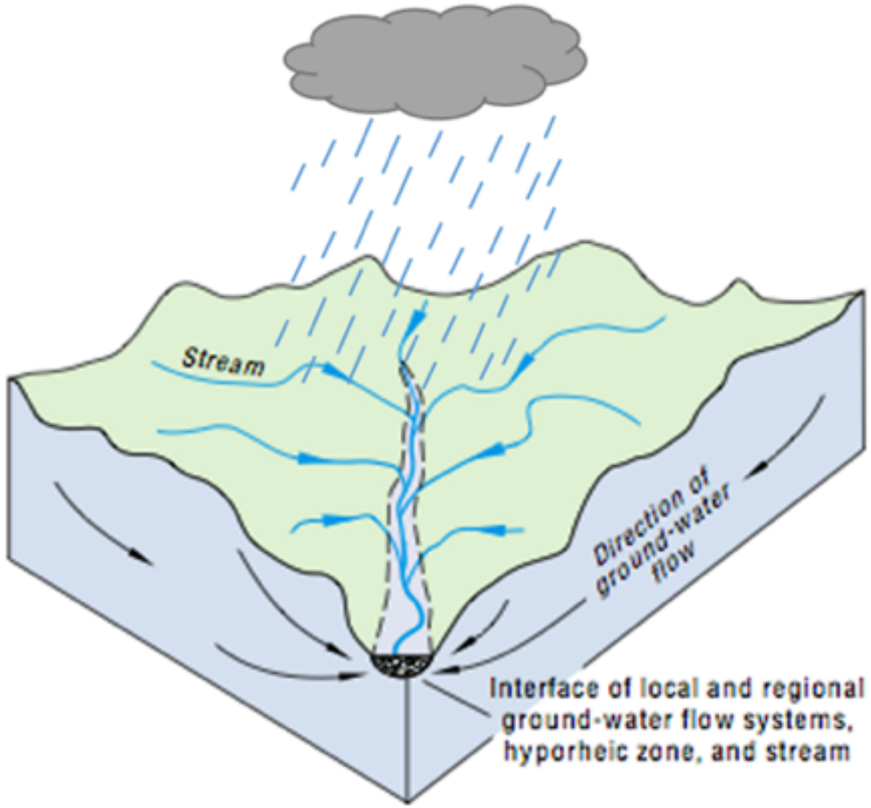


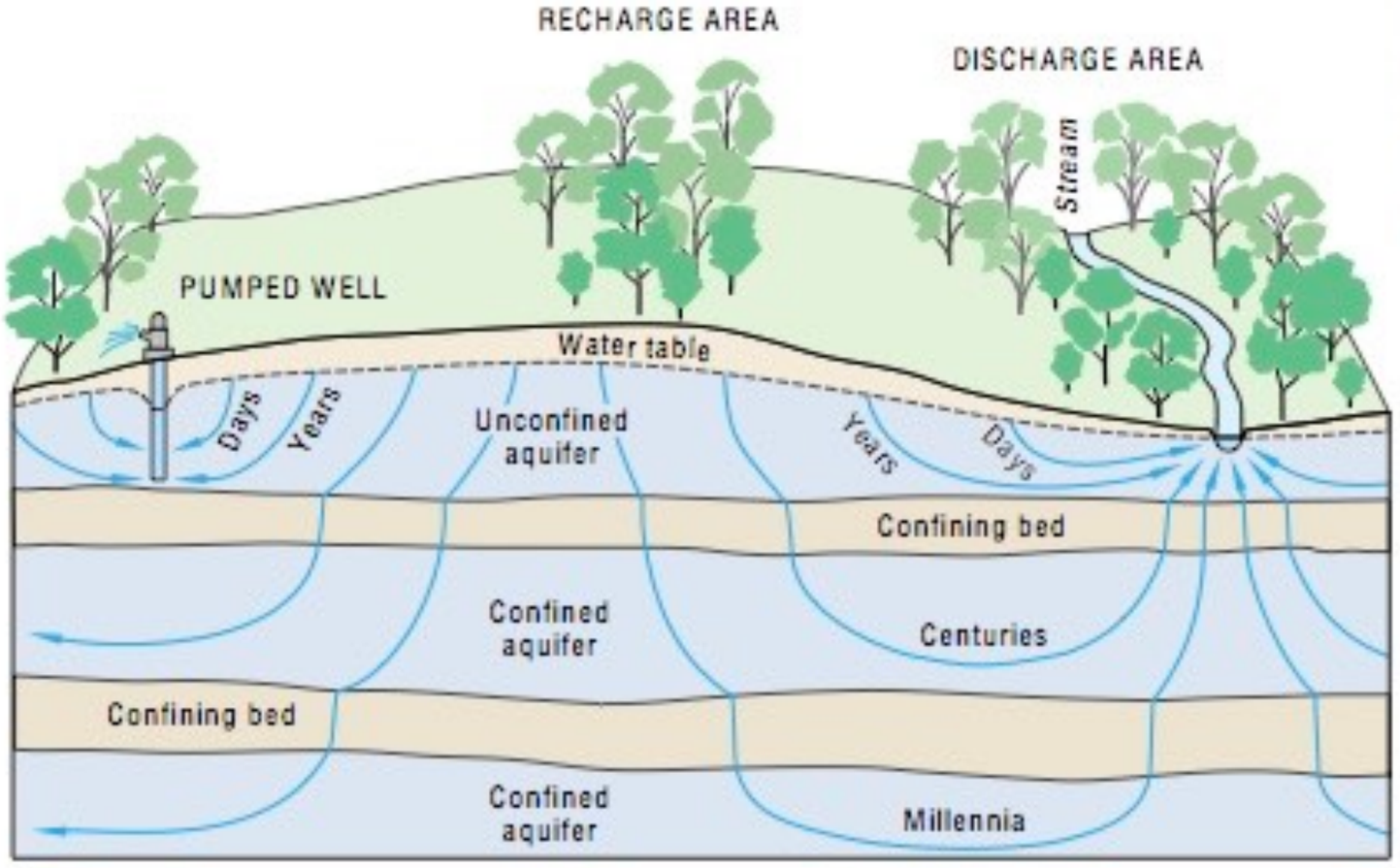
Aquachem database for chemical analysis and data plotting

Example showing piper diagram for all the aquifer across PRRD and evolution of water type for aquifer 440 IIIB(9) as well as running the trend test analysis

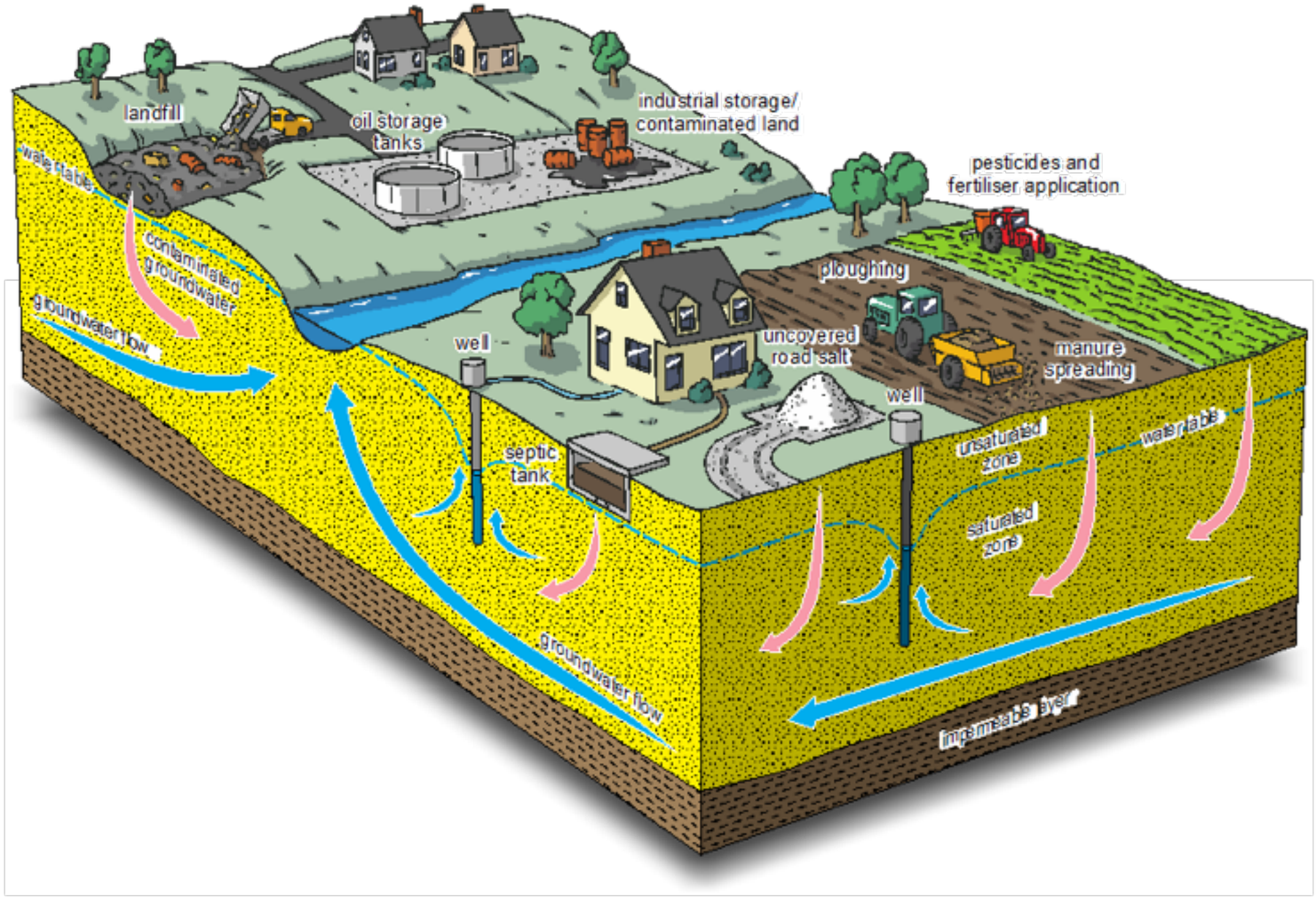


SURFACE WATER GROUNDWATER INTERACTION & HUMAN ACTIVITIES

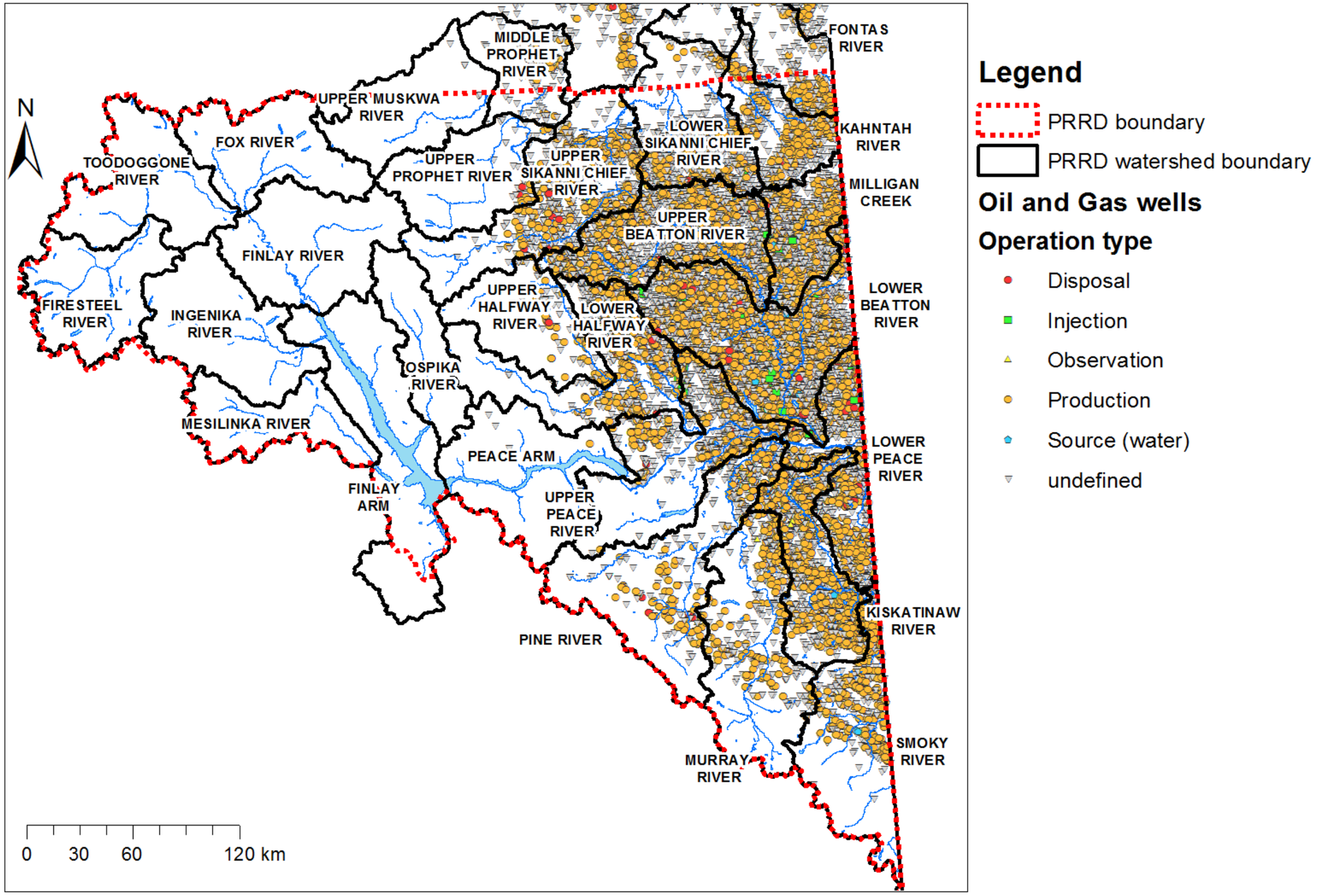




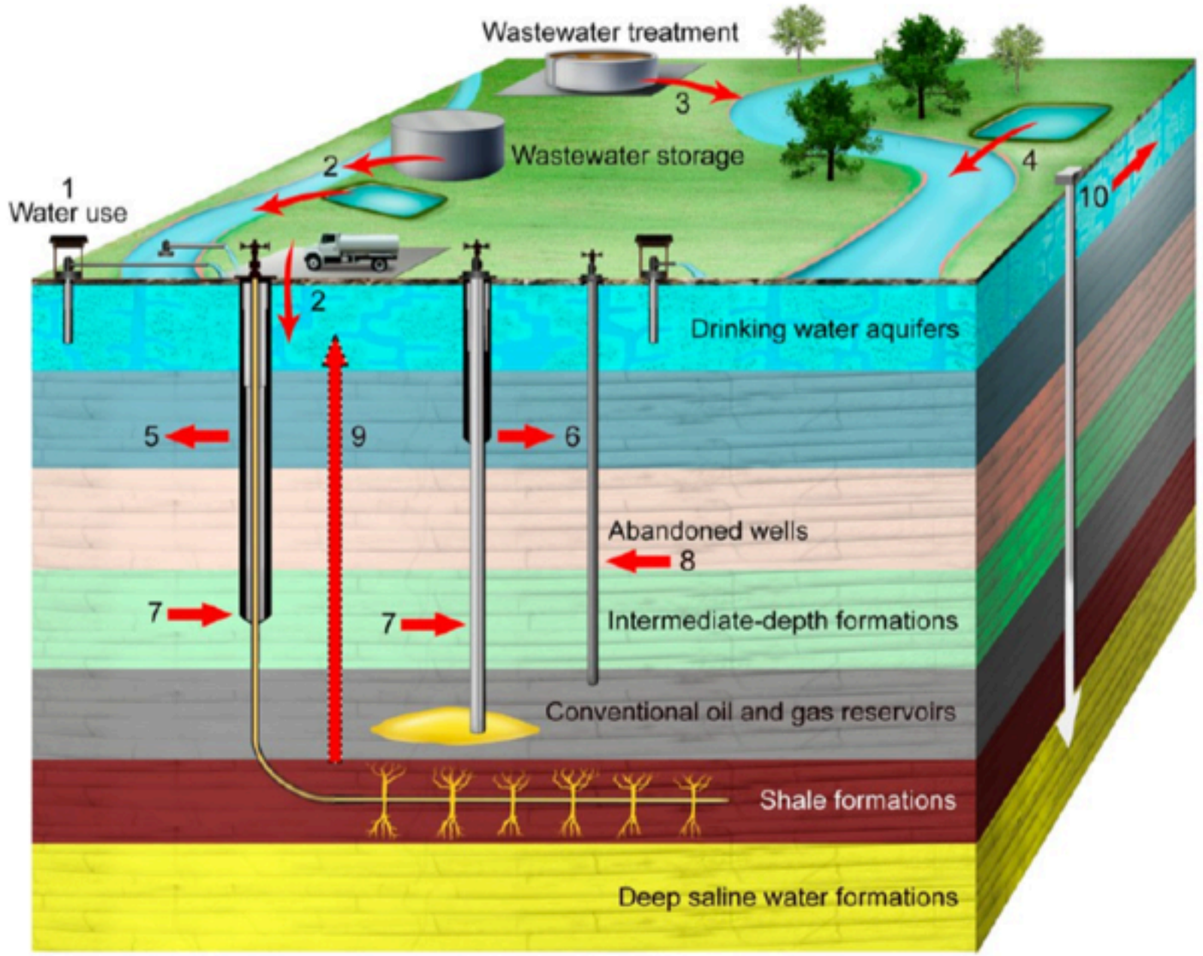
Streams hydrological components (modified from USGS Circular 1139)



