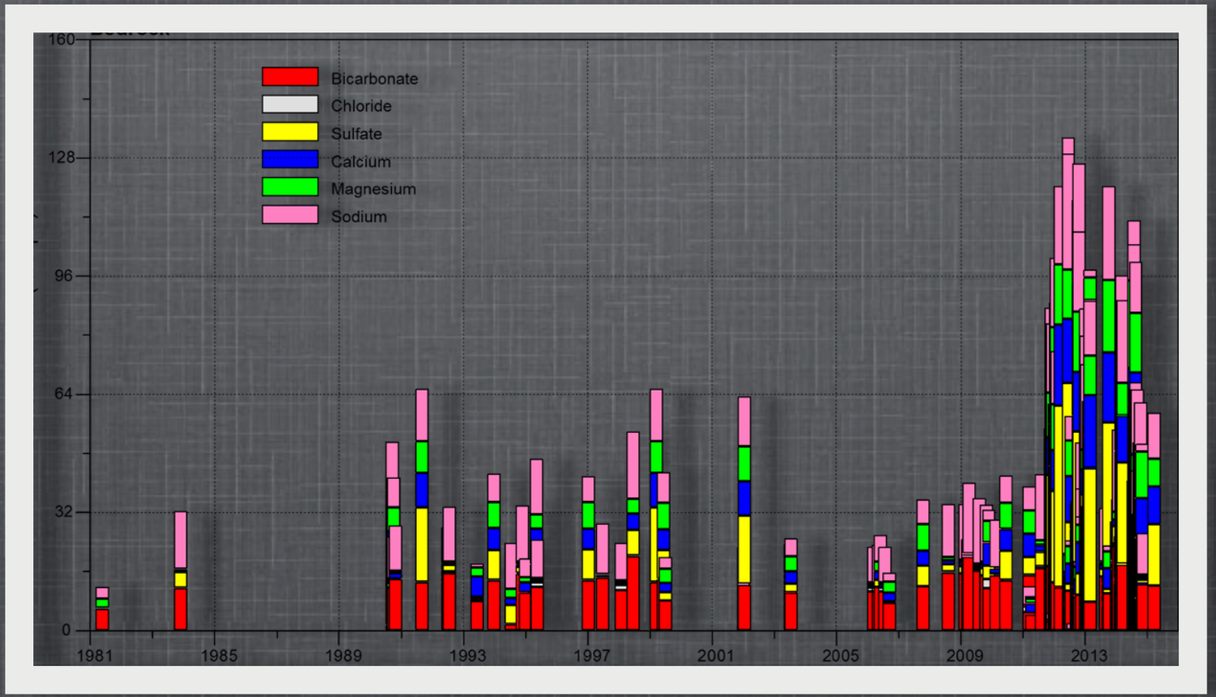
PEACE RIVER REGIONAL DISTRICT
WATER QUALITY BASELINE



PRRD - T8TA

GW Solutions - Interraplan

Kamloops, March 2017

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

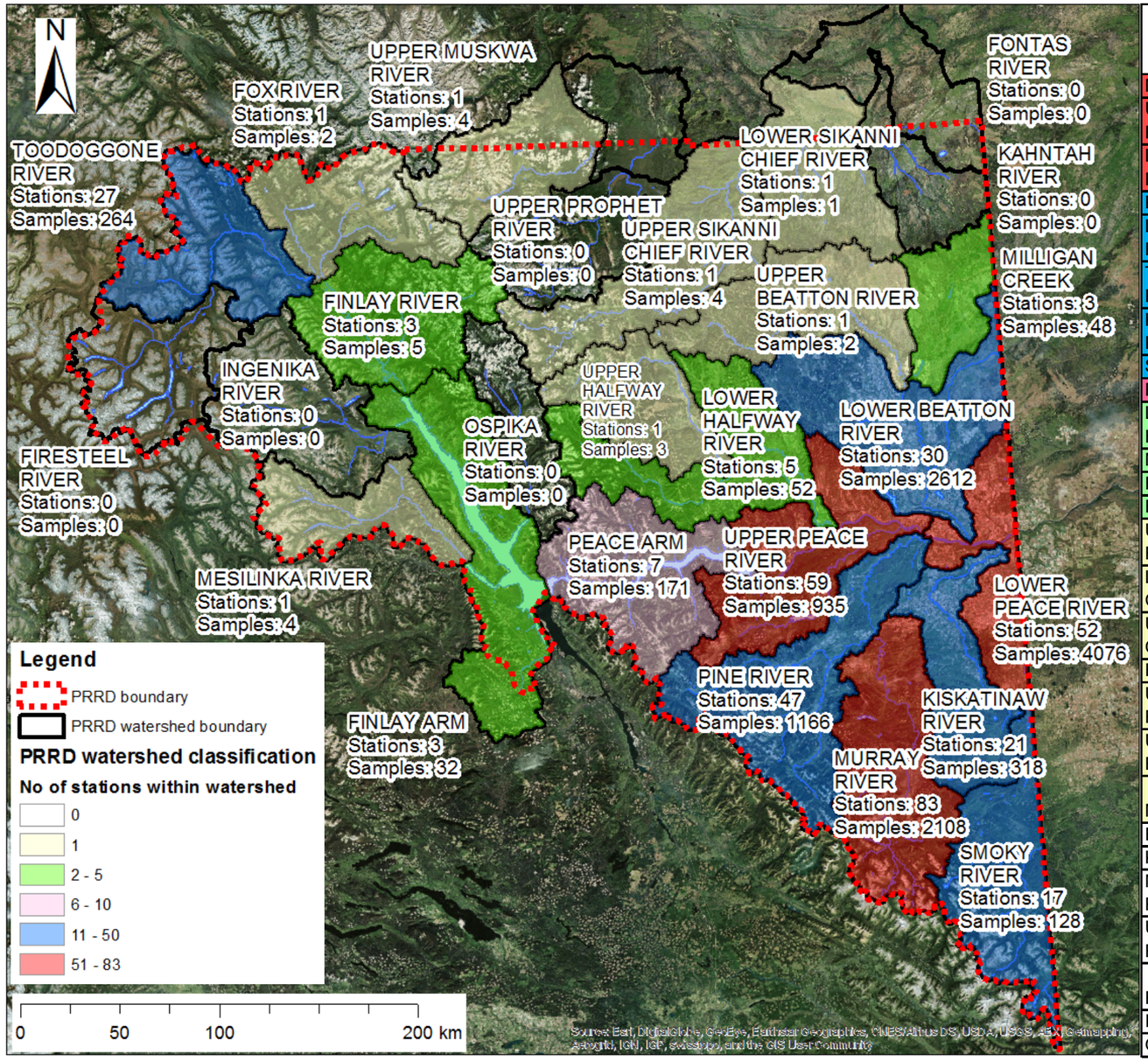
OUTLINE

- Challenges - Data and Tools
- Comparison to Guidelines - Detailed Analyses / Results
- Water Quality Index
- Anomalies & Potential Impact on Water Supply
- 3D Hydrostratigraphic modelling
- Conclusions & Recommendations

CHALLENGES, DATA AND TOOLS


N
Peace River Regional District
0 87.5 175 350 km

Surface Water - Stations and Samples

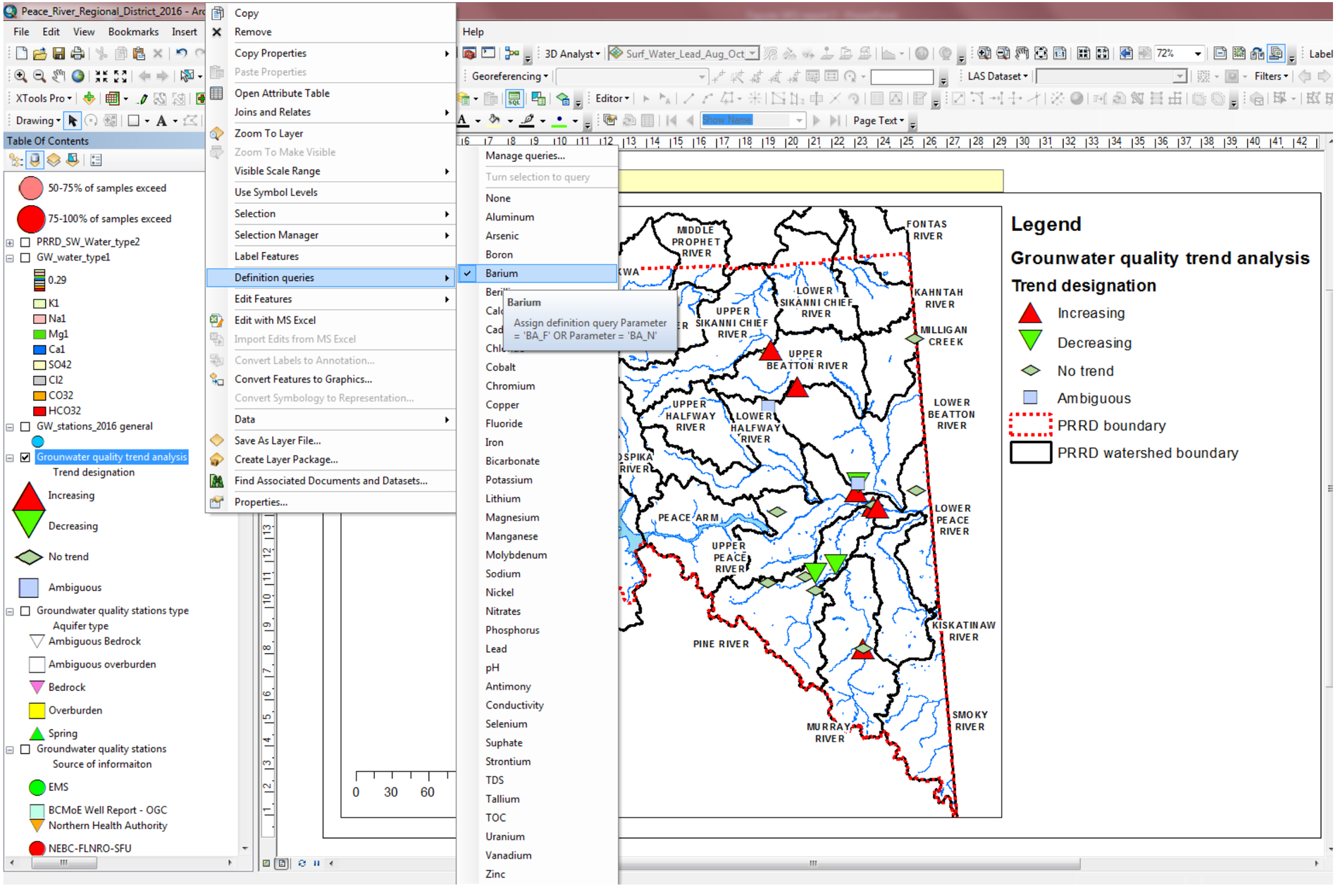


PRRD Watershed	Area (km^2)	% Area compared to PRRD	No of stations	No of samples
MURRAY RIVER	6489.2	5.4%	83	2108
UPPER PEACE RIVER	5736.6	4.8%	59	935
LOWER PEACE RIVER	3268.9	2.7%	52	4076
PINE RIVER	7015.0	5.9%	47	1166
LOWER BEATTON RIVER	7167.8	6.0%	30	2612
TOODOGGONE RIVER	4831.2	4.1%	27	264
KISKATINAW 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