Human activities that may impact groundwater quality (Rivera, A., 2014)

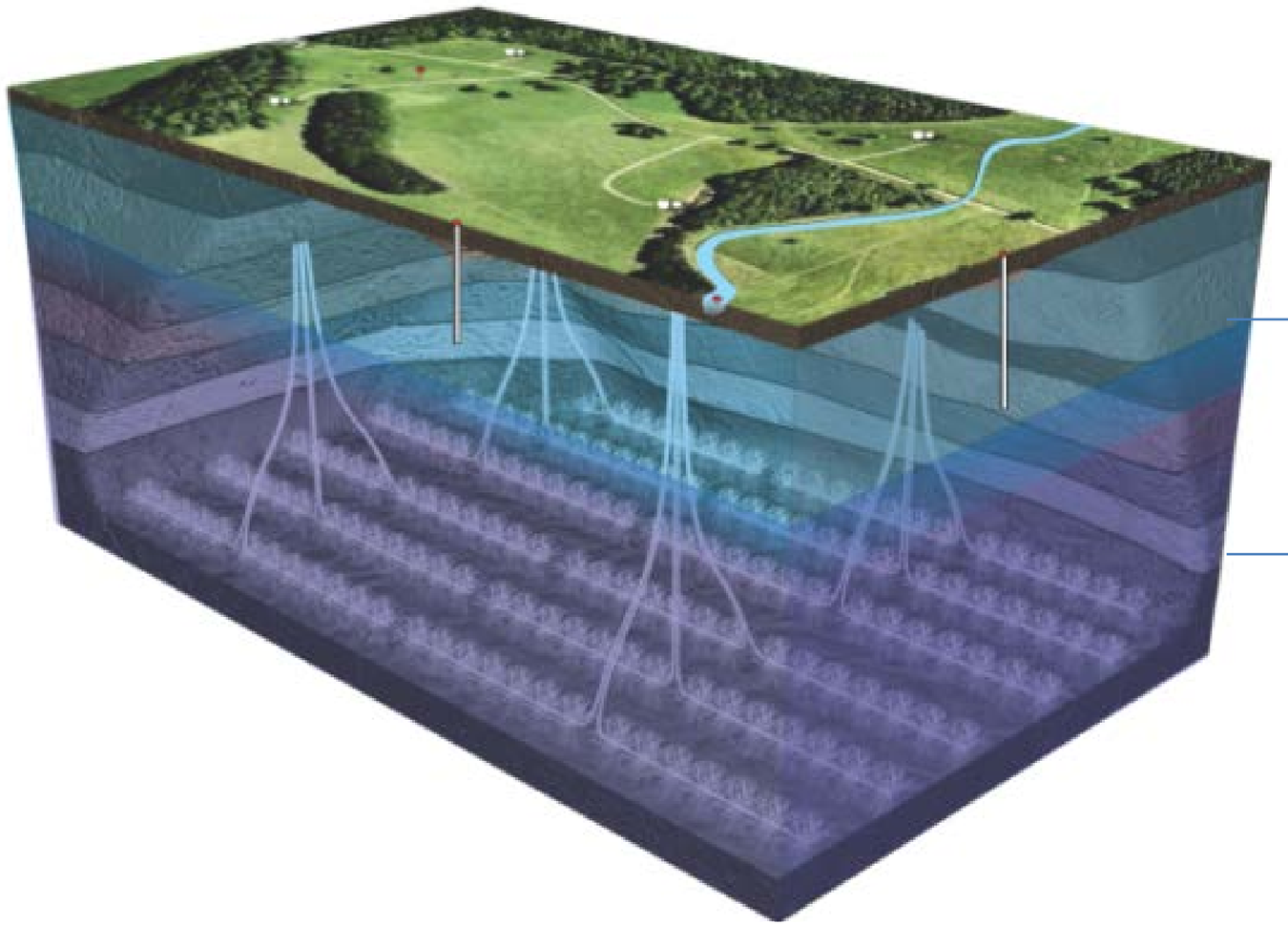


Oil and gas wells in PRRD (approx. 24,000 wells - Aug. 2016)



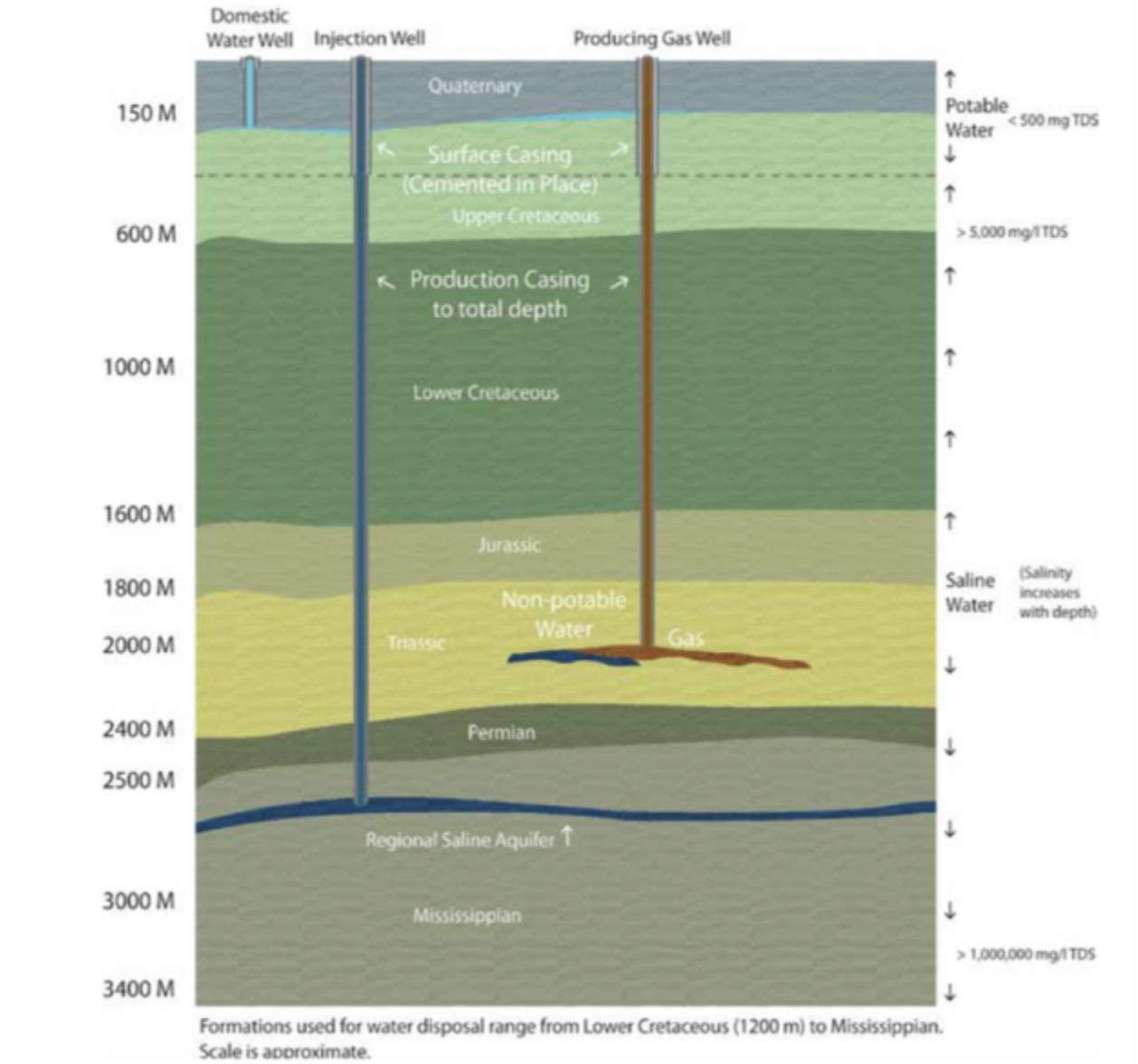
(1) overuse of water that could lead to depletion and water- quality degradation particularly in water-scarce areas;
(2) surface water and shallow groundwater contamination from spills and leaks of wastewater storage and open pits near drilling;
(3) disposal of inadequately treated wastewater to local streams and accumulation of contaminant residues in disposal sites;
(4) leaks of storage ponds that are used for deep-well injection;
(5) shallow aquifer contamination by stray gas that originated from the target shale gas formation through leaking well casing. The stray gas contamination can potentially be followed by salt and chemical contamination from hydraulic fracturing fluids and/or formational waters;
(6) shallow aquifer contamination by stray gas through leaking of conventional oil and gas wells casing;
(7) shallow aquifer contamination by stray gas that originated from intermediate geological formations through annulus leaking of either shale gas or conventional oil and gas wells;
(8) shallow aquifer contamination through abandoned oil and gas wells;
(9) flow of gas and saline water directly from deep formation waters to shallow aquifers; and
(10) shallow aquifer contamination through leaking of injection wells.

Schematic illustration (not to scale) of possible modes of water impacts associated with shale gas development (Vengosh et al., 2014)



Shallow (fresh), Intermediate and Deep groundwater zones

(Modified from John Cherry, Munk School of Global Affairs, May 2014)



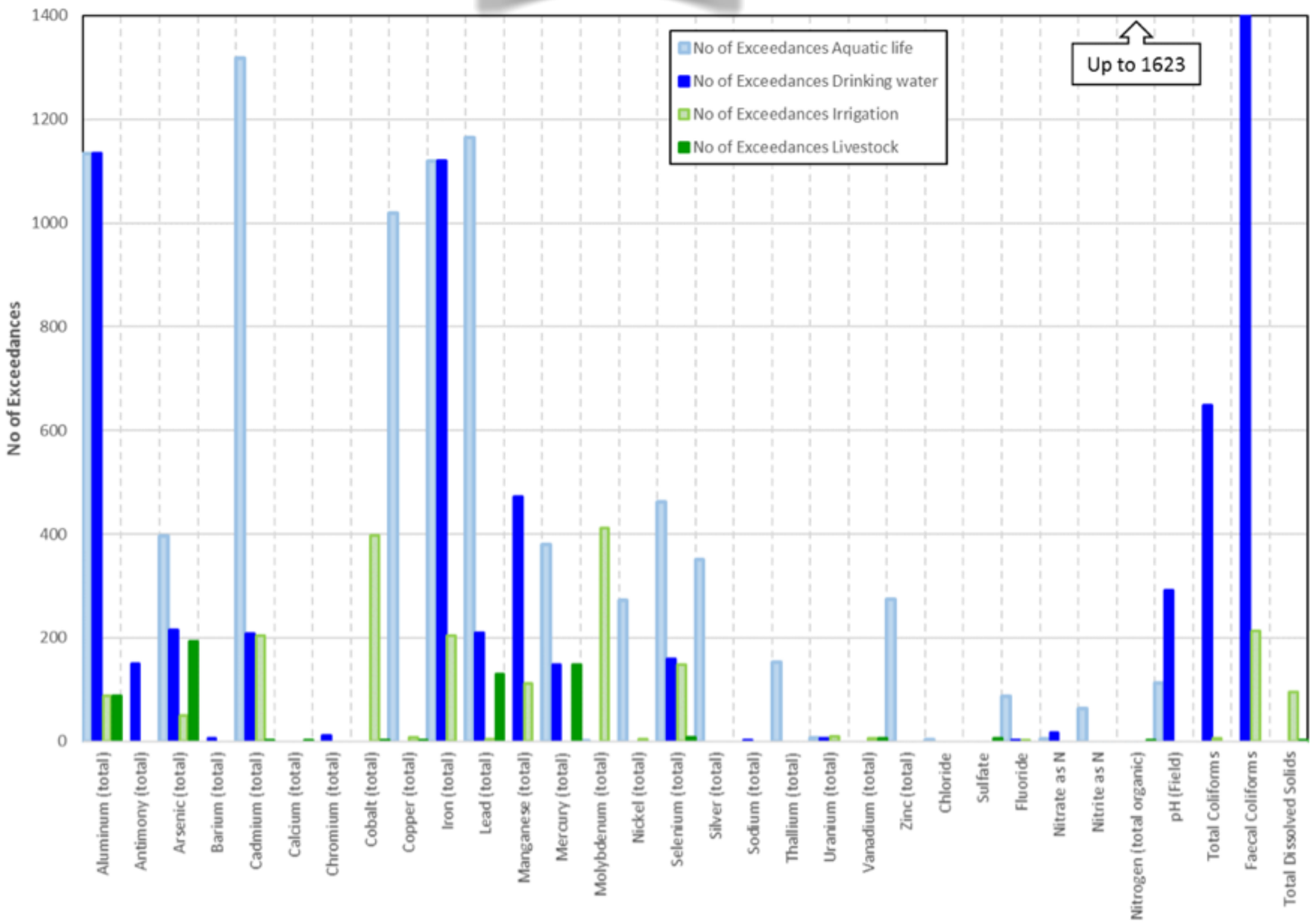
Formations used for water disposal range from Lower Cretaceous (1200 m) to Mississippian. Scale is approximate.

Salinity versus depth in deep groundwater (from BC Oil and Gas Commission)

COMPARISON TO GUIDELINES

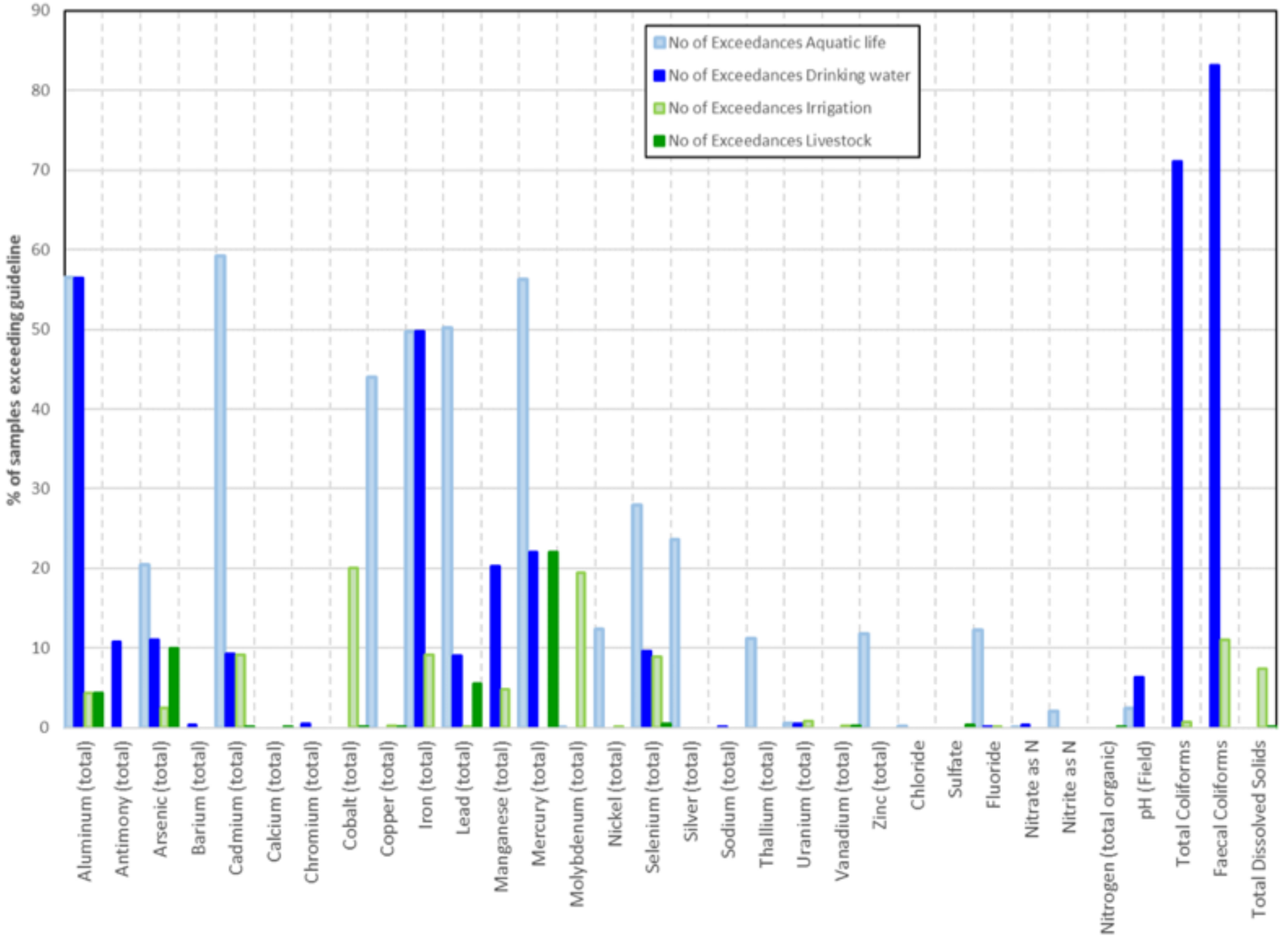
Federal guidelines	Provincial guidelines
Aquatic Life Freshwater Short Term (Chronic)	Aquatic Life Freshwater Chronic (30-Day Mean)
Aquatic Life Freshwater Long Term (Acute)	Aquatic Life Freshwater Acute (Maximun)
Agriculture Livestock	Agriculture Livestock Watering Chronic (30-Day Mean)
	Agriculture Livestock Watering Acute (Maximun)
Agriculture Irrigation	Agriculture Irrigation Chronic (30-Day Mean)
	Agriculture Irrigation Acute (Maximun)
Recreational	Recreational Chronic (30-Day Mean)
	Recreational Acute (Maximun)
	Wildlife Chronic (30-Day Mean)
	Wildlife (Acute Maximun)
Guidelines for Canadian Drinking Water Quality (GCDWQ)	Drinking Water Chronic (30-Day Mean)
	Drinking Water Acute (Maximun)

Surface Water



Number of samples exceeding federal guidelines

Surface Water



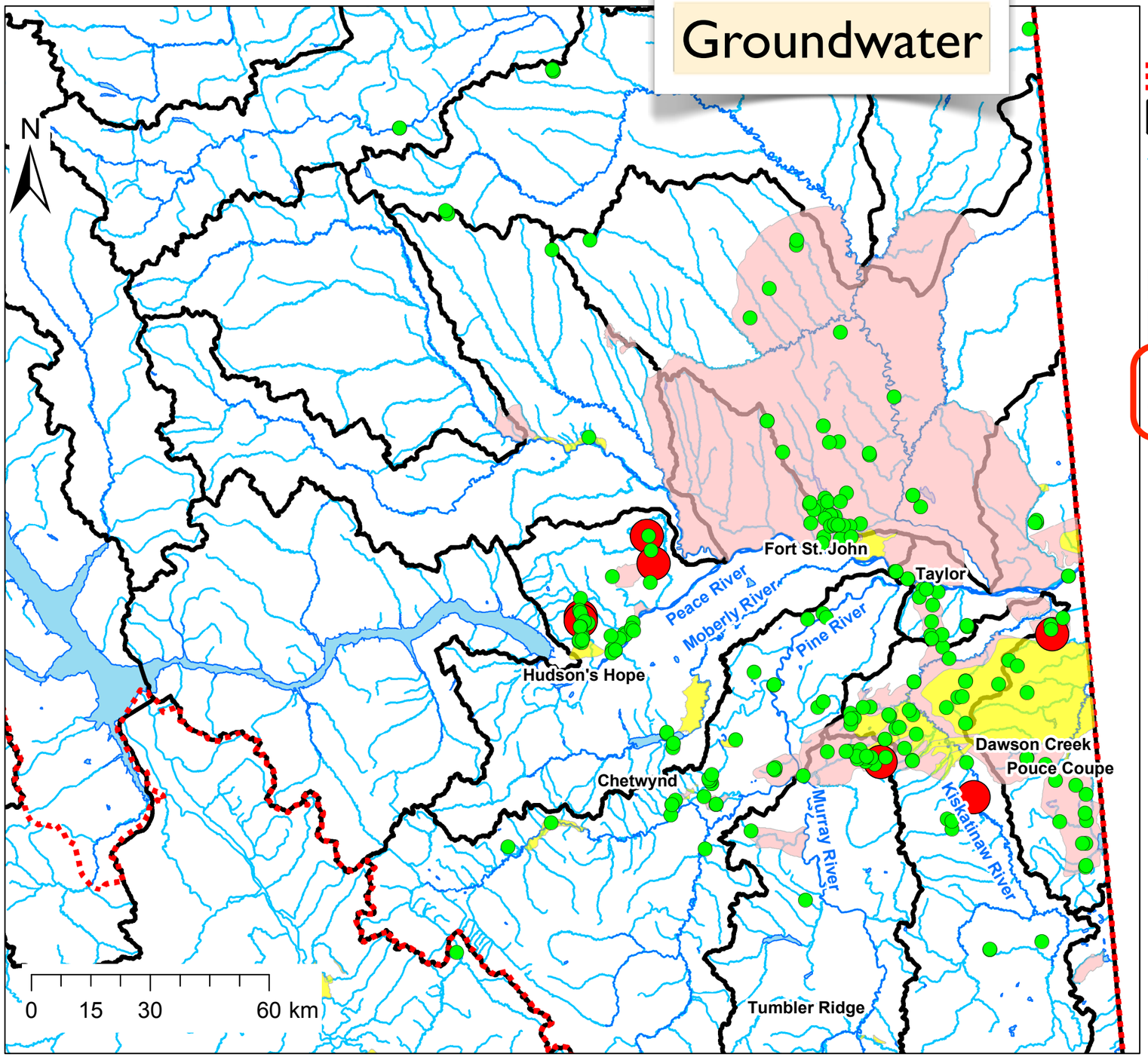
Percentage of samples exceeding federal guidelines compared to the total number of analyzed samples

Groundwater

Parameters	Groundwater - % Samples Exceeding Federal Guidelines			
	Freshwater Aquatic Life	Drinking Water	Livestock	Irrigation
Aluminum total	3%	4%	0.2%	0.2%
Antimony		1%		
Arsenic	34%	17%	3%	0.2%
Barium		6%		
Boron	0.2%			12%
Cadmium	1%	1%		1%
Cobalt				1%
Copper	49%	1%	2%	4%
Iron	40%	40%		7%
Lead	15%	2%	1%	
Manganese		56%		26%
Mercury	4%			
Molybdenum	1%			9%
Nickel	2%			
Selenium	10%			
Thallium	1%			
Uranium	1%	1%		3%
Vanadium			1%	1%
Zinc	26%	0.2%		2%
Chloride	3%	1%		1%
Fluoride	48%	2%	5%	5%
Sodium		33%		
Sulphate		15%	9%	
Nitrate	6%	2%		
Nitrite	5%	1%	1%	
Phosphorus	11%			
pH	4%	6%		
Total Dissolved Solids		56%	5%	56%

lung, liver and bladder cancer

Groundwater



Legend

- PRRD boundary
- Watershed boundary
- Main Streams

Mapped aquifers

Aquifer type

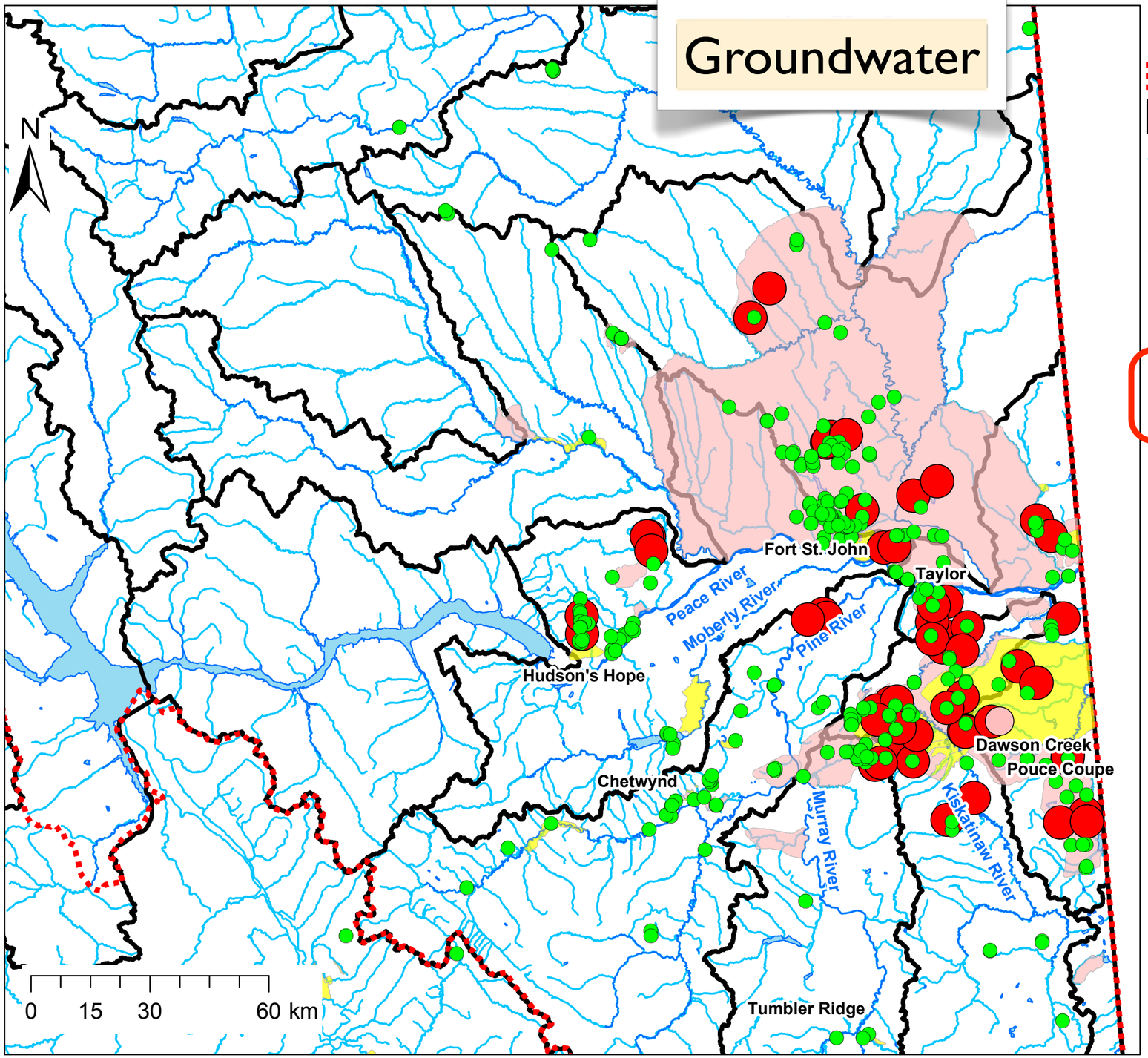
- Bedrock
- Overburden

GW Provincial drinking water (BCMoE)

% of samples exceeding guideline

- No exceedance
- =< 25% of samples exceed
- 25-50% of samples exceed
- 50-75% of samples exceed
- 75-100 of samples exceed

Exceedance analysis for fluoride (F)



Legend

- PRRD boundary
- Watershed boundary
- Main Streams

Mapped aquifers

Aquifer type

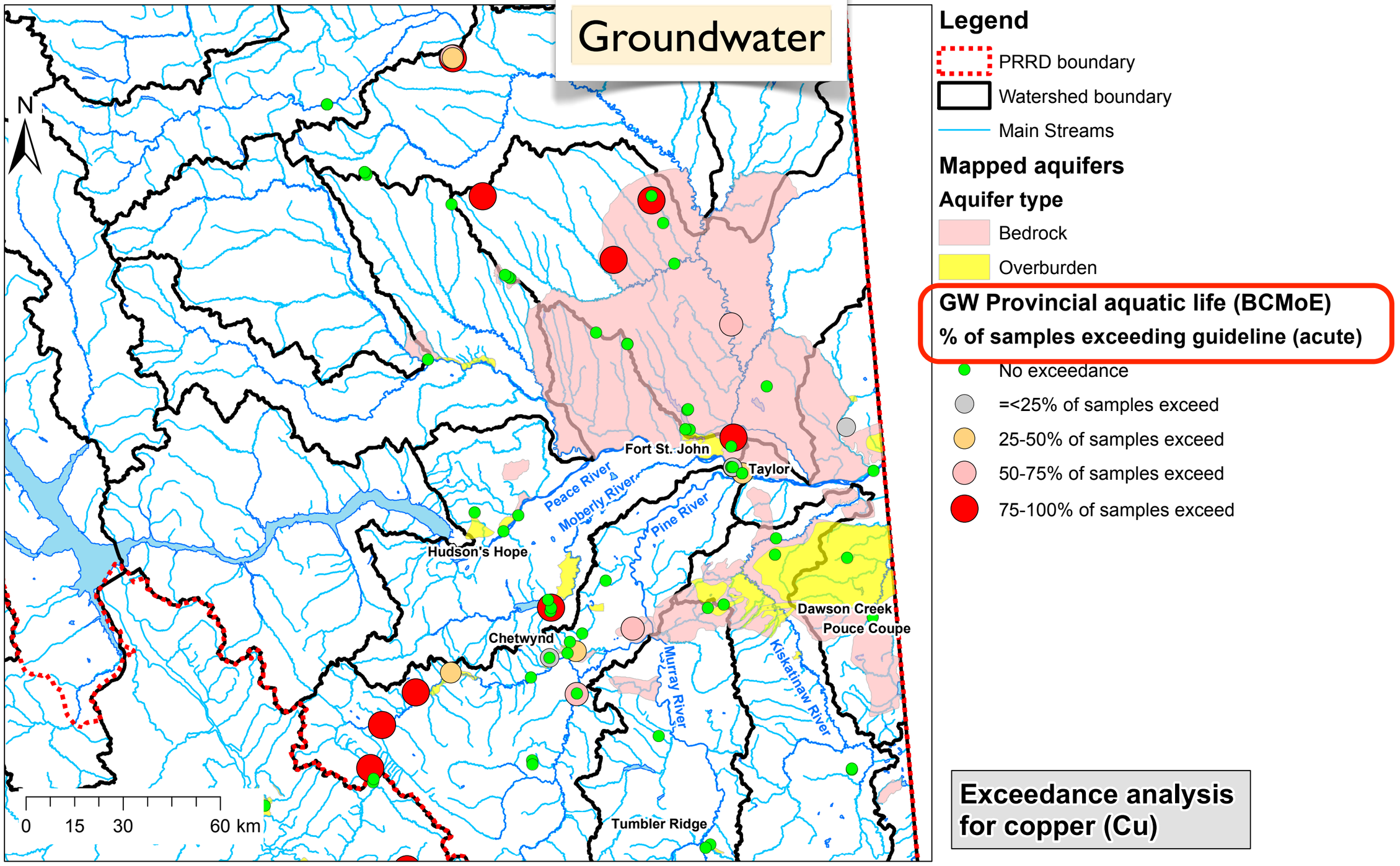
- Bedrock
- Overburden

GW Provincial drinking water (BCMoE)

% of samples exceeding guideline

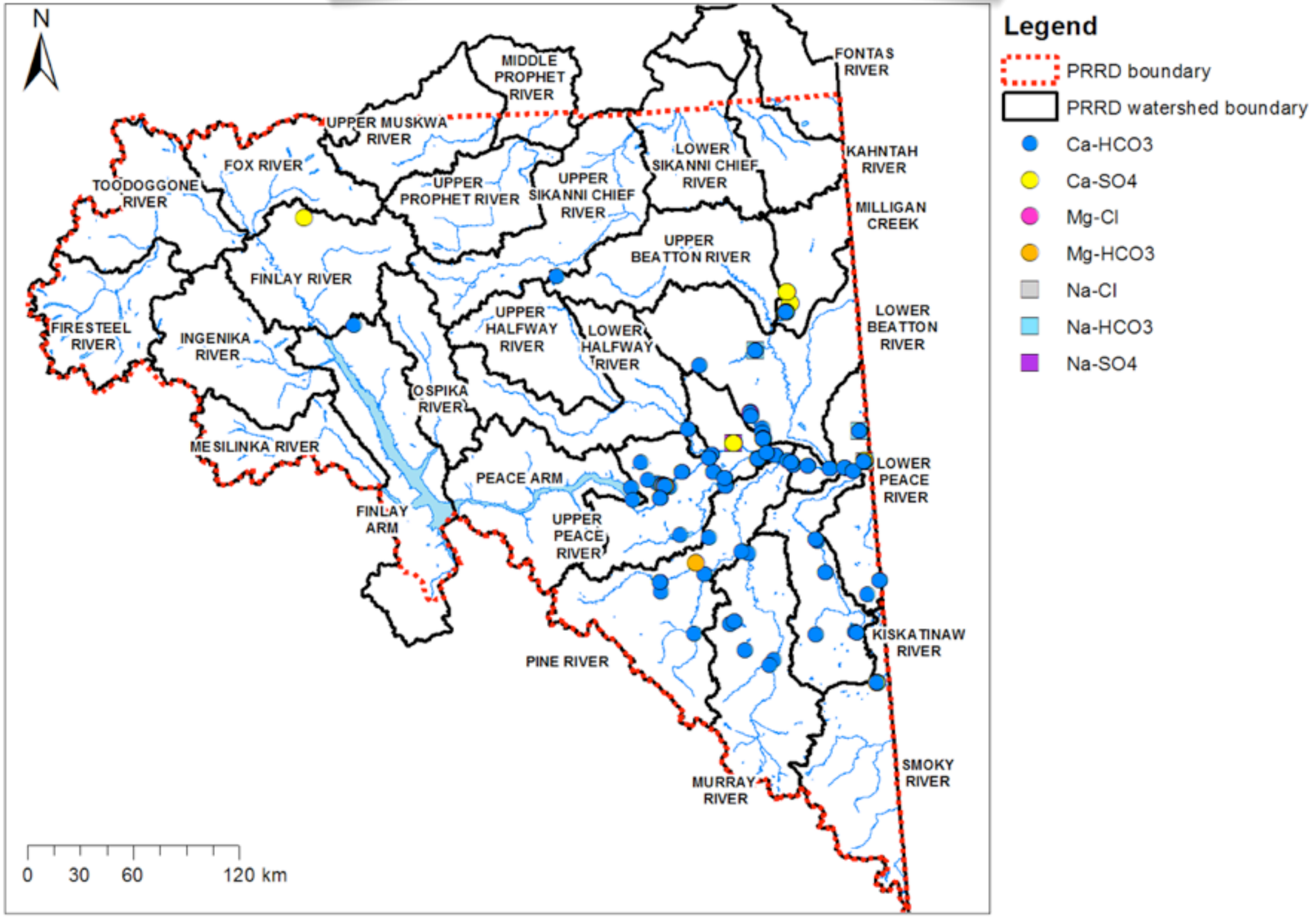
- No exceedance
- =< 25% of samples exceed
- 25-50% of samples exceed
- 50-75% of samples exceed
- 75-100 of samples exceed