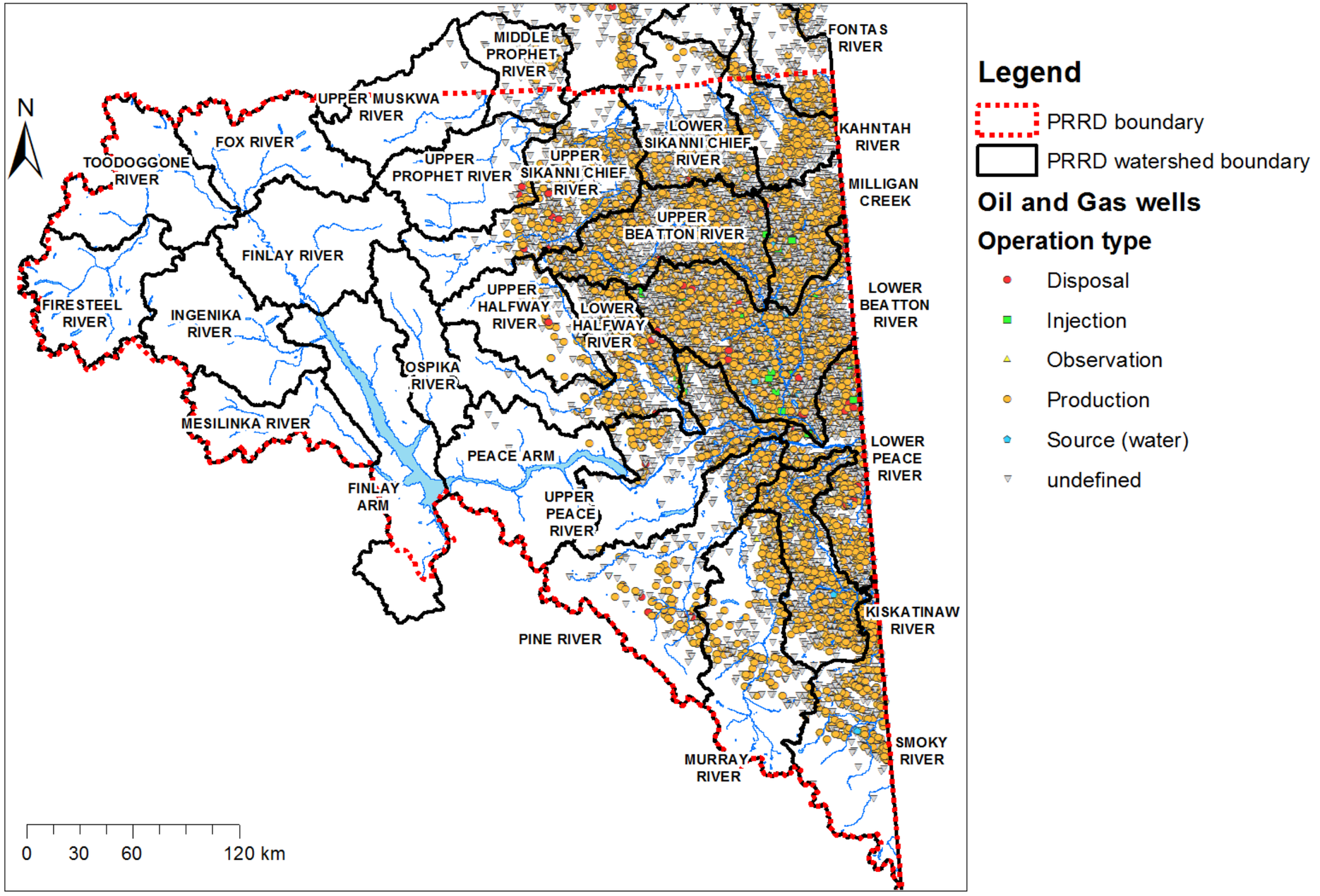
11935 samples

GIS Database platform data analysis and presentation

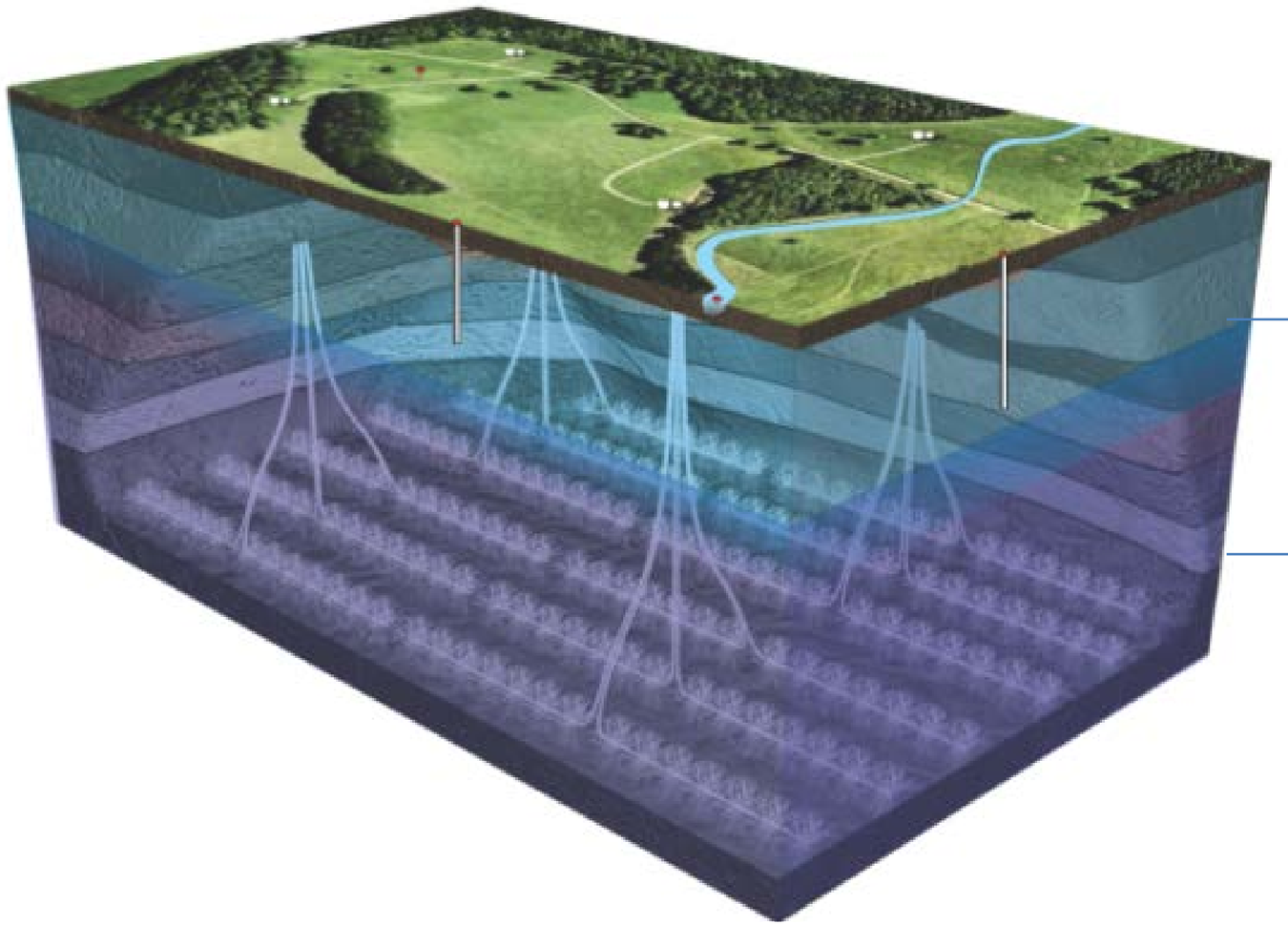
Example showing the groundwater quality trend analysis and result for Barium