Exceedance analysis for sulphate (SO4)


Groundwater
N
Fort St. John
Taylor
Peace River
Moberly River
Pine River
Hudson's Hope
Chetwynd
Dawson Creek
Pouce Coupe
Murray River
Kiskatinaw River
Tumbler Ridge
0 15 30 60 km
Legend
PRRD boundary
Watershed boundary
Main Streams
Mapped aquifers
Aquifer type
Bedrock
Overburden
GW Provincial aquatic life (BCMoE)
% of samples exceeding guideline (acute)
No exceedance
=<25% of samples exceed
25-50% of samples exceed
50-75% of samples exceed
75-100% of samples exceed
Exceedance analysis for copper (Cu)

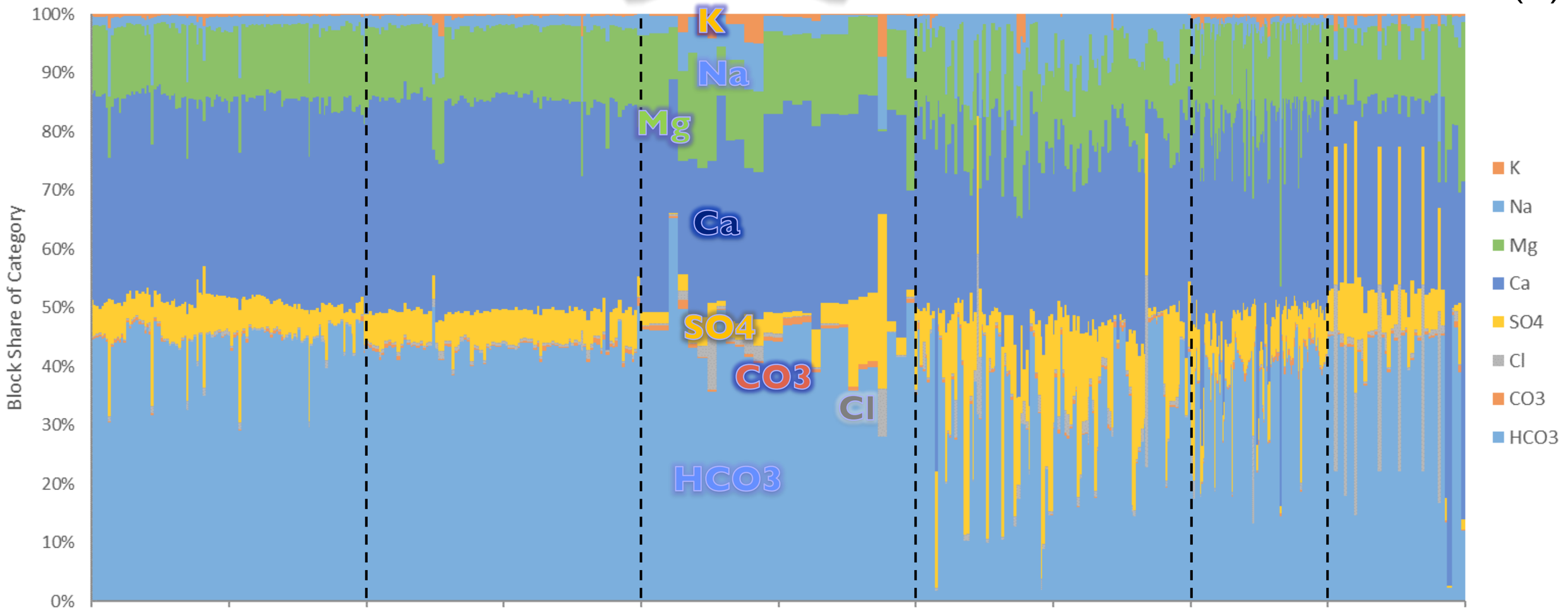
DETAILED ANALYSIS SCATTER, PIPER, MEKKO PLOTS

Surface Water - Water Types



Surface Water

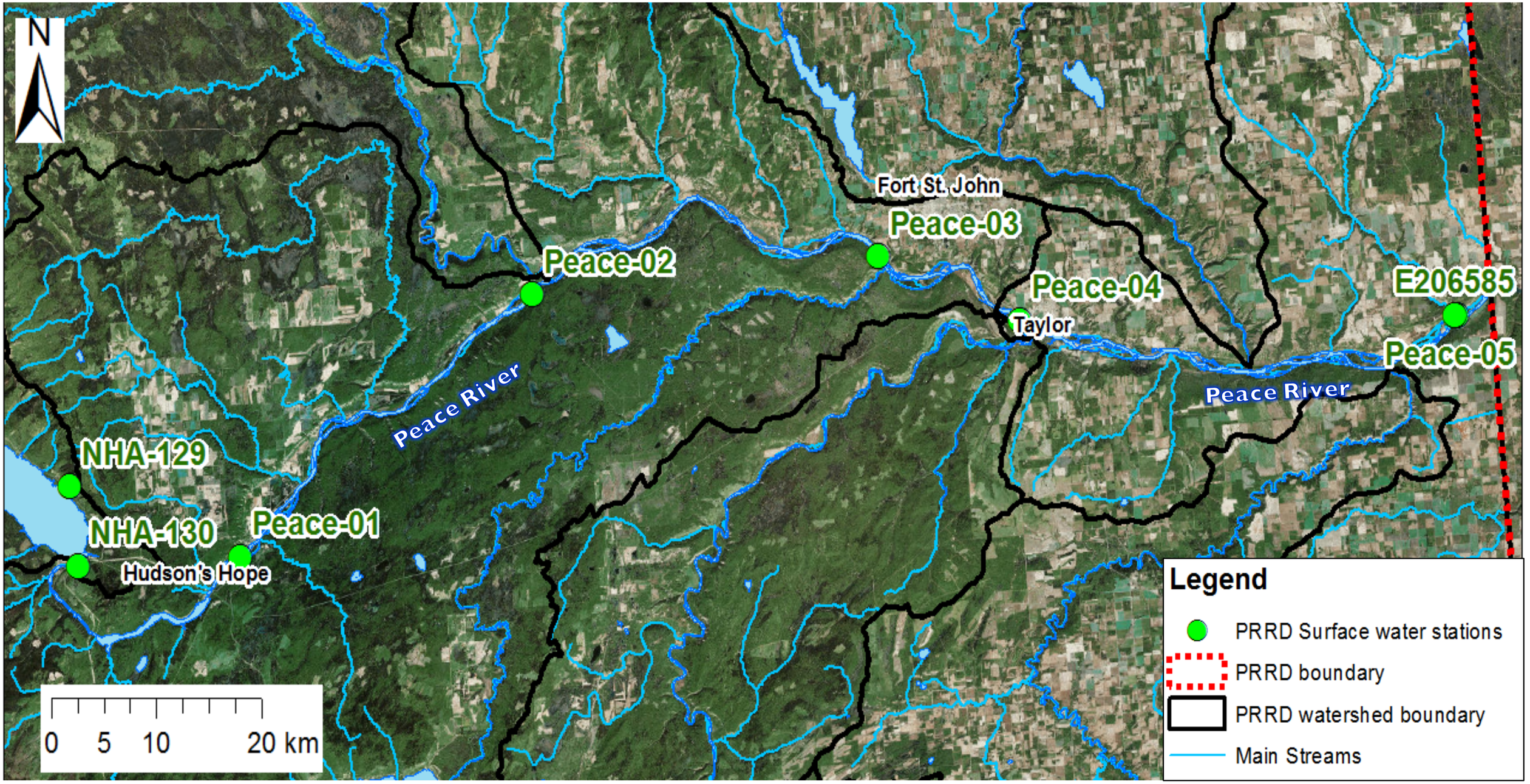
Cation (+)



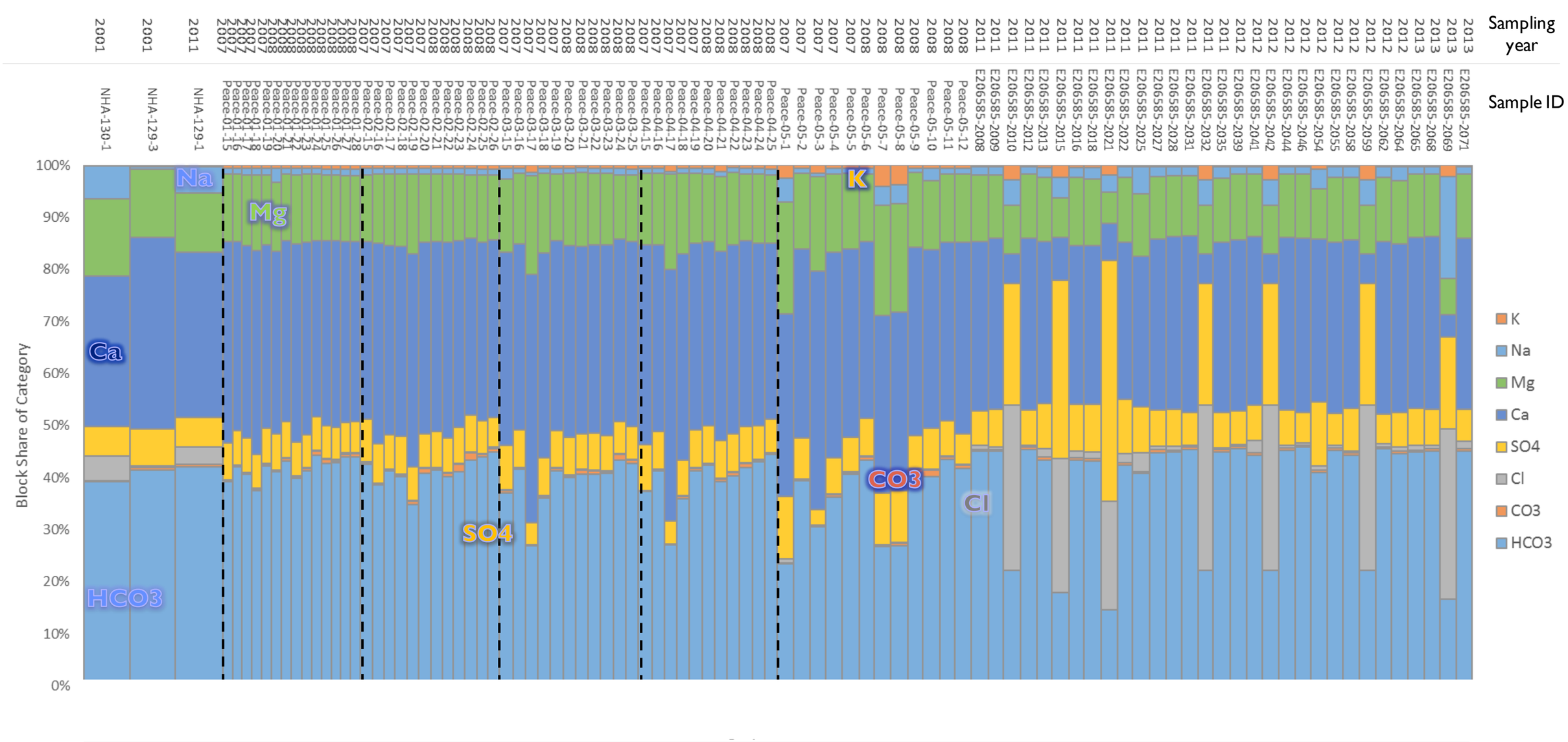
Anion (-)

Sampling year	1972-1980	1981-1990	1991-2000	2001-2005	2006-2010	2011-2014
No of Samples	110	87	29	112	134	41

(note: only presenting major ions)



178 Km	146 Km	107 Km	67 Km	50 Km	4.5 km upstream

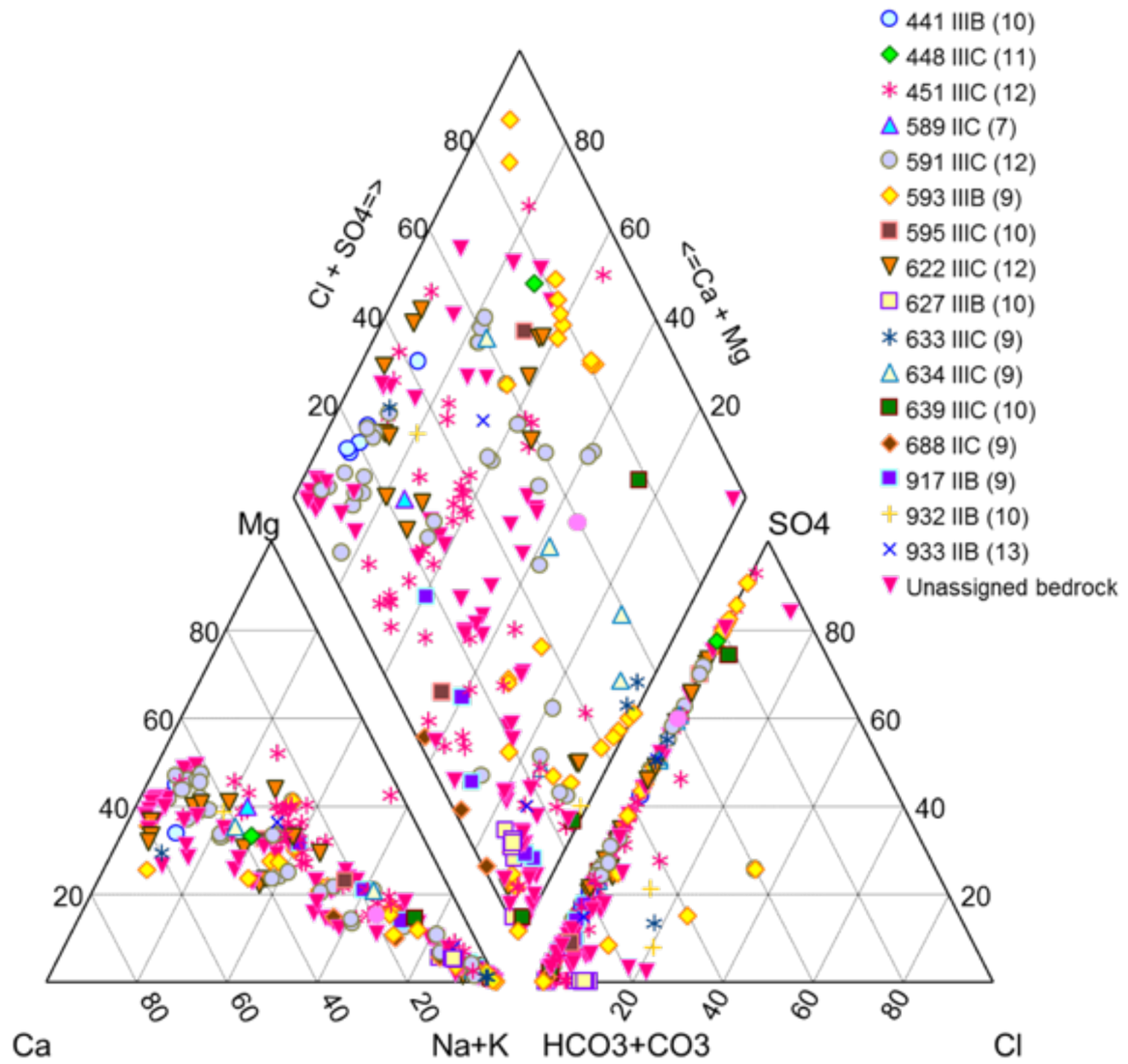


178 Km upstream (Williston Reservoir) Samples 2001-2011	146 Km upstream (Hudson's Hope) Samples 2007-2008	107 Km upstream (Attachie) Samples 2007-2008	67 Km upstream (Grand Haven) Samples 2007-2008	50 Km upstream (Taylor) Samples 2007-2008	4.5 km upstream (at the mouth) Clayhurst Samples 2007-2013