SURFACE WATER GROUNDWATER INTERACTION & HUMAN ACTIVITIES



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



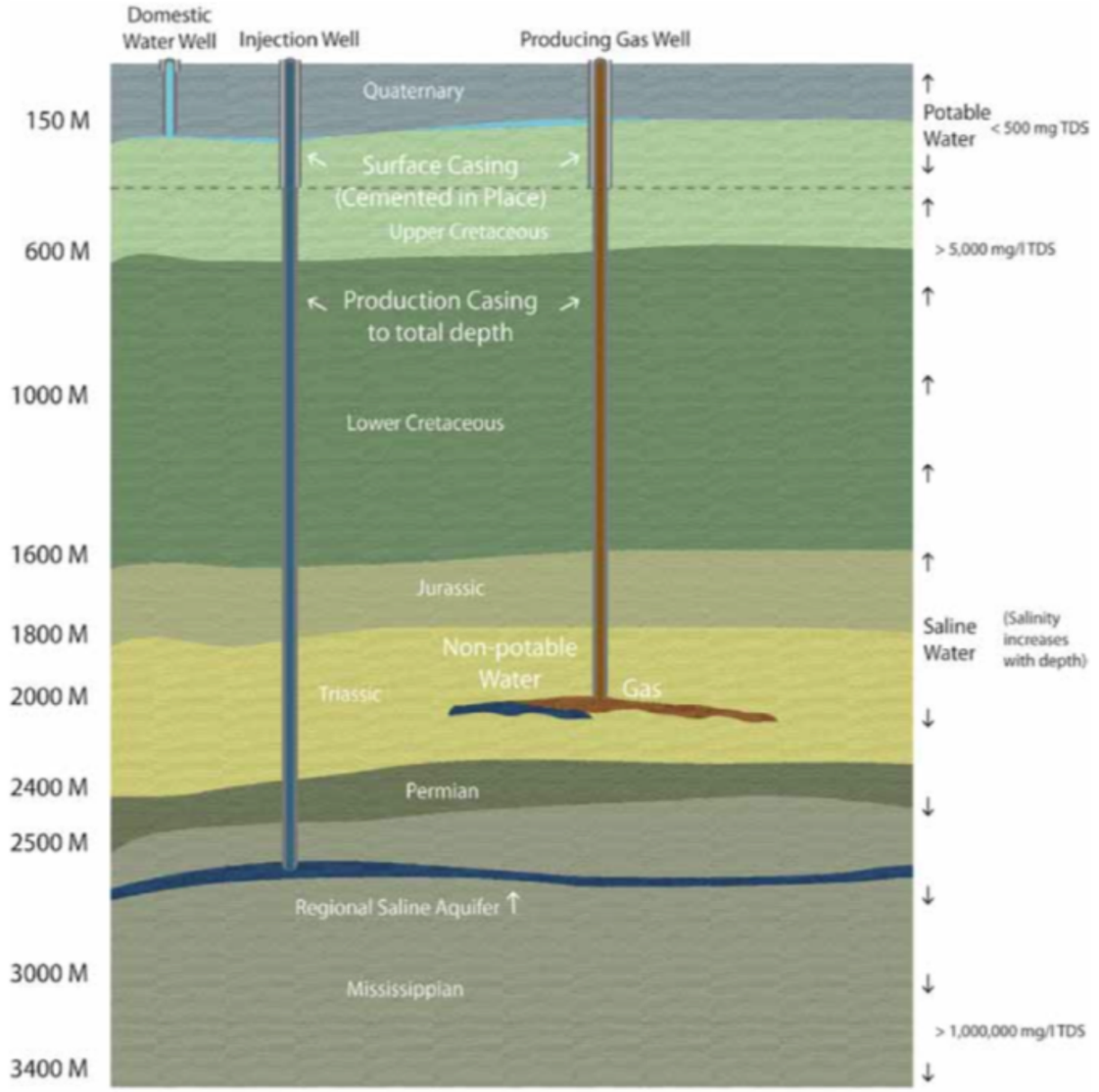
FRESH

INTERMEDIATE

DEEP

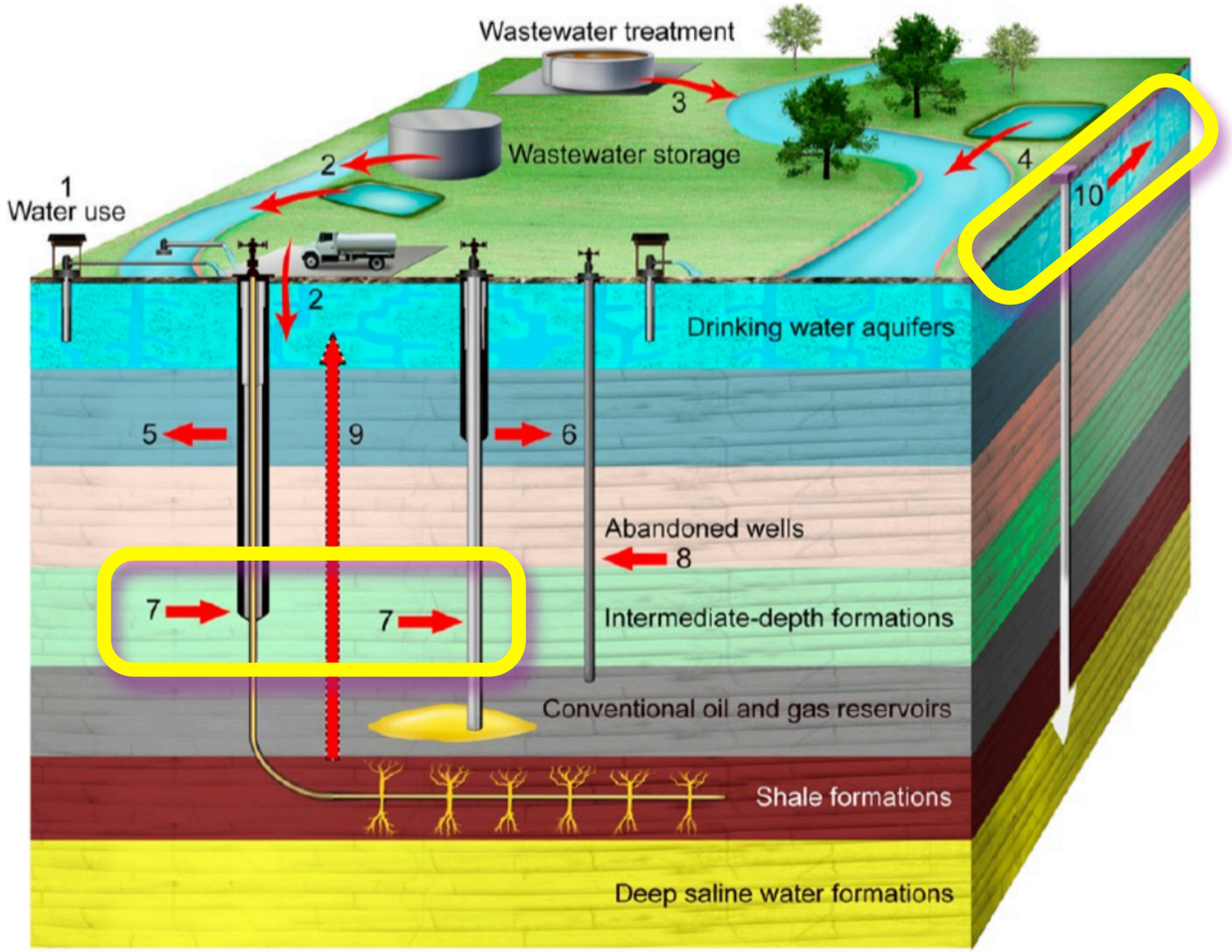
Shallow (fresh), Intermediate and Deep groundwater zones

(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)



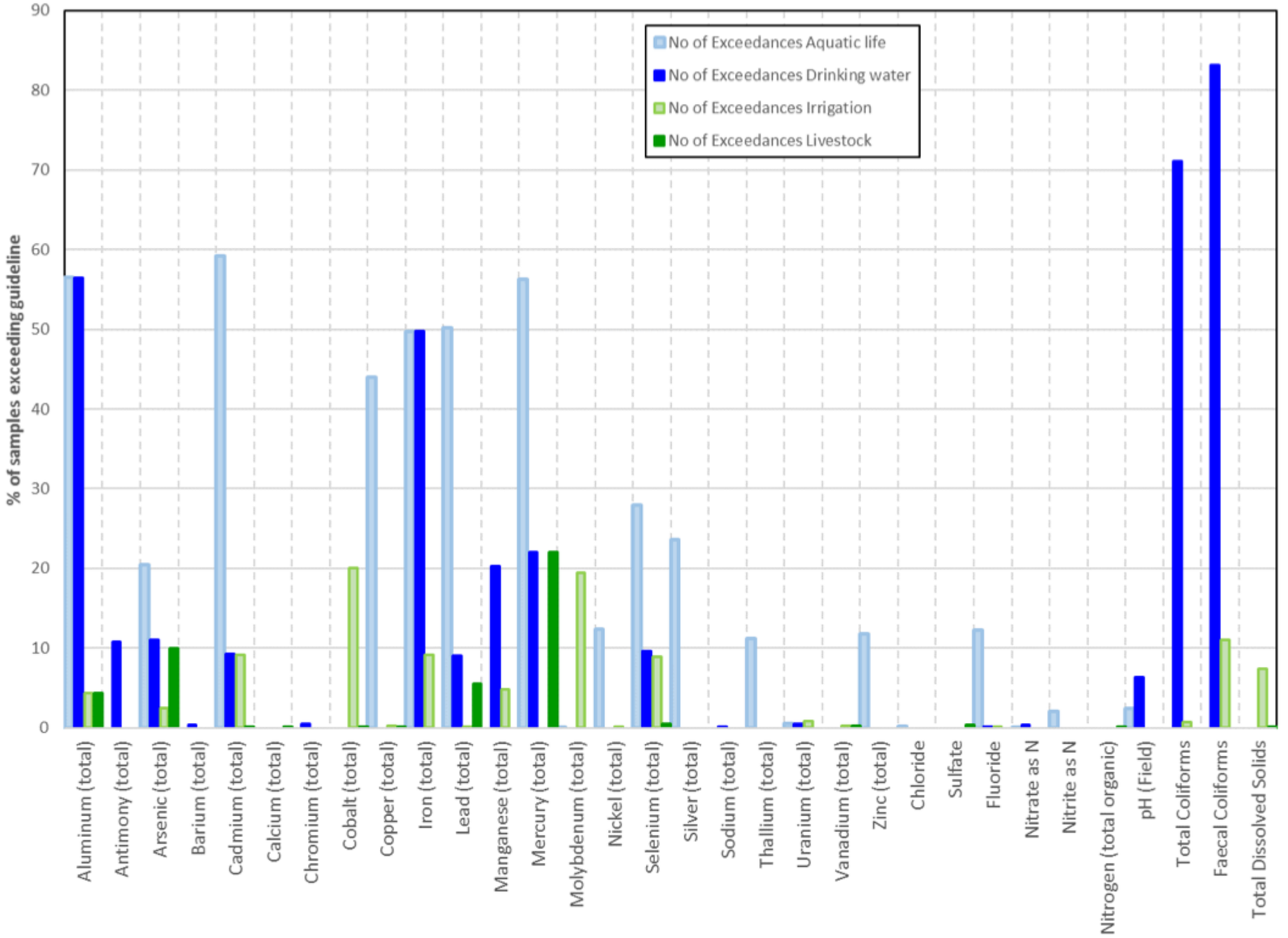
(1) overuse of water that could lead to depletion and water- quality degradation particularly in water-scarce areas;
(2) surface water and shallow groundwater contamination from spills and leaks of wastewater storage and open pits near drilling;
(3) disposal of inadequately treated wastewater to local 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)

COMPARISON TO GUIDELINES

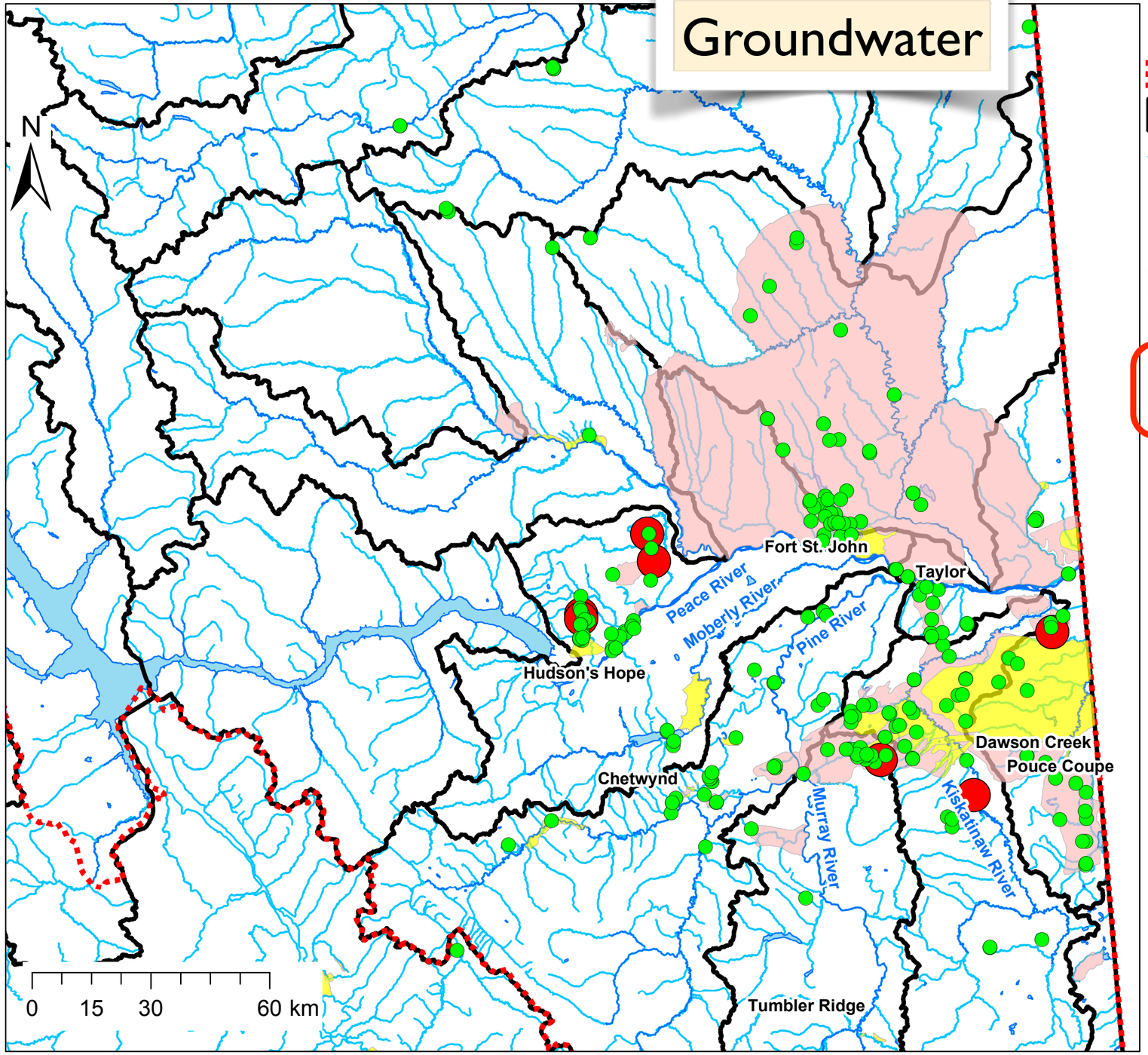
Federal guidelines	Provincial guidelines
Aquatic Life Freshwater Short Term (Chronic)	Aquatic Life Freshwater Chronic (30-Day Mean)
Aquatic Life Freshwater Long Term (Acute)	Aquatic Life Freshwater Acute (Maximun)
Agriculture Livestock	Agriculture Livestock Watering Chronic (30-Day Mean)
	Agriculture 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