Surface Water

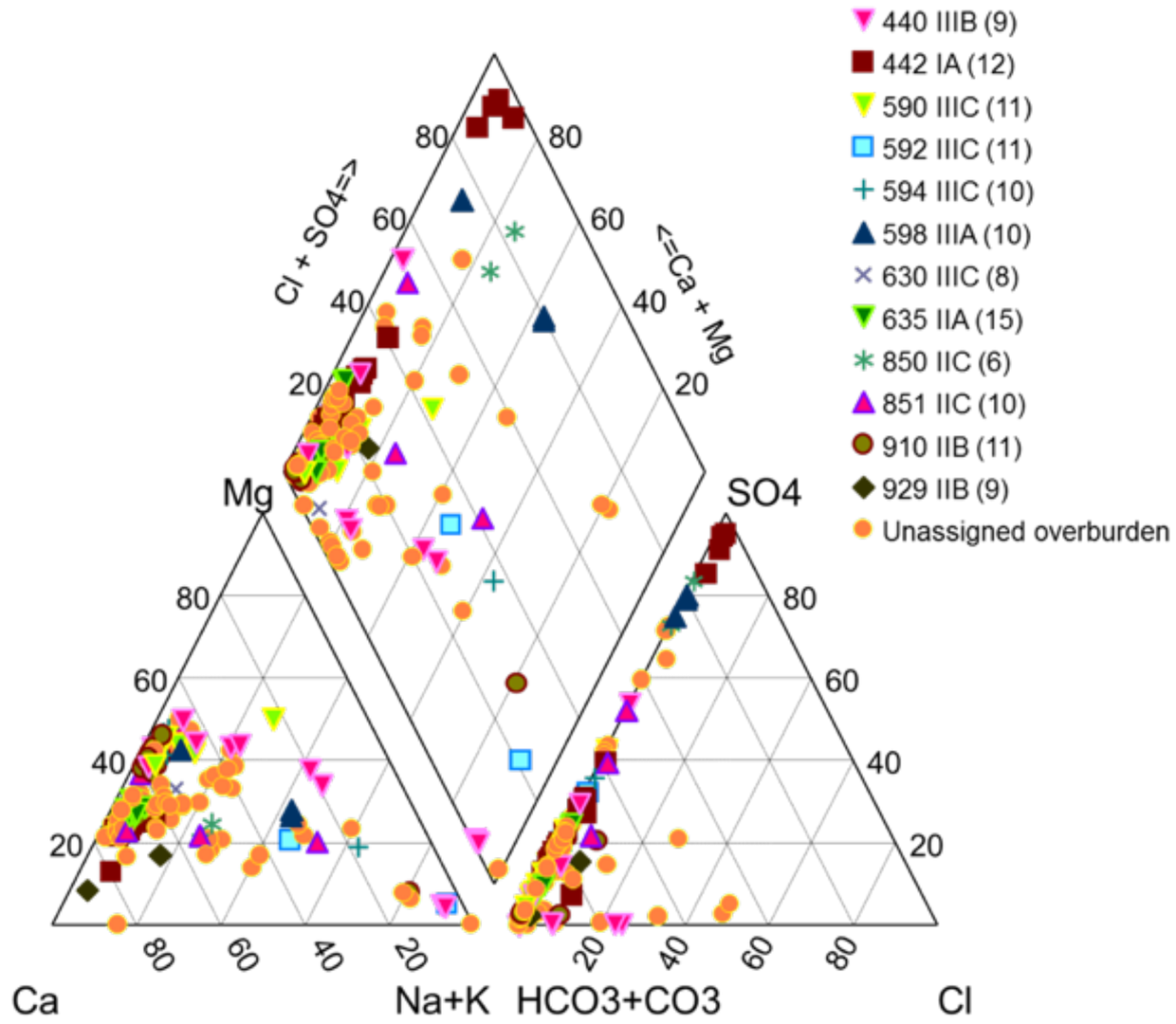
(note: only presenting major ions)

Groundwater - Bedrock Wells



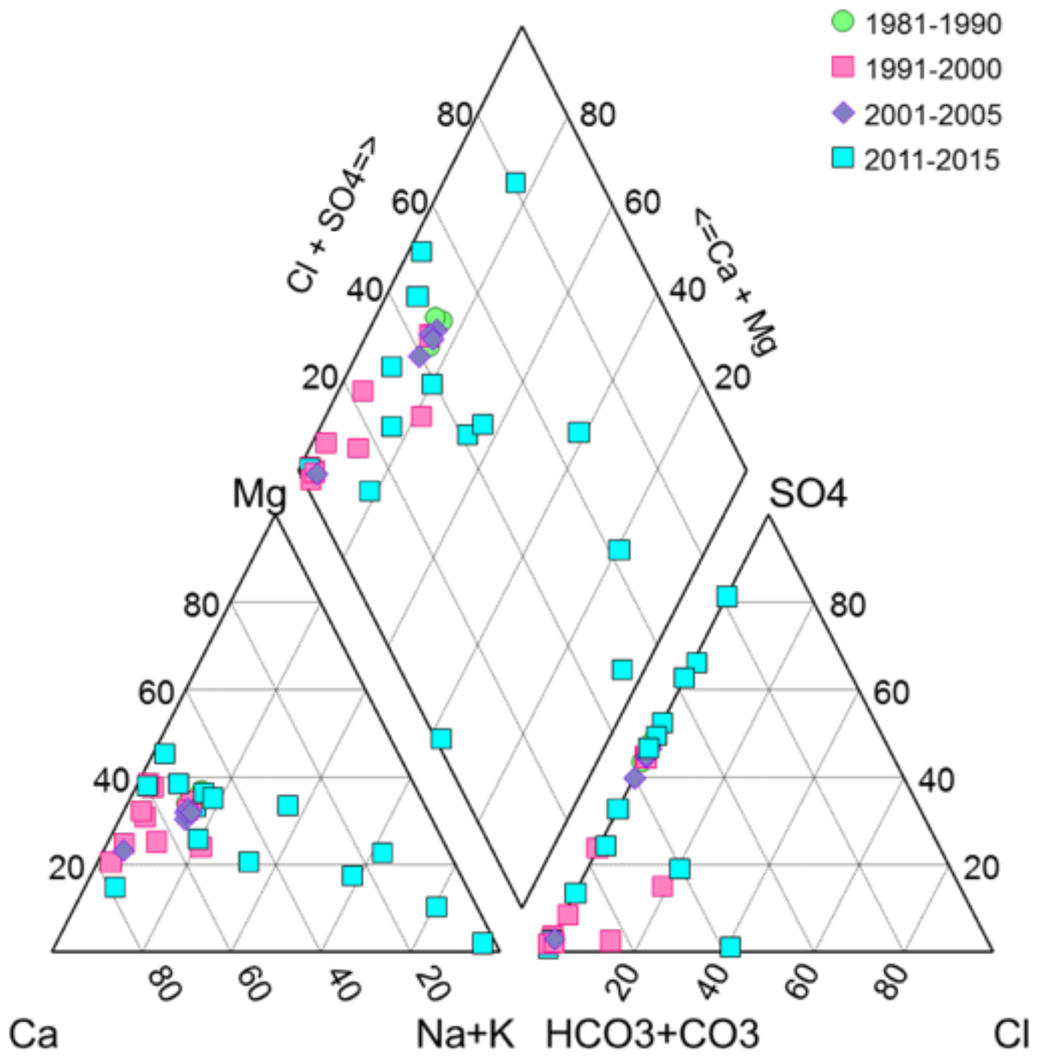
Piper plot for bedrock wells classified by mapped aquifer

Groundwater - Wells in Surficial Aquifers



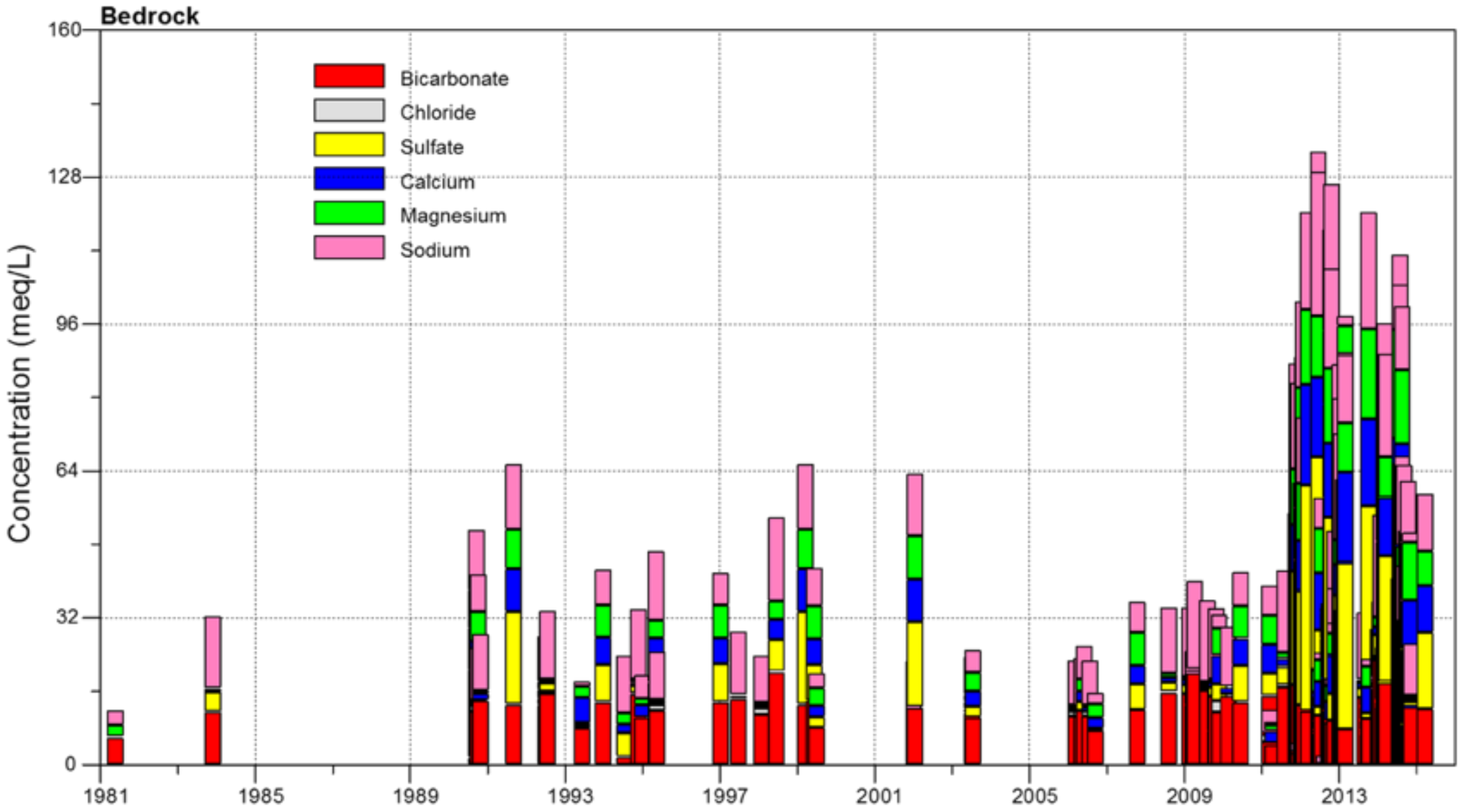
Piper plot for wells in surficial aquifers classified by mapped aquifer

Groundwater - Springs



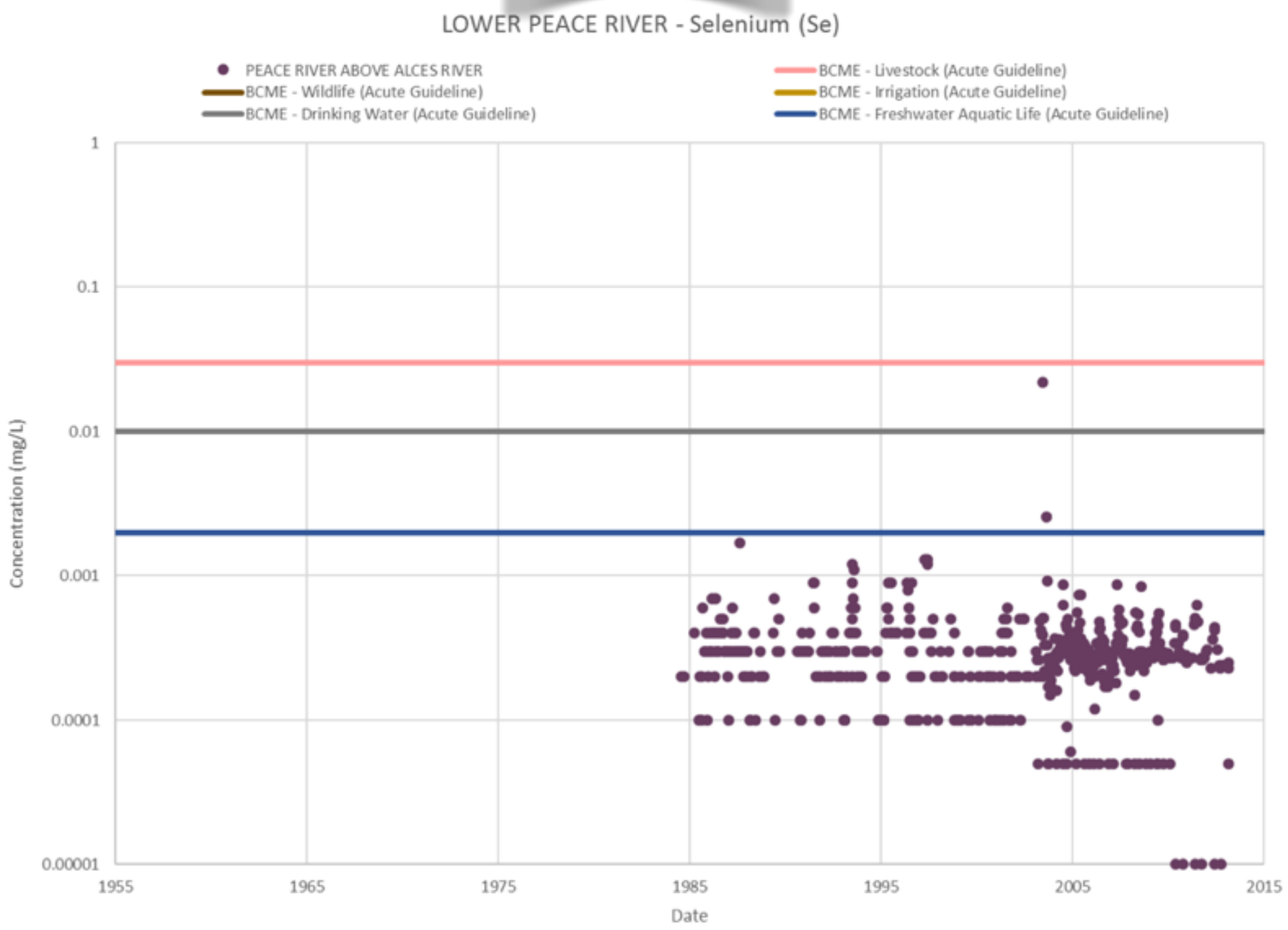
Piper plot for samples taken from springs grouped by sampling periods

Groundwater - Bedrock Wells



Bar plot over time for the major ions (Ca, Mg, Na, HCO3, Cl and SO4) for samples taken from bedrock wells