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

Groundwater



Legend

- PRRD boundary
- Watershed boundary
- Main Streams

Mapped aquifers

Aquifer type

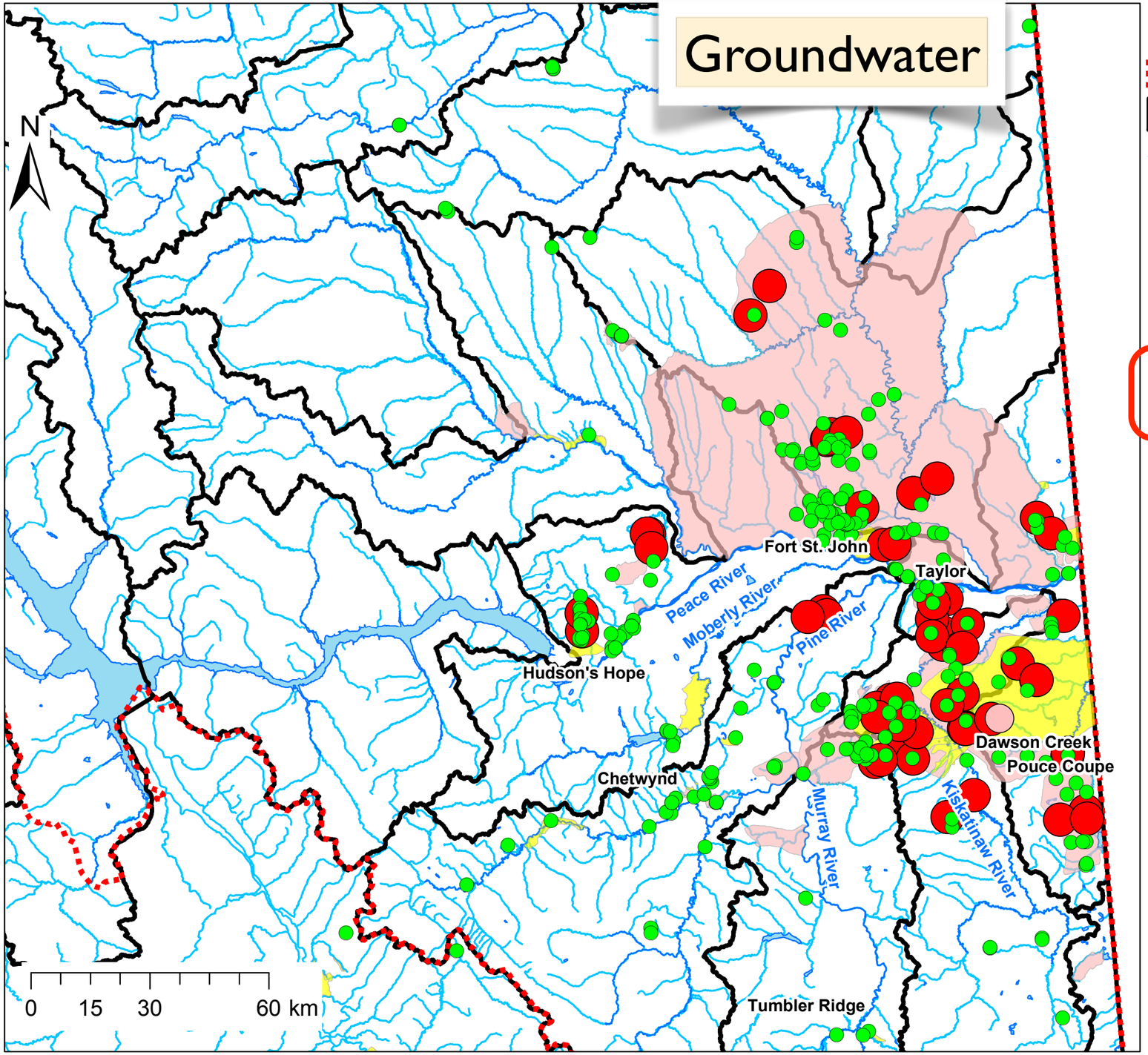
- Bedrock
- Overburden

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

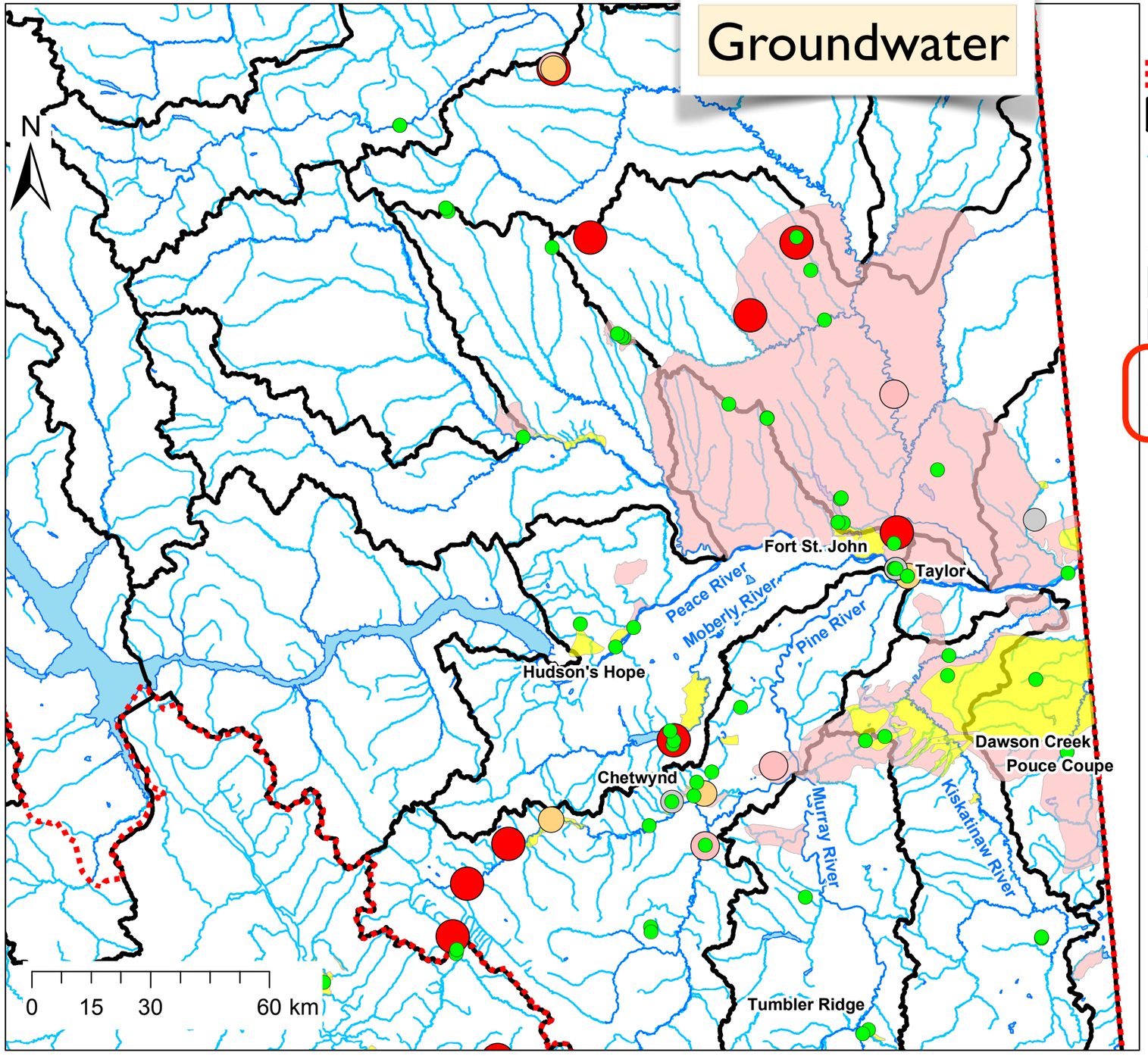
Overburden

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)



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

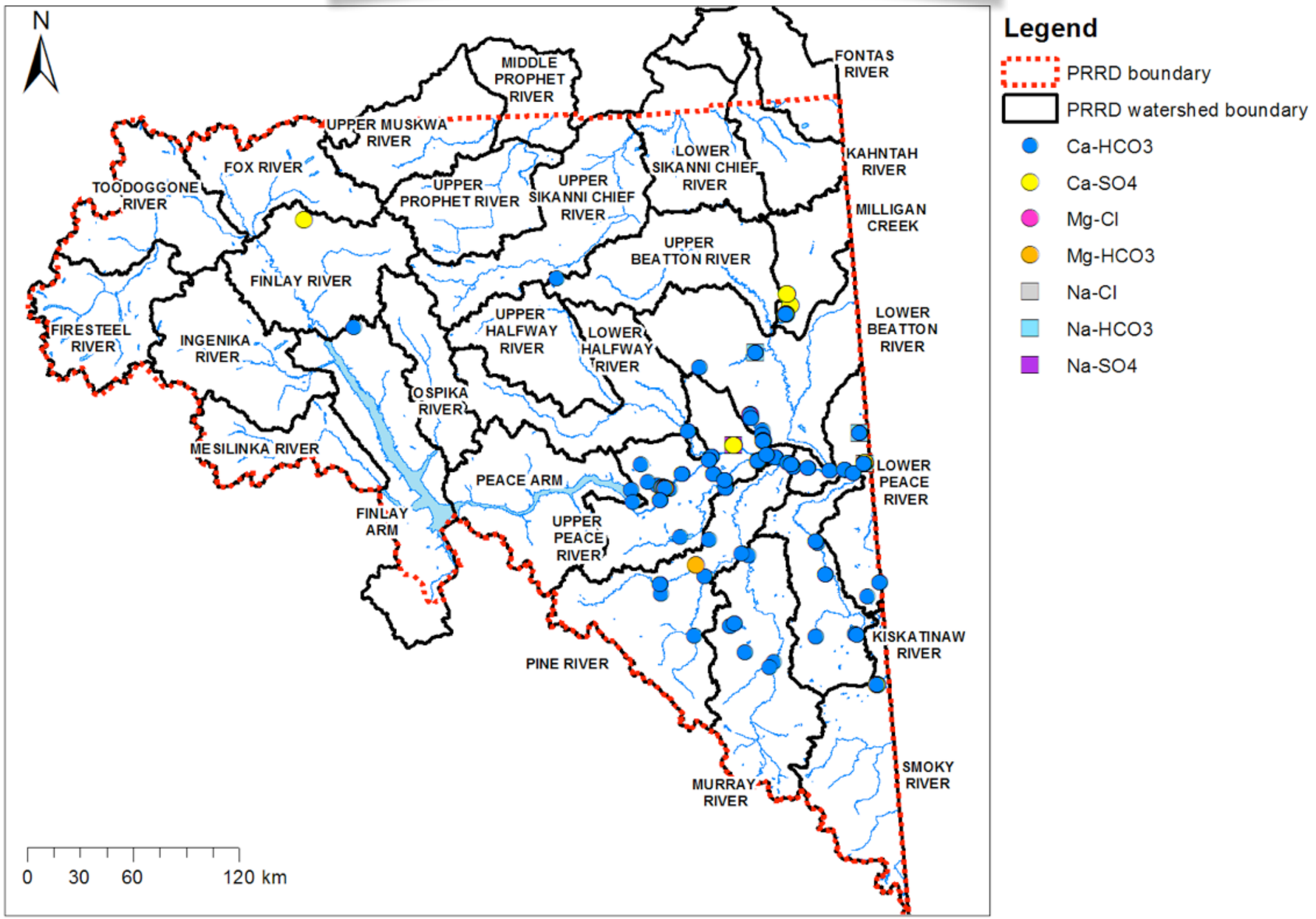
50-75% of samples exceed

75-100% of samples exceed

Exceedance analysis for copper (Cu)

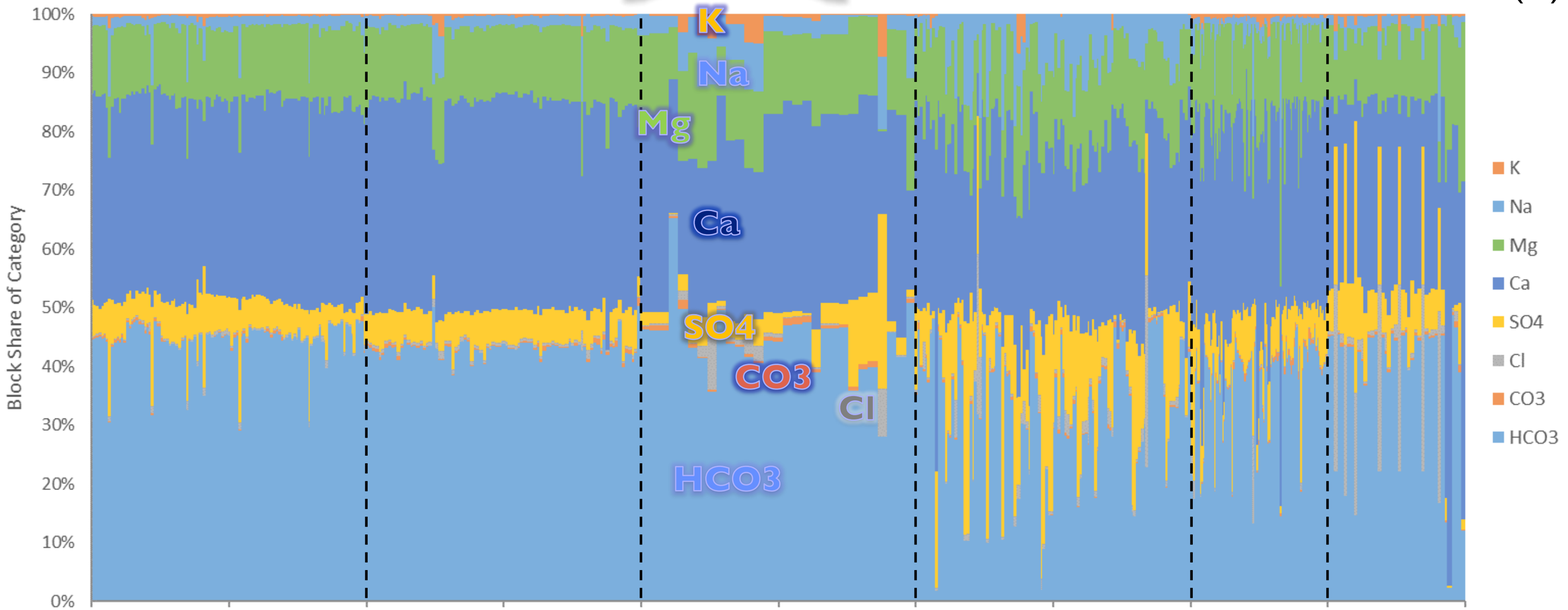
DETAILED ANALYSIS SCATTER, PIPER, MEKKO PLOTS

Surface Water - Water Types



Surface Water

Cation (+)

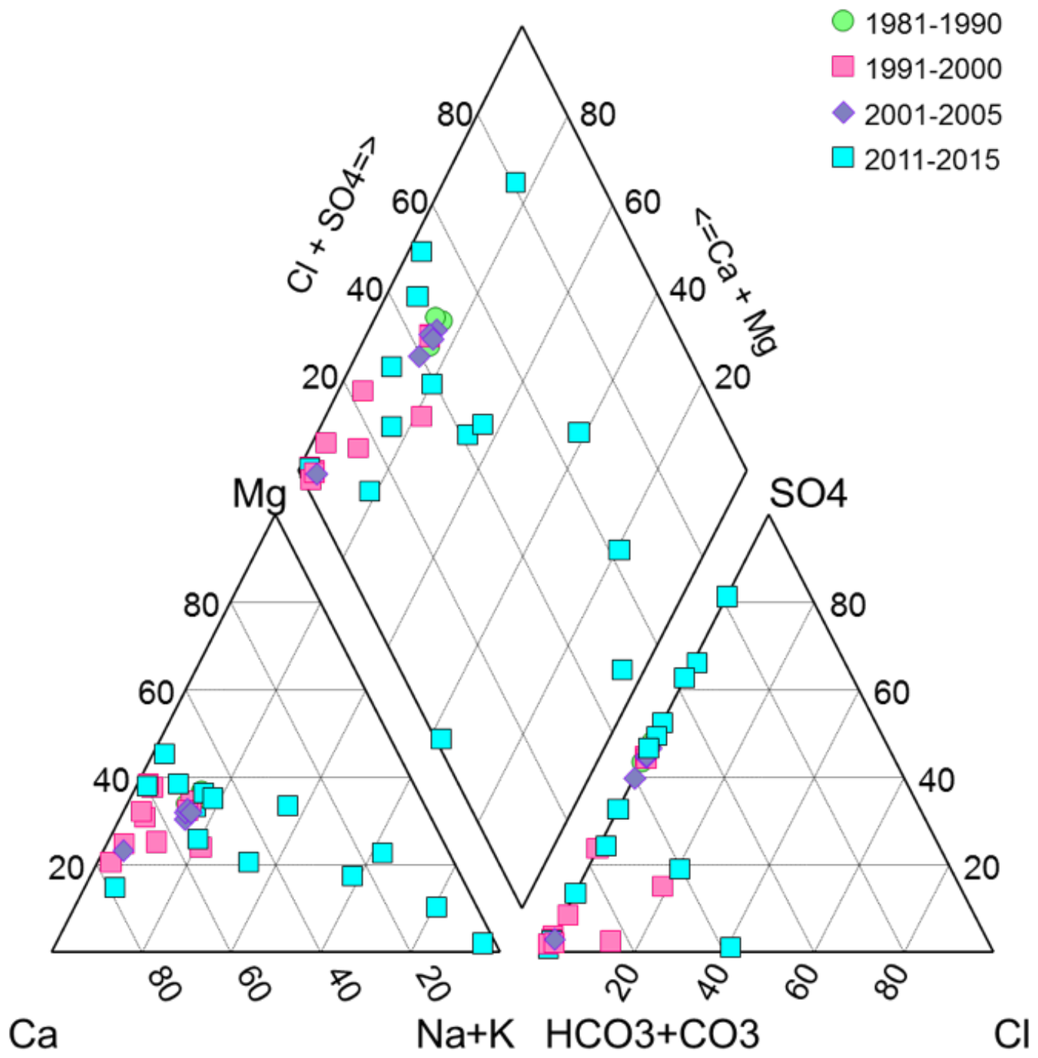


Anion (-)