Surface Water

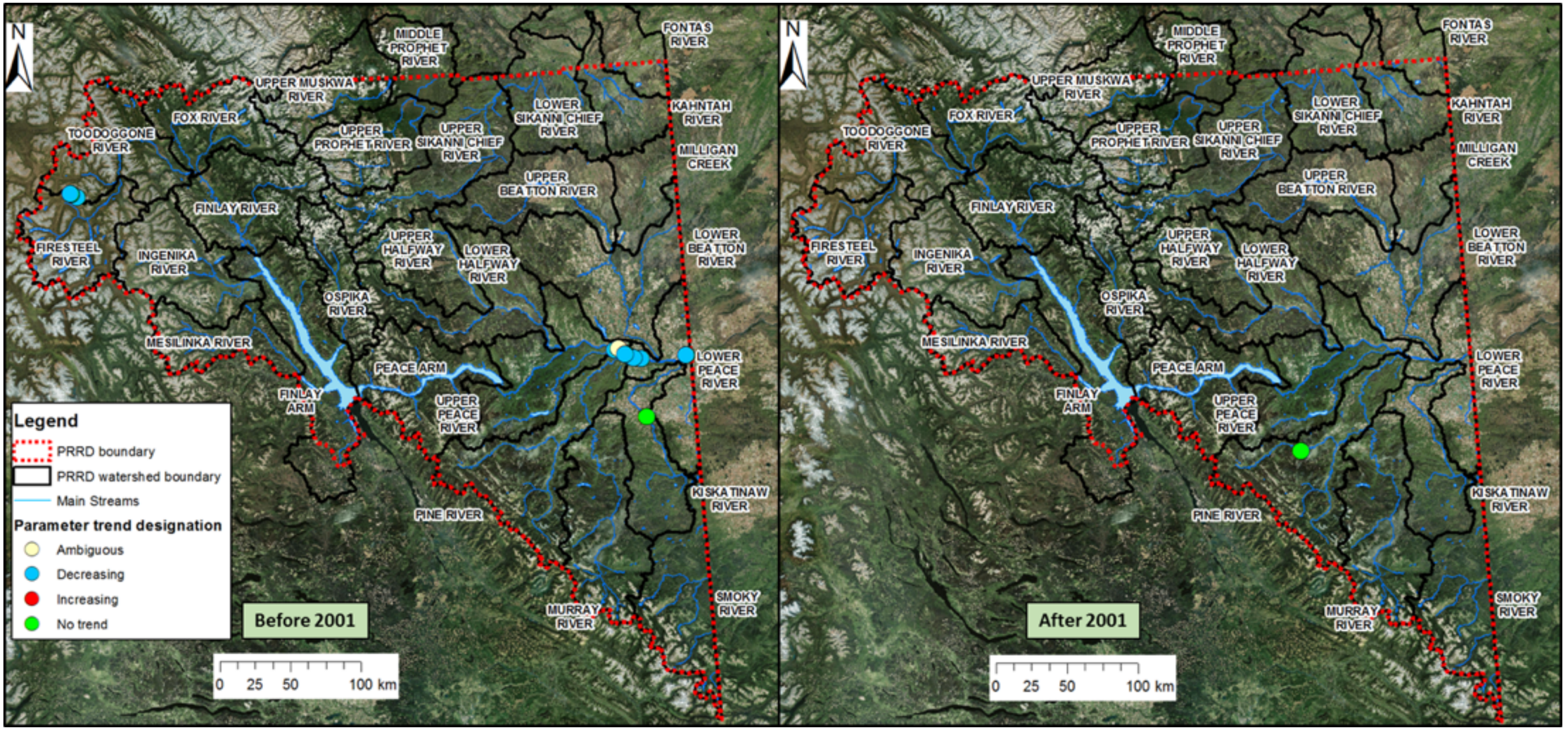


Scatter plot for Selenium (total) for the Lower Peace River Watershed Station E206585 (Peace River above Alces River)

TREND ANALYSES

- Requirement: at least 10 samples and five years of data
- Before 2001: 57 stations meet requirements
- After 2001: Only 5 stations meet requirements
- Results of the trend analysis are presented in Appendix 7 of report.

Surface Water



Trend analysis results for Cadmium (total)

WATER QUALITY INDEX

Water Quality Index

No	Parameter	Unit	CCME Aquatic Life objective (Long term)	Comment
1	Aluminum (total)	µg/L	100	Depends on pH. 100 µg/L for pH>6.5
2	Arsenic (total)	µg/L	5	
3	Cadmium (total)	µg/L	0.09	
4	Copper (total)	µg/L	2	Depends on Hardness. 2 µg/L for Unknown hardness
5	Iron (total)	µg/L	300	
6	Lead (total)	µg/L	1	Depends on Hardness. 1 µg/L for Unknown hardness
7	Mercury (total)	µg/L	0.026	
8	Molybdenum (total)	µg/L	73	
9	Nickel (total)	µg/L	25	Depends on Hardness. 25 µg/L for Unknown hardness
10	Selenium (total)	µg/L	1	
11	Silver (total)	µg/L	0.1	
12	Thallium (total)	µg/L	0.8	
13	Uranium (total)	µg/L	15	
14	Zinc (total)	µg/L	30	
15	Chloride	µg/L	120000	
16	Fluoride	µg/L	120	
17	Nitrate as N	µg/L-N	13000	
18	Nitrite as N	µg/L-N	60	
19	pH (Field)		6.5-9.0	

The 19 parameters selected to calculate the WQI

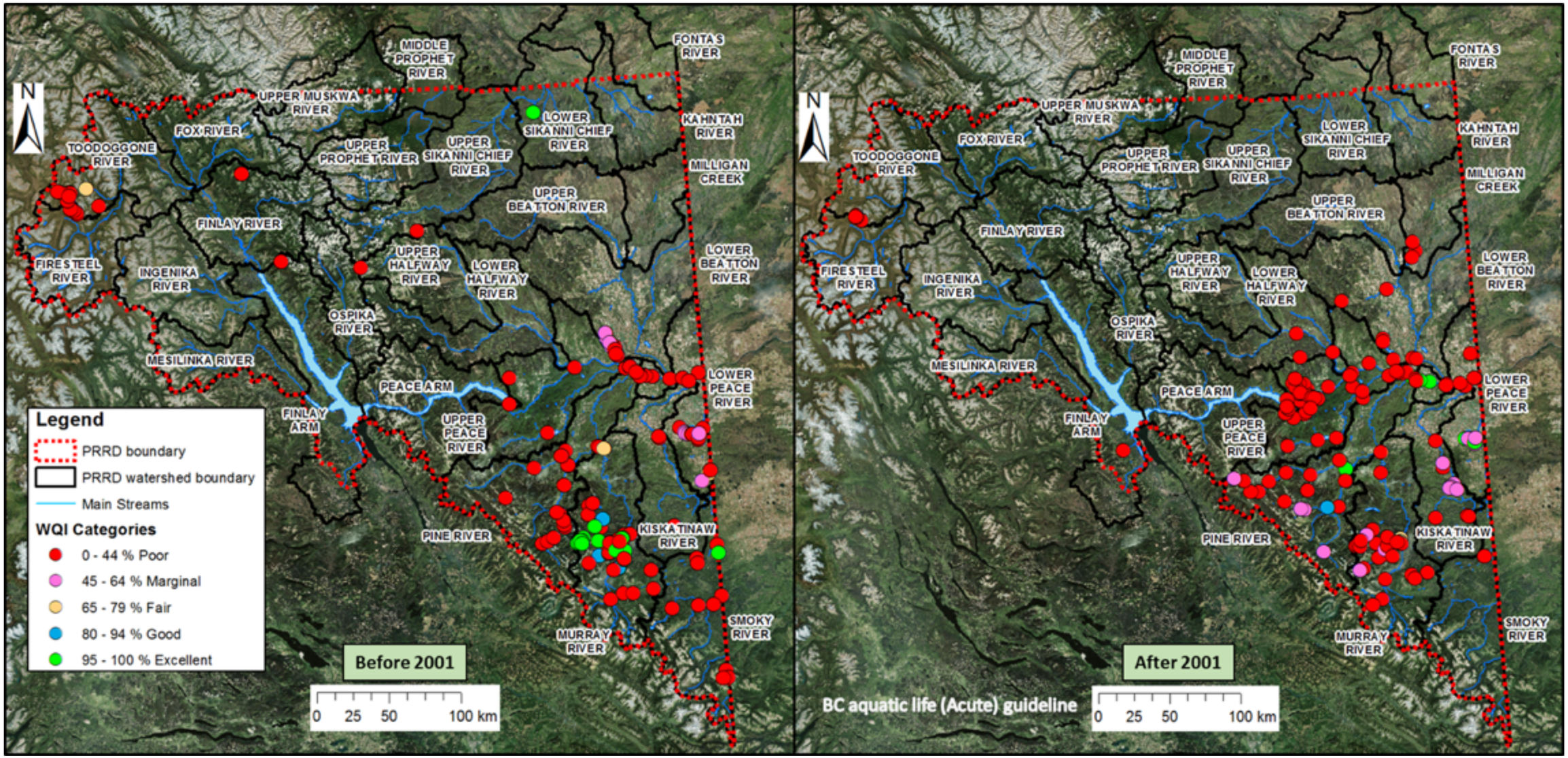
Water Quality Index

A water quality index (WQI) allows integrating three different factors:

- F1 (scope): The factor relates to the number of failed variables (parameters) compared to the total number of analyzed parameters that have a guideline value (e.g., 3 of 19).
- F2 (frequency): This factor incorporates the number of exceedances compared to the total number of tests carried out in all the samples (e.g., 55 over 216).
- F3 (amplitude): This factor includes the percentage at which the exceedance occurred compared to the guideline value (e.g., 3 ppm/1 ppm ---> 300%).

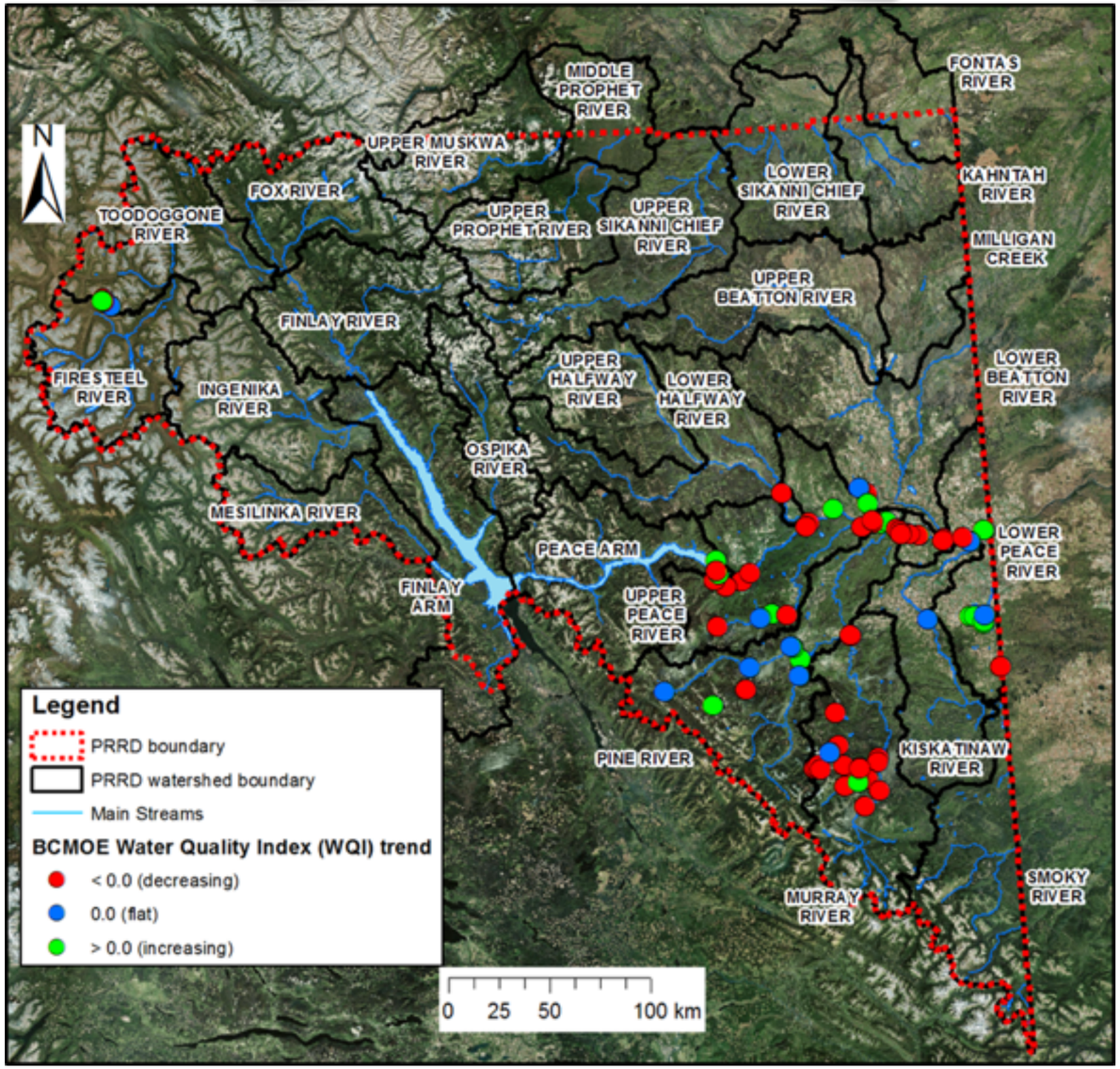
This method was developed by the Canadian Council of Environmental Ministers (CCME).