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

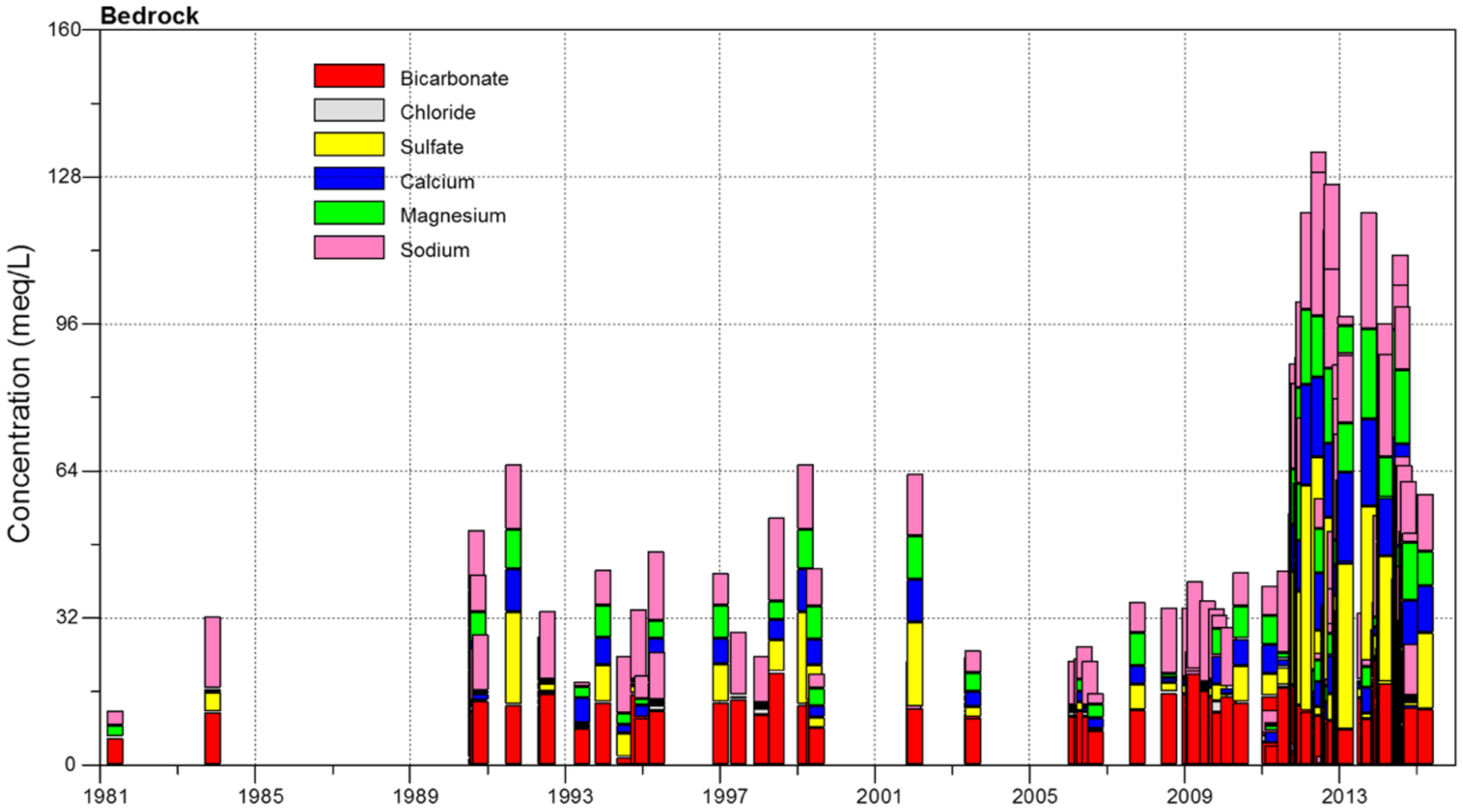
(note: only presenting major ions)

Groundwater - Springs

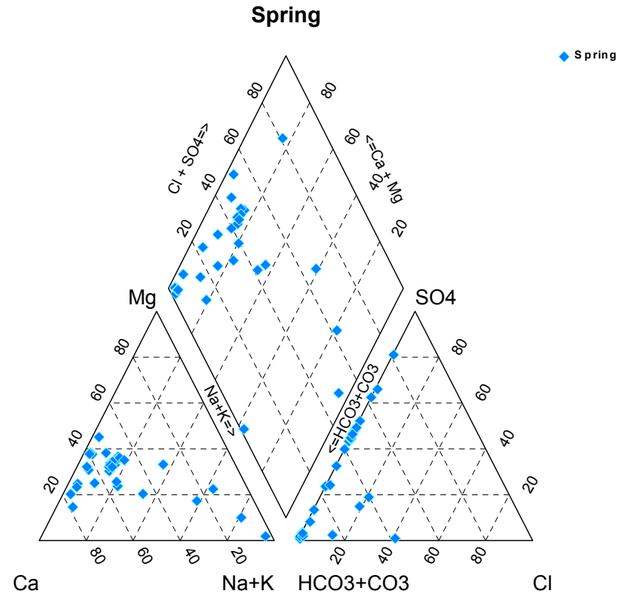


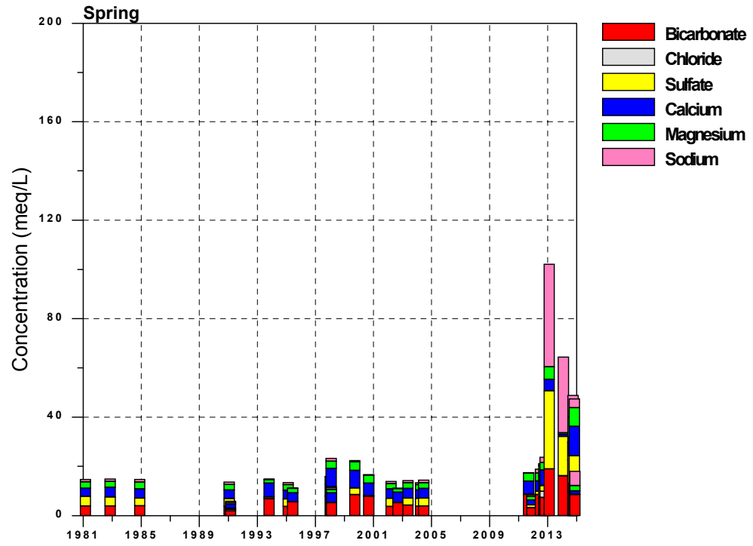
Piper plot for samples taken from springs grouped by sampling periods

Groundwater - Bedrock Wells



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





Appendix: 8

Piper diagram and bar plot for springs

Project: PRRD water quality baseline	Date: June 2016
Project No: 14-18	Author: GW Solutions Inc.

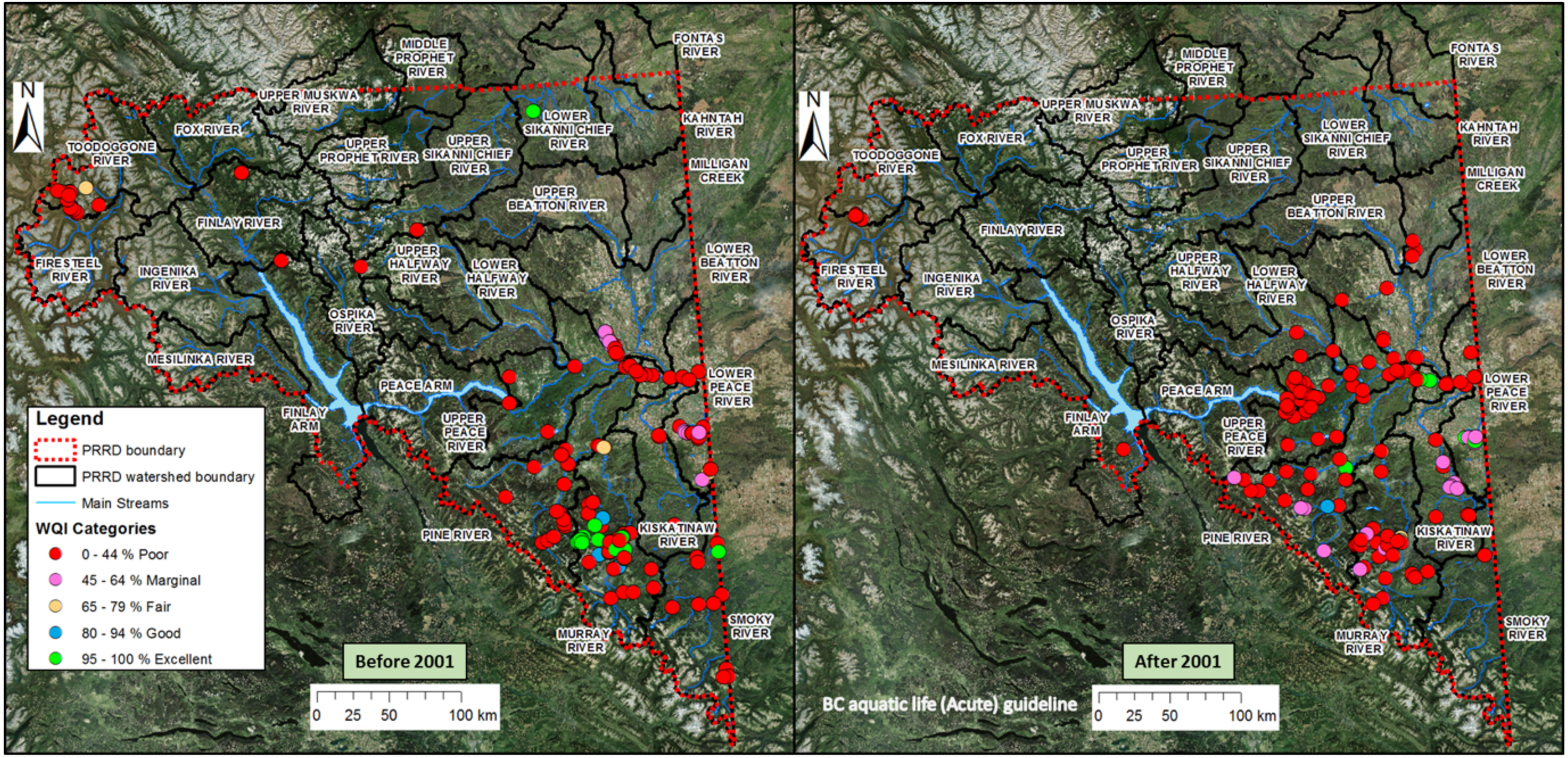
WATER QUALITY INDEX

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	

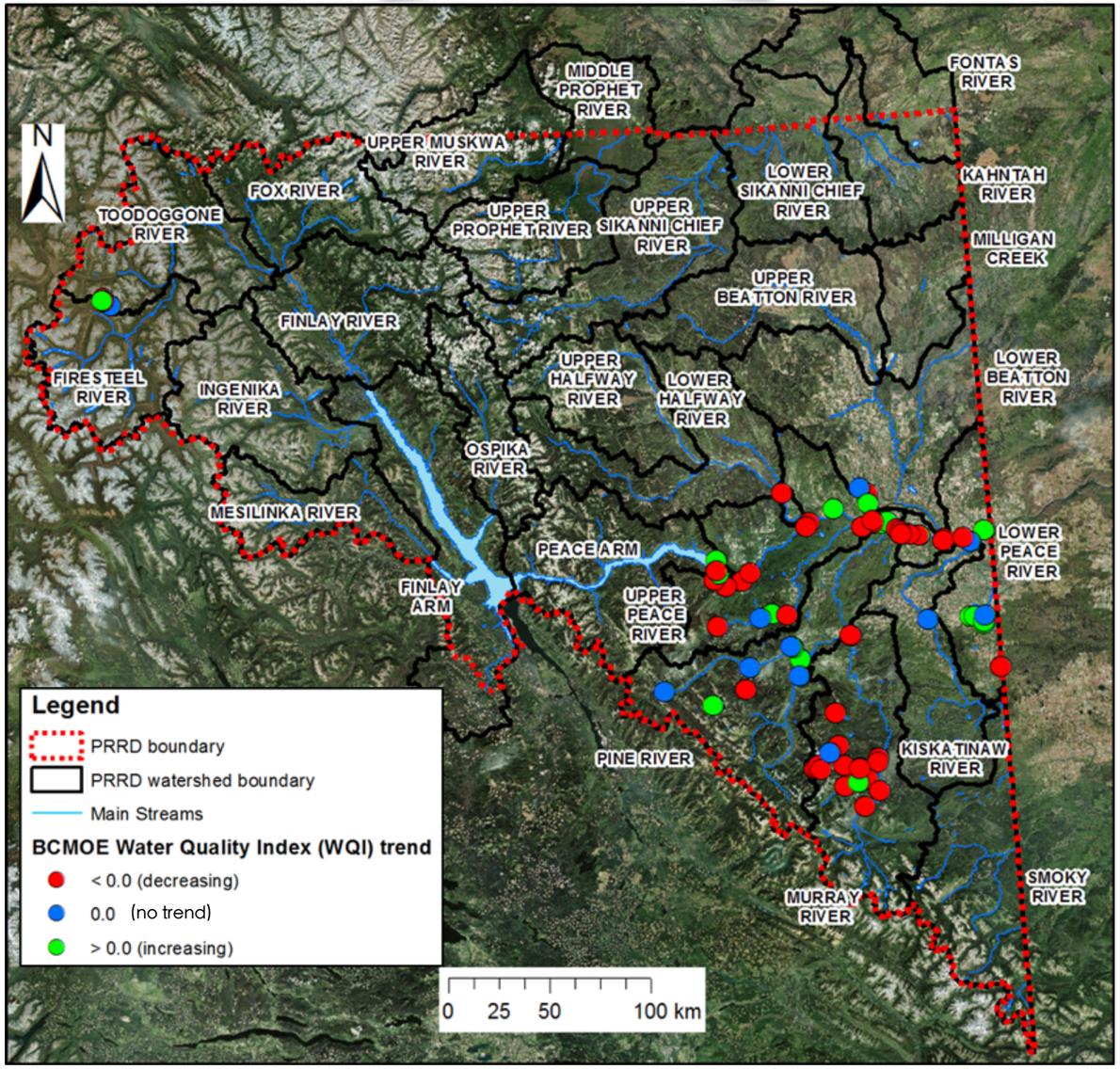
The 19 parameters selected to calculate the WQI

Water Quality Index



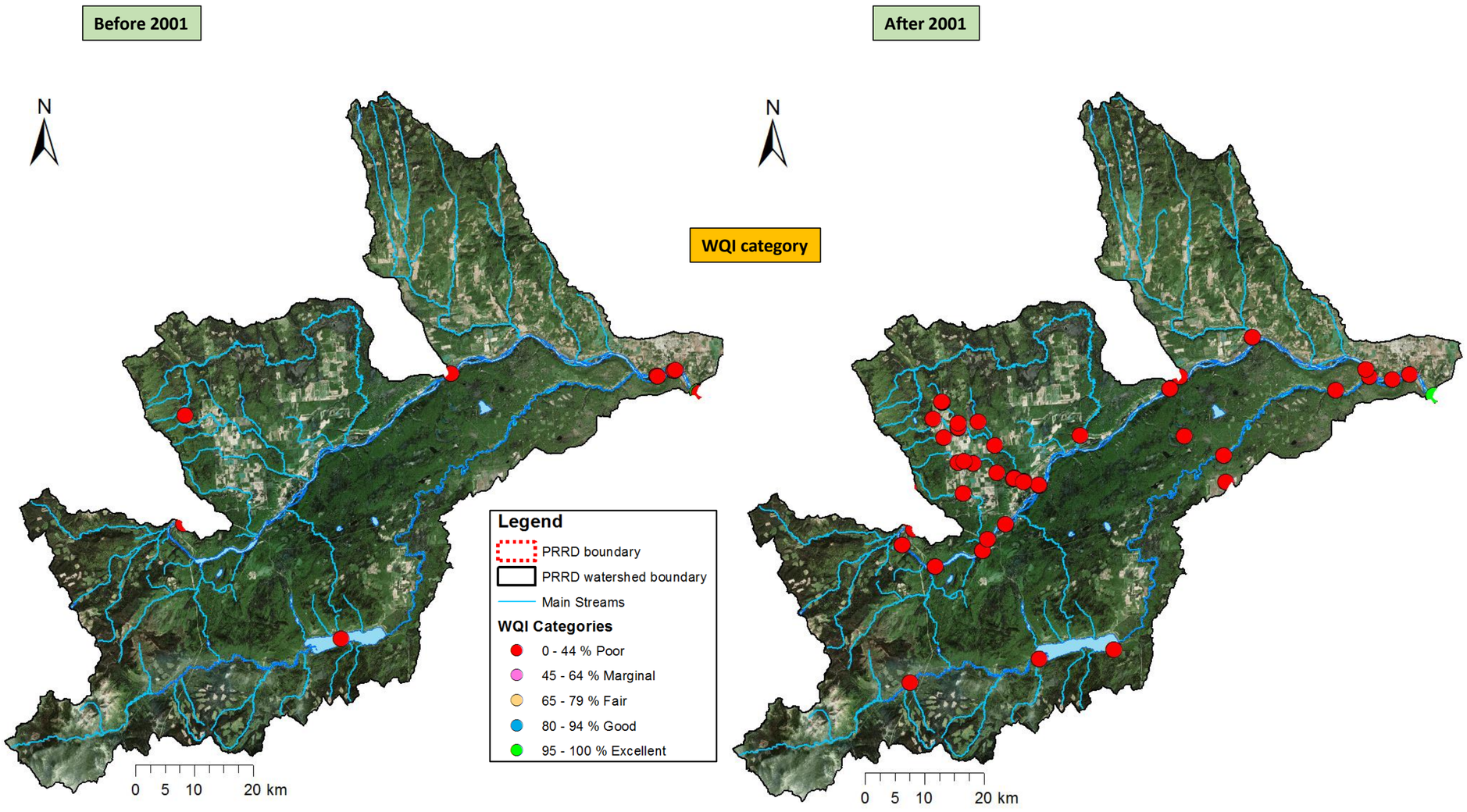
WQI, referring to BC MOE Aquatic Life Guideline - before 2001 and after 2001

WQI Trend

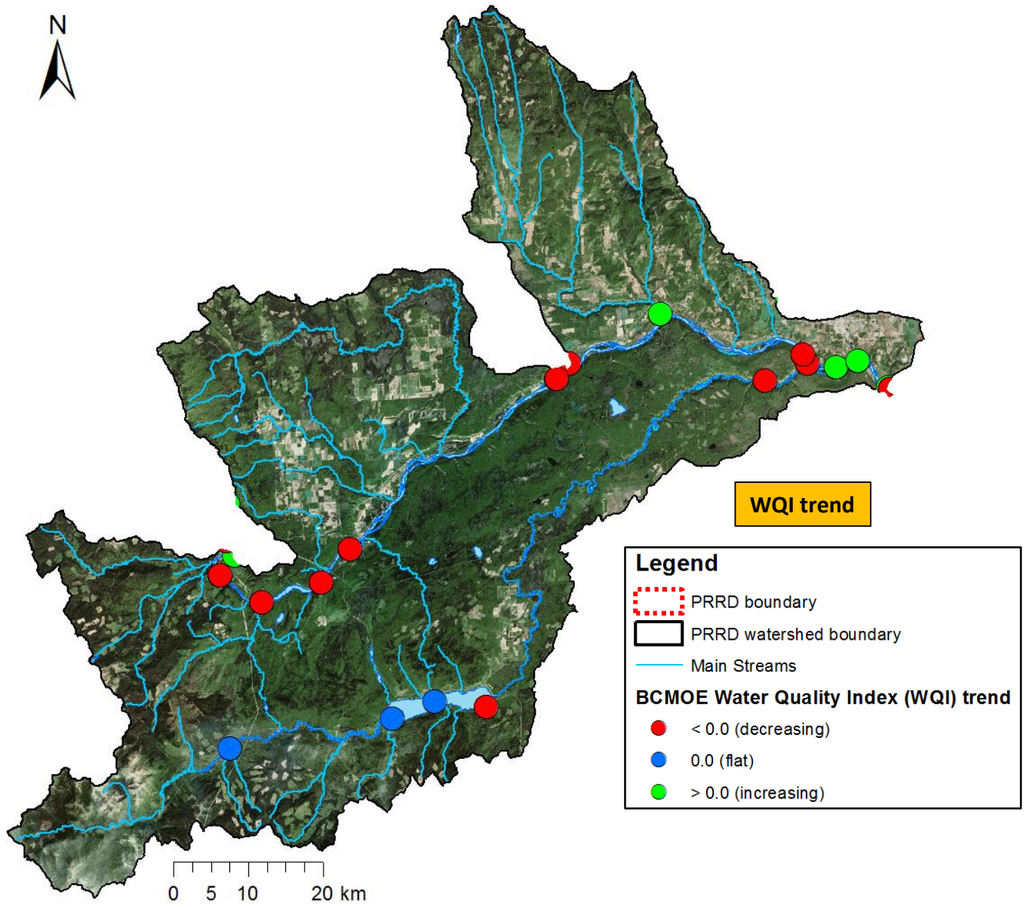


Only stations with five years of data with at least 10 samples are considered

WQI Trend – referring to BC MOE Aquatic Life Guideline


Before 2001
After 2001
N
N
WQI category
Legend
PRRD boundary
PRRD watershed boundary
Main Streams
WQI Categories
0 - 44 % Poor
45 - 64 % Marginal
65 - 79 % Fair
80 - 94 % Good
95 - 100 % Excellent
0 5 10 20 km
0 5 10 20 km

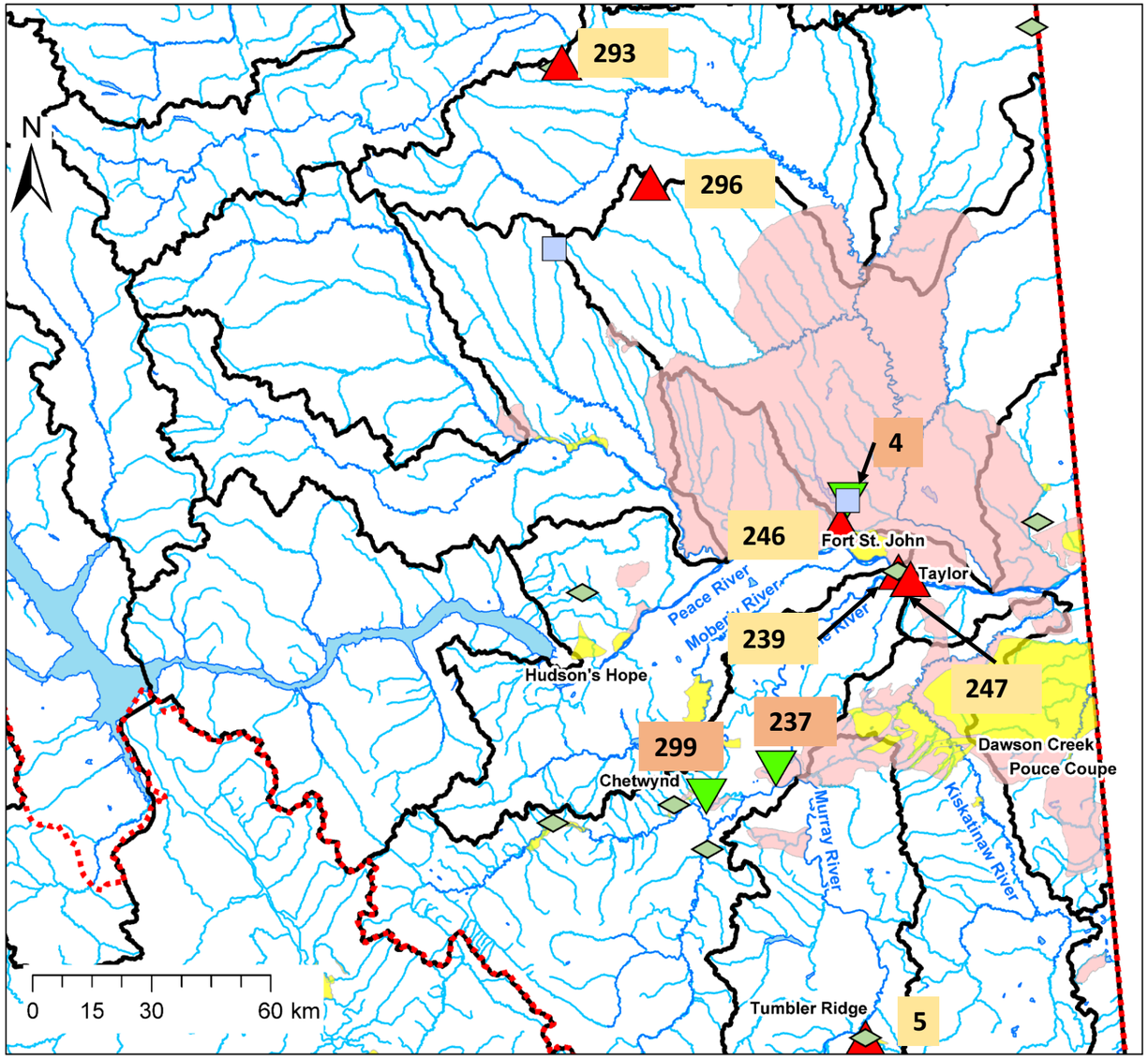
2.- Upper Peace River watershed



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

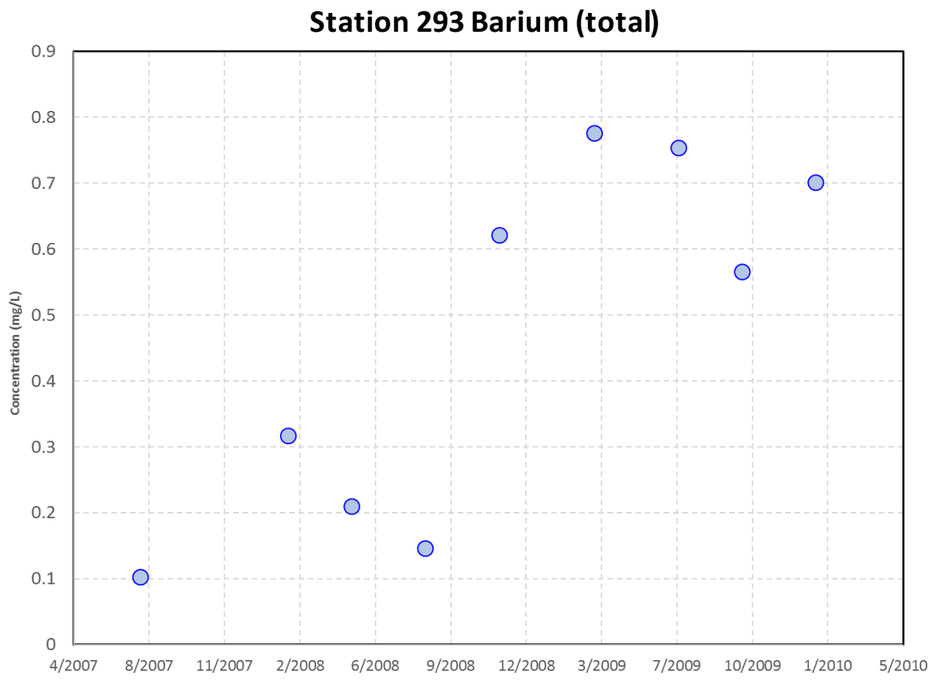
Bedrock

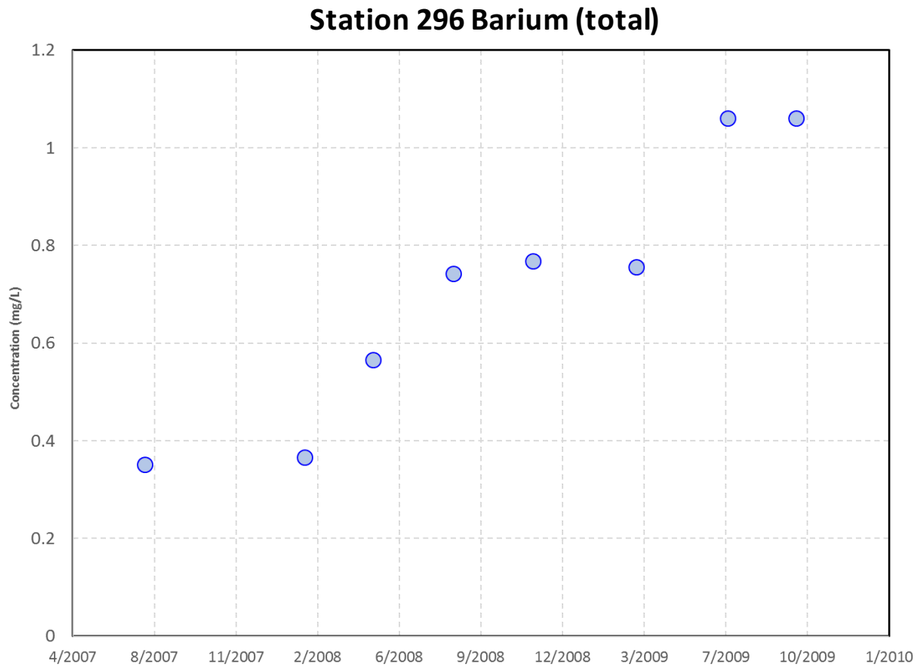
Overburden

Station ID

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

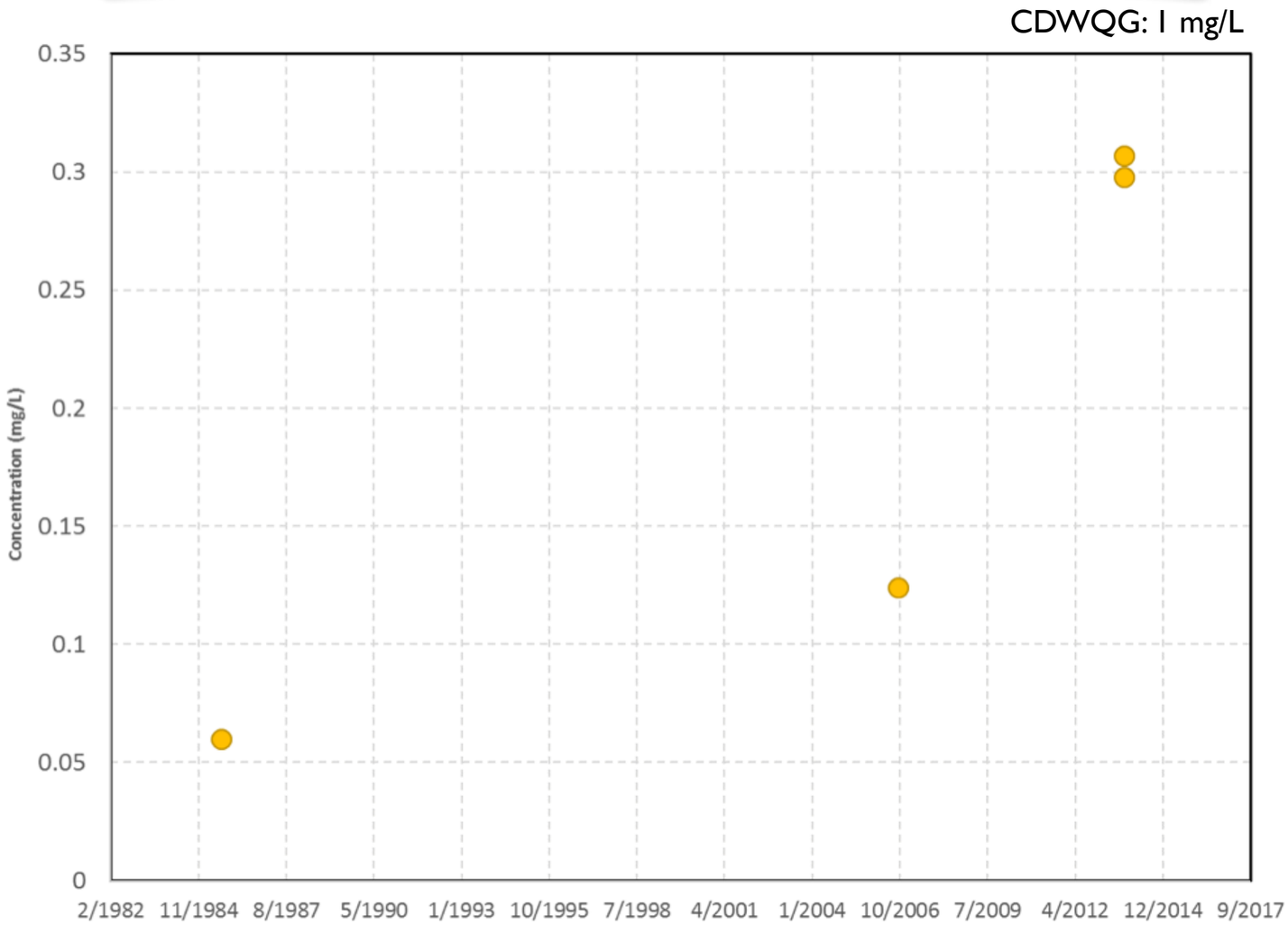
Groundwater - Barium Concentration
Station 293 and 296



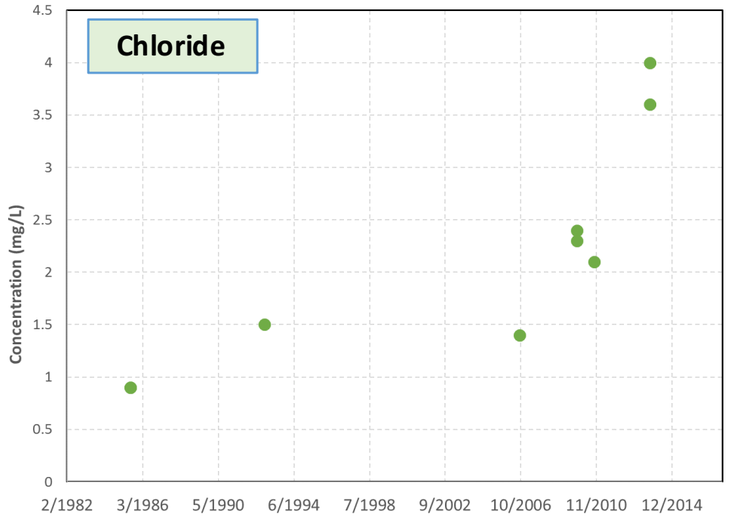