Water Quality Index



WQI, referring to BC MOE Aquatic Life Guideline - before 2001 and after 2001

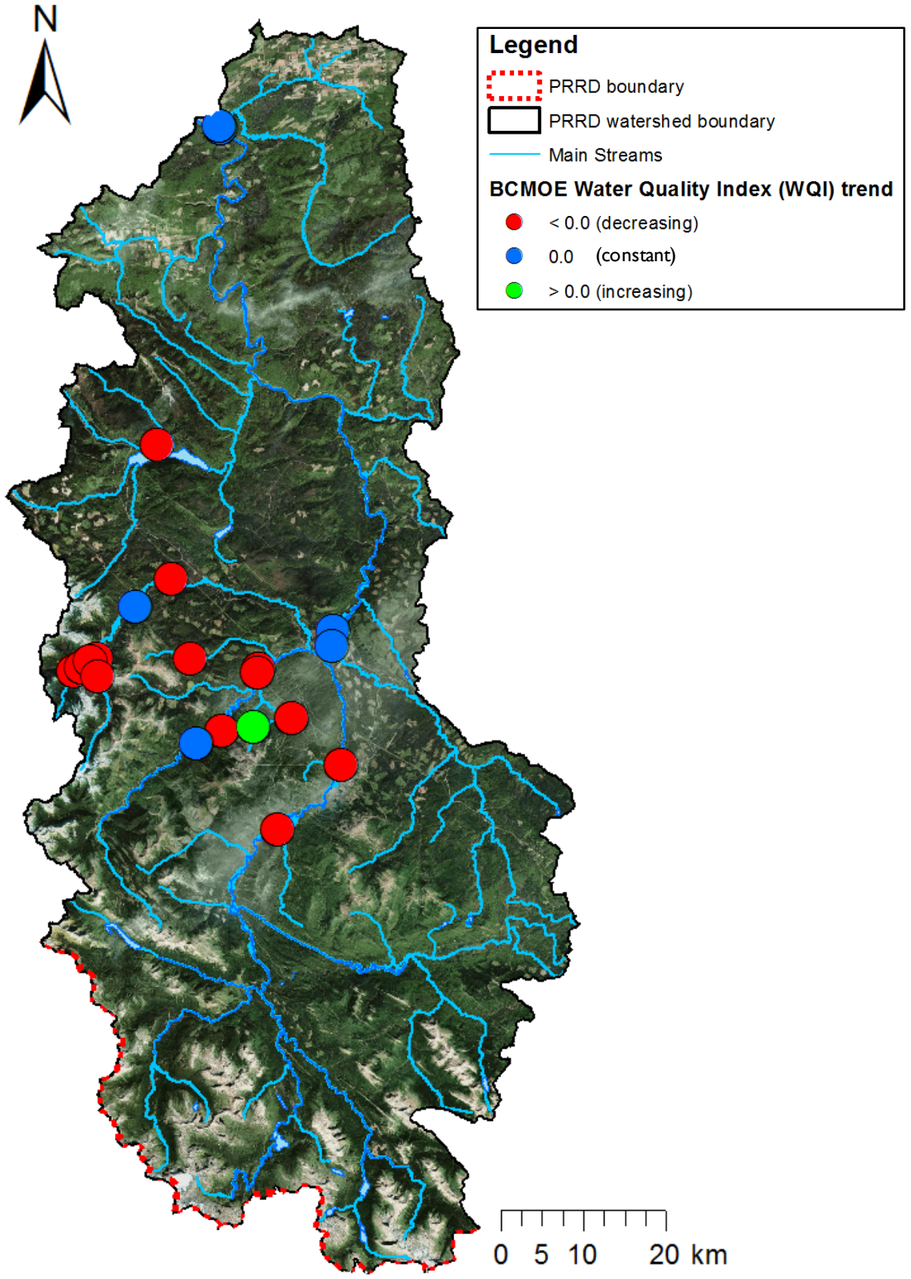
Water Quality Index

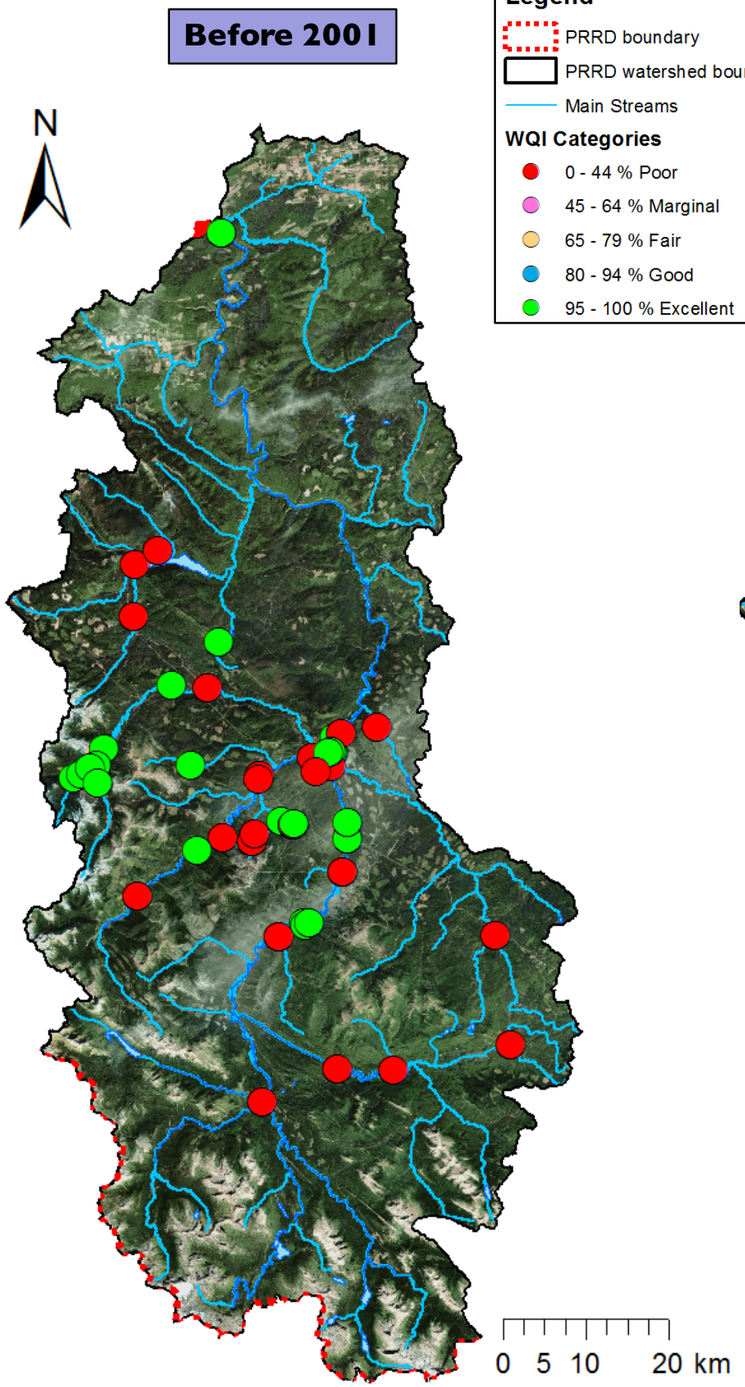


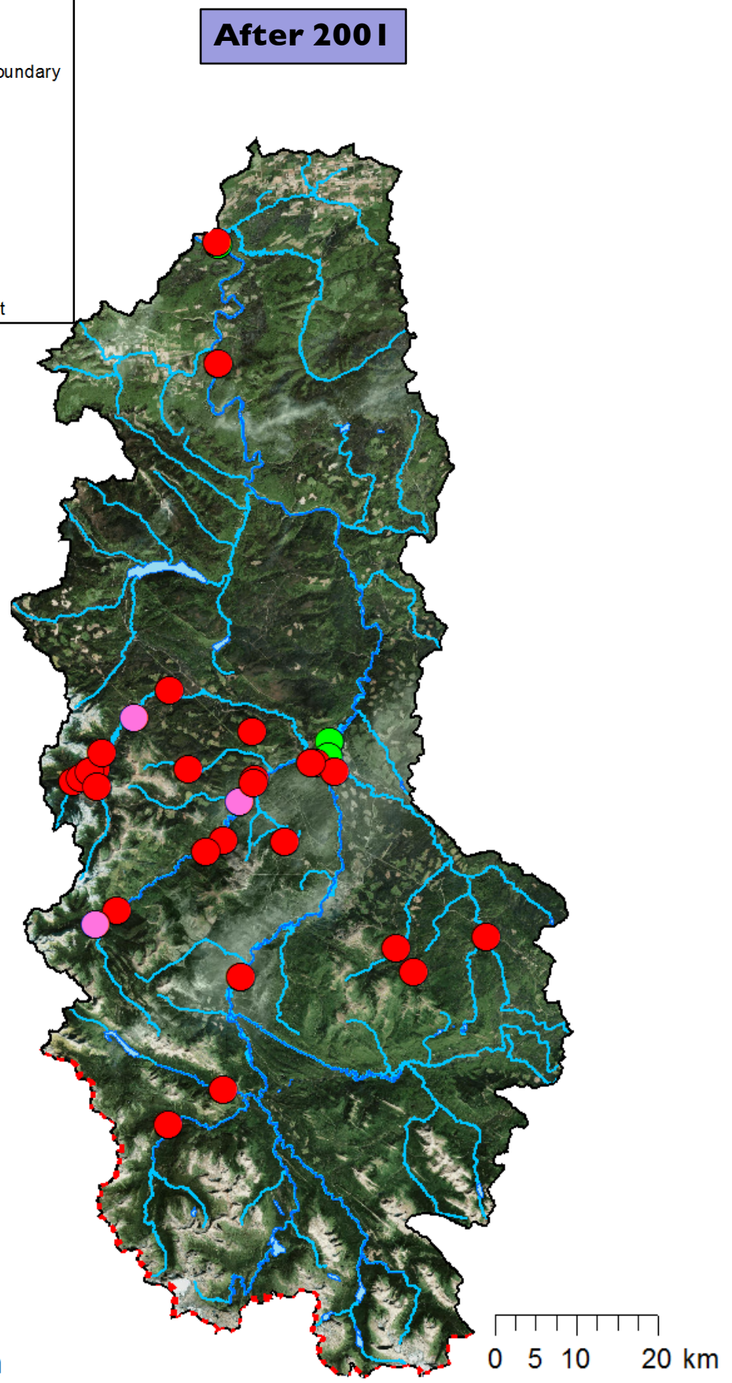
Only stations with five years of data with at least 10 samples are considered

WQI Trend – referring to BC MOE Aquatic Life Guideline

7- Murray River



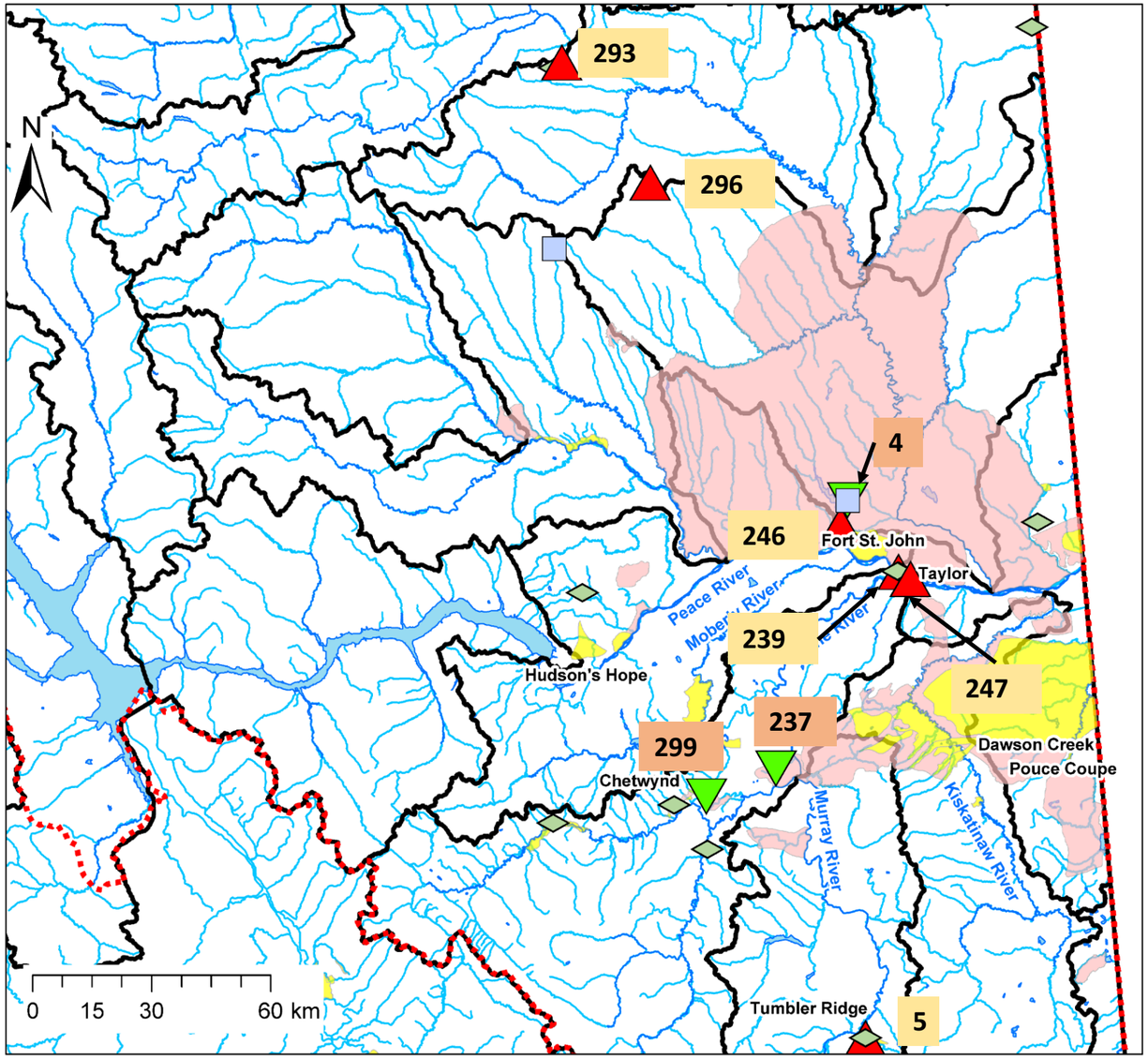




ANOMALIES
&
POTENTIAL IMPACT ON WATER SUPPLY

BARIUM IN GROUNDWATER

Groundwater - Barium Concentration Trends



PRRD boundary

Watershed boundary

Main Streams

Grounwater quality trend analysis

Trend designation

Increasing

Decreasing

No trend

Ambiguous

Mapped aquifers

Aquifer type

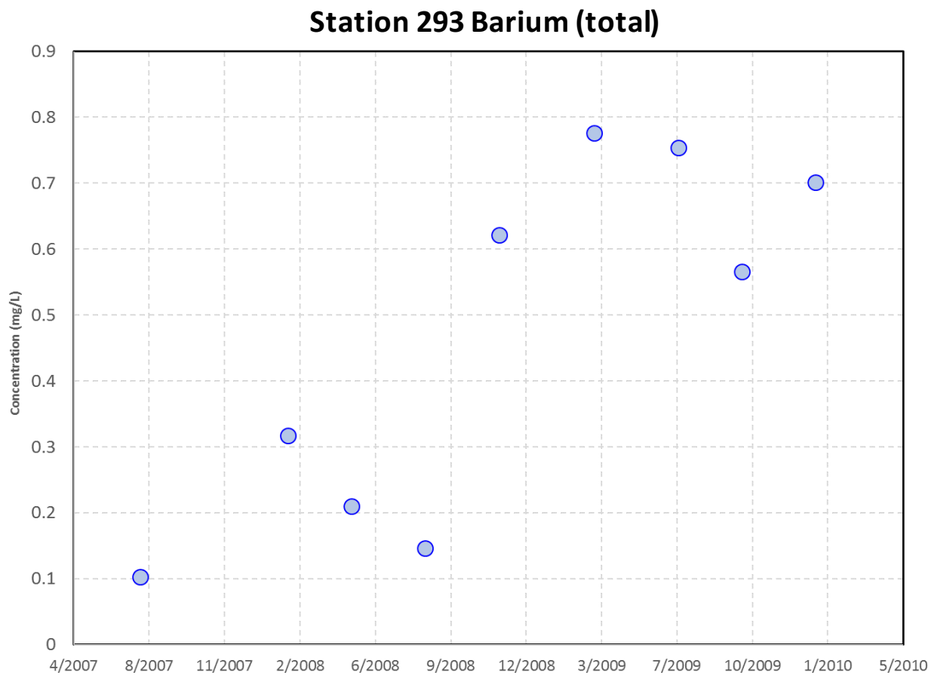
Bedrock

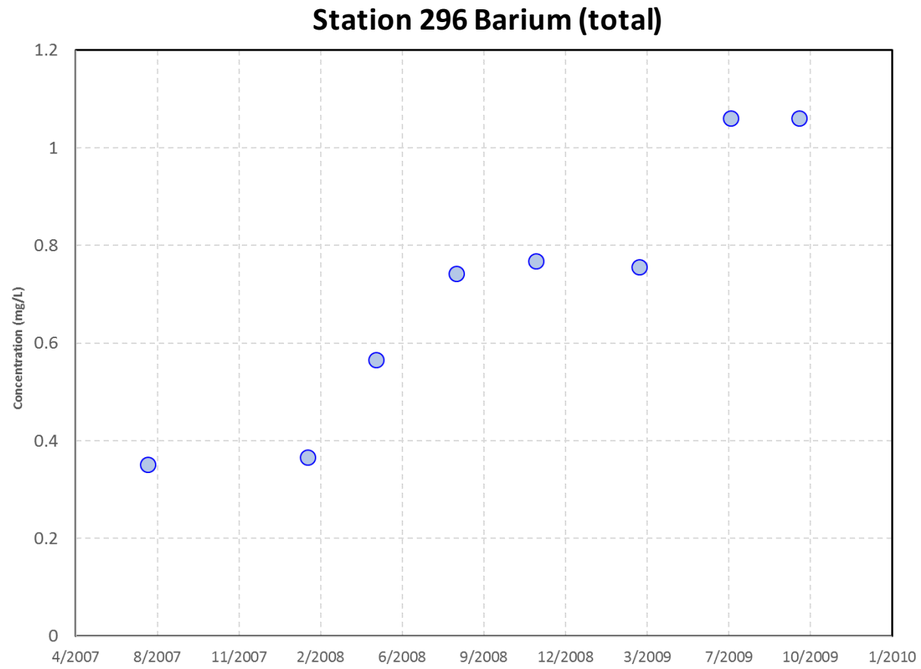
Overburden

Station ID

Groundwater trend result for barium (Ba) (dissolved/total)

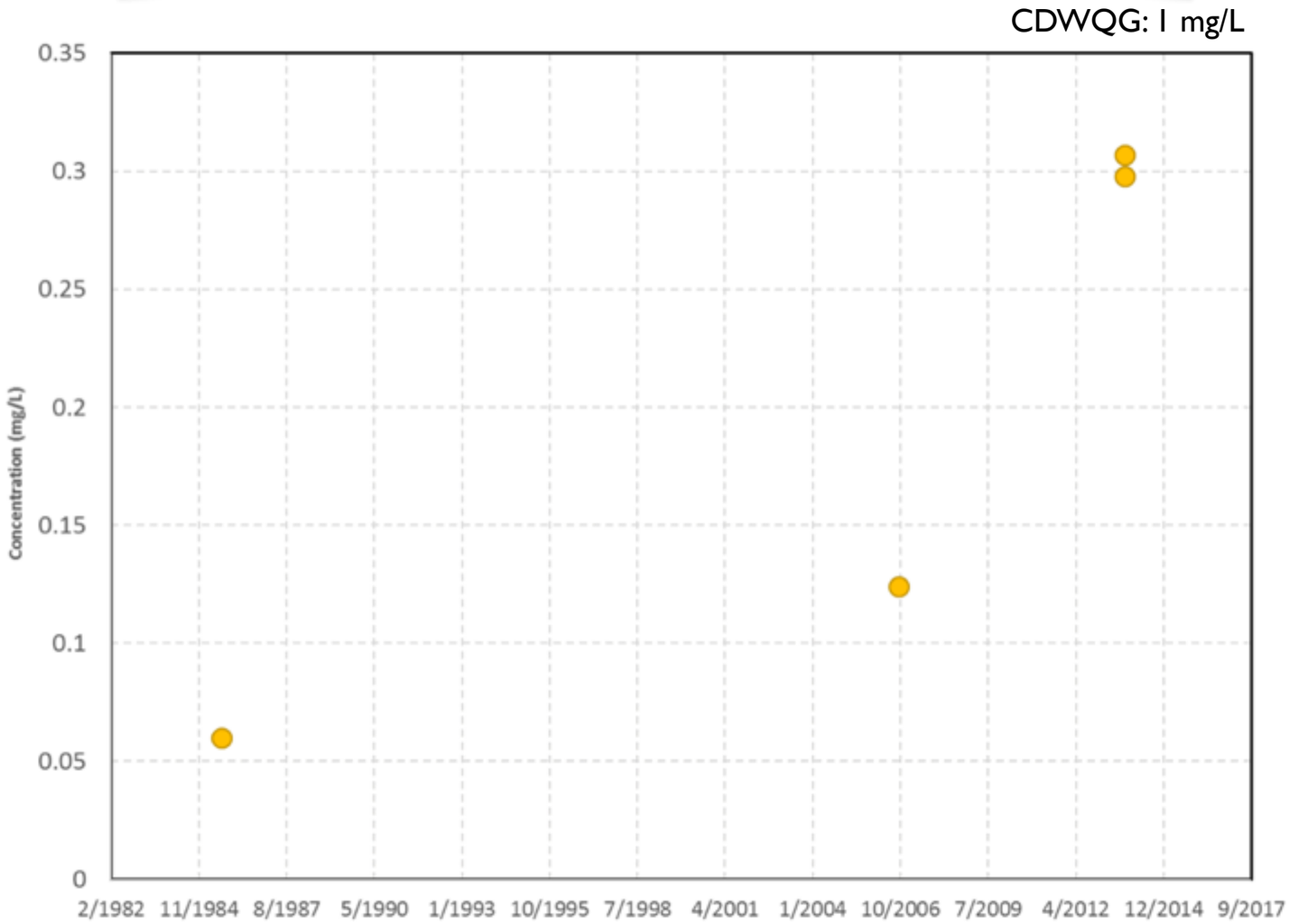
Groundwater - Barium Concentration
Station 293 and 296



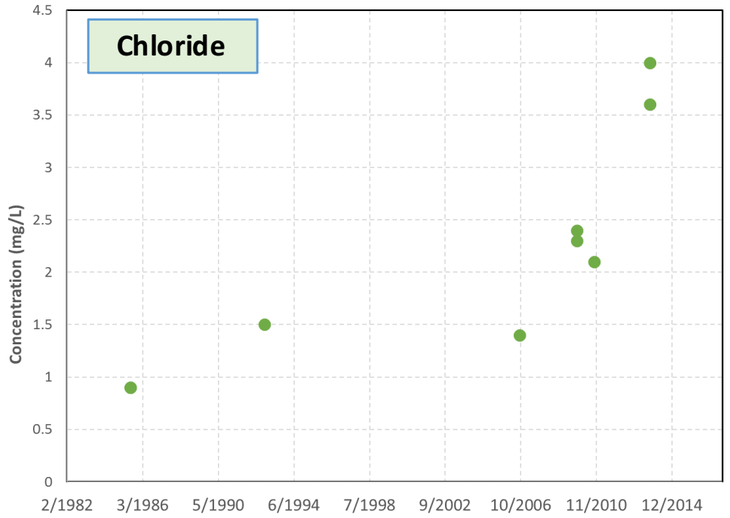


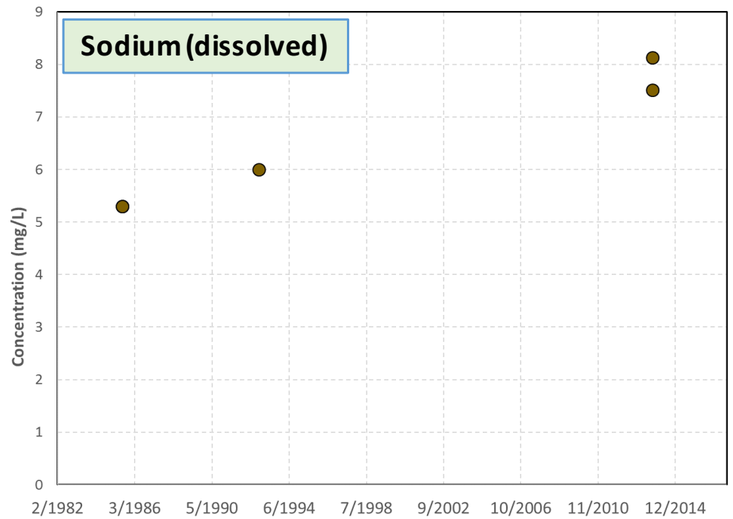
CDWQG: 1 mg/L

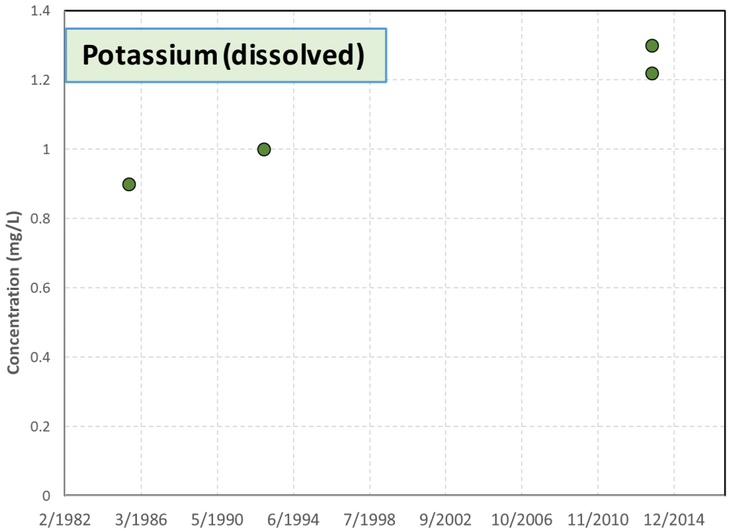
Groundwater - Barium Concentration Station 5 (BC MoE ObsW # 286)

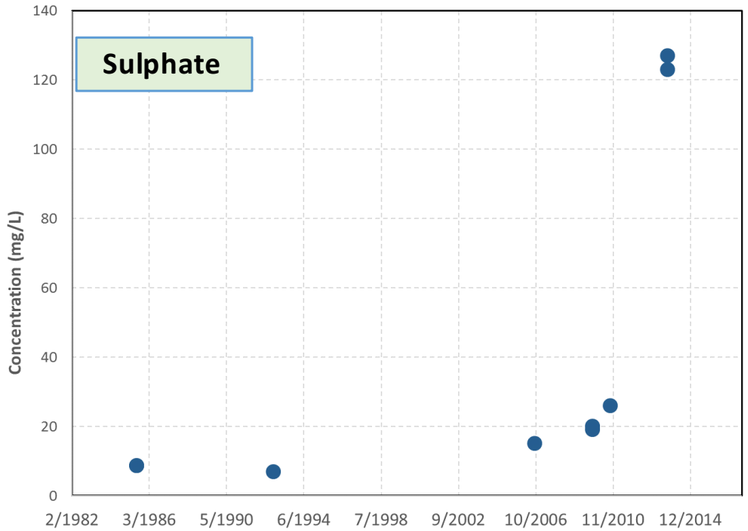


Groundwater - Cl, Na, K, and SO4 concentrations Station 5 (BC MoE ObsW # 286)

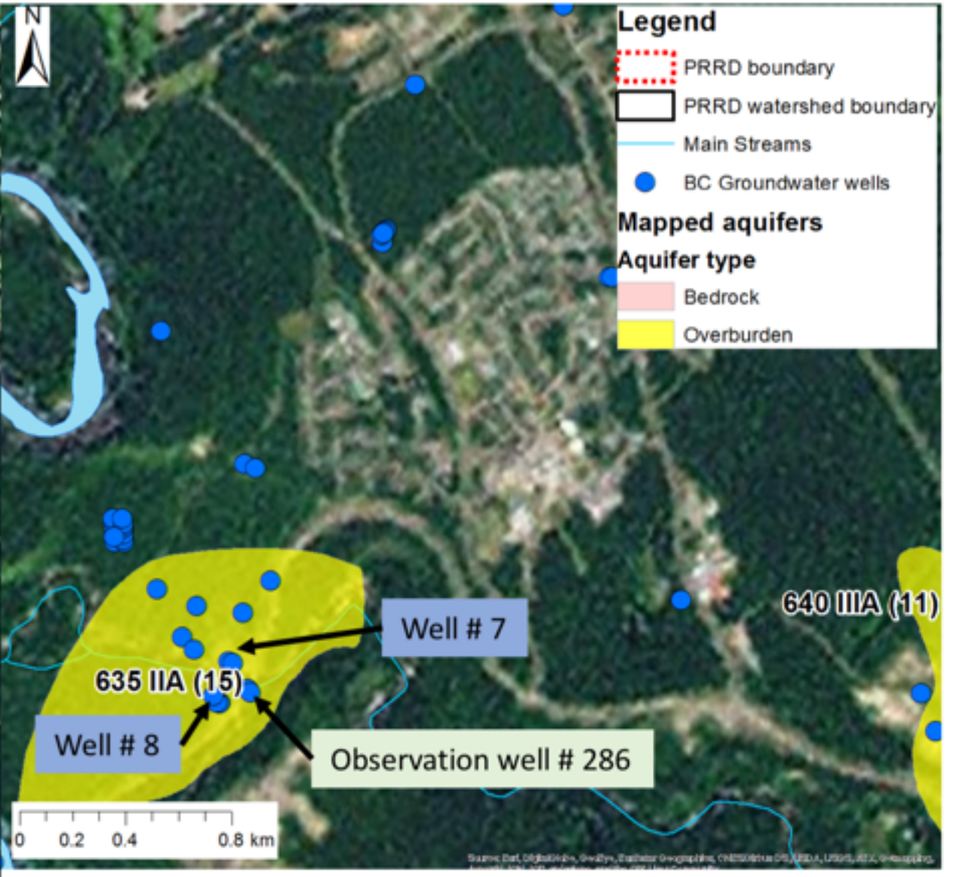








Note: BCMoE DW guideline: 500 mg/L for sulphate



Well #7 and #8 (high producing wells) are the main source for water supply for Tumbler Ridge.

Overburden aquifer 635: Thickness 7 - 12 m.

Depth between 30 - 45 m below ground.

CONCLUSIONS

CONCLUSIONS - GENERAL

1. GW Solutions has constructed a database for the PRRD region from publicly available data by sorting, formatting and standardizing available surface water and groundwater quality data.

2. Access to data on surface water and groundwater is difficult in the PRRD. What has been achieved through this project should improve public access to water related information.

3. Electro-neutrality was used as a quality control protocol to select reliable water quality data.

4. GW Solutions has compared the results to applicable provincial and federal guidelines.

CONCLUSIONS - GENERAL (2)

5. GW Solutions has analyzed the data to classify the water samples per water type, based on the presence of the major ions dissolved in the water. At the regional scale, the water appeared to originally be predominantly calcium-bicarbonate for surface water and calcium/sodium-bicarbonate/sulphate for the groundwater samples.

6. Groundwater and surface water are intimately connected. Groundwater is a key contributor to surface water in periods of low flow and droughts. Should groundwater quality deteriorate, it will affect the quality of the surface water.

7. The lack of information on water, both on quality and quantity prior to the 1970s has prevented the definition of the baseline before human activities started having a footprint both at surface and in the subsurface.

CONCLUSIONS - GENERAL (3)

8. Data review has revealed the absence of adequate temporal and spatial monitoring of both surface water and groundwater prior to and concurrent with human activities that may impact water. A proper surface water and groundwater monitoring plan is urgently needed. It should monitor the following:

a. springs;
b. streams;
c. lakes;
d. wetlands;
e. unconfined surficial aquifers;
f. confined surficial aquifers;
g. bedrock aquifers; and
h. the intermediate zone.

CONCLUSIONS - GENERAL (4)

9. An adequate set of each of these water bodies should be selected to have a proper spatial distribution.

10. Sampling and analyses have to be completed on a yearly basis, from mid-summer to early fall. The plan should be carried out for a duration of at least 10 years.

11. The monitoring plan should be adequately planned and funded.

CONCLUSIONS - SURFACE WATER

- 1. The database includes a total of 11,935 surface water samples from 364 locations, and collected between 1955 and 2014.
- 2. The parameters for which concentrations exceed the provincial guidelines have been listed (Table 10 of report).
- 3. The parameters for which concentrations exceed the federal guidelines have been listed (Table 11 of report).

CONCLUSIONS - SURFACE WATER (SW2)

- 4. GW Solutions has used Water Quality Indexes (WQI) to assign values indicative of their water quality to samples. The WQIs have been used to illustrate the water quality at stations over selected time periods. Maps have been produced illustrating whether the water quality is poor to excellent for the region and for each watershed.

- 5. The change in WQI has been used to estimate the improvement or worsening of the water quality over time. Maps have been produced illustrating WQI trends for the region and for each watershed. The trends for the region, using both provincial and federal guidelines, are shown in Figure 19 and Figure 23 of the report. They appear to indicate a general worsening of the water quality versus time.

- 6. After 2000 we observe an increasing presence of chloride, sodium and sulphate in surface water.

CONCLUSIONS - GROUNDWATER

- 1. The database includes a total of 875 groundwater samples from 522 locations collected between 1943 and 2015.

- 2. The parameters for which concentrations exceed the provincial guidelines are listed (Table 12 of the report).

- 3. The parameters for which concentrations exceed the federal guidelines are listed (Table 13 of the report).

- 4. We observe an increasing presence of sodium and sulfate in groundwater (after 2000), and in spring water (after 2011), and we also observe a higher level of mineralization of the groundwater from bedrock wells after 2011 (i.e., the major ions are present at a higher concentration). However, we cannot draw the conclusion that there has been an increase over time because we don't have the dataset from the same wells. This confirms the need of building a dataset over time for selected monitoring locations.

CONCLUSIONS - GROUNDWATER (GW2)

- 5. Barium concentration has increased in groundwater at several locations over a relatively short time period. Such an increase is not expected under natural conditions. The observed increase in barium concentration in groundwater could possibly result from the intense drilling activity in the region, through mobilization of deep groundwater containing higher concentration of barium and/or the release of barium into the shallow aquifers during drilling. For Station 5 (provincial monitoring well # 286), in Tumbler Ridge, the concentration of chloride, sodium, potassium, and sulphate has also increased over the same time period. Further investigation is required to determine the cause of the observed change in concentrations.

CONCLUSIONS - GROUNDWATER (GW3)

- 6. The groundwater regime has been very poorly monitored and is still very poorly monitored. Aquifers need to be adequately characterized and monitored.

- 7. There is a profound absence of knowledge about the presence and migration of fluids in the intermediate zone of the subsurface, approximately located between 500 m and 2 km depth. This needs to be addressed in the areas of intense oil and gas activities. Adequate characterization and monitoring programs need to be designed and implemented very rapidly.

RECOMMENDATIONS

- 1. That the PRRD Board of Directors acknowledges and affirms that it is the Province who is ultimately the steward and regulator for water in the Province of BC, and that the Province recognizes that the quantity and quality of our water supply is essential to public health and sustainable communities, and that, the PRRD has received the report regarding the studies done on watersheds in the Peace, which will be posted for public use.

- 2. That the newly developed data base be presented to appropriate regulators and provincial decision makers and request that, in collaboration with the PRRD, a review of all updated information be completed biannually in order to continue with trend analysis.

- 3. That the Province be encouraged to share with the public, all new water information in a timely manner.

RECOMMENDATIONS

- 4. That the Province, through the North East Water Strategy Working Group (a working group that includes input of local knowledge on water initiatives), determines at risk watersheds or parts of watersheds and conducts further assessment to identify causes and create mitigation strategies.

- 5. That the BC Ministry of Environment and the Ministry of Forests, Lands and Natural Resource Operations be requested to create regulations to characterize and monitor the movement of fluids in the intermediate zone between the depths of 500 meters and 2,000 meters.

- 6. That the Province be requested to implement monitoring programs to continue to define water baselines both for quantity and quality in areas of the region that are poorly defined or monitored.

ACKNOWLEDGEMENT

- Thank you,
  - The Real Estate Foundation of BC
  - The Peace River Regional District
  - Treaty 8 Tribal Association
  - The Peer Reviewers

LIMITATIONS

- This presentation and associated report (further referred as “this report”) was prepared for the PRRD and T8TA. In evaluating the available information, GW Solutions has relied in good faith on information provided by others.
- The produced graphs, images, and maps, have been generated to visualize results and assist in presenting information in a spatial and temporal context. The conclusions and recommendations presented in this report are based on the review of information available at the time the work was completed, and within the time and budget limitations of the scope of work.
- The findings and conclusions documented in this report have been prepared for the specific scope of work of this project, and have been developed in a manner consistent with that level of care normally exercised by hydrogeologists currently practicing under similar conditions in BC.
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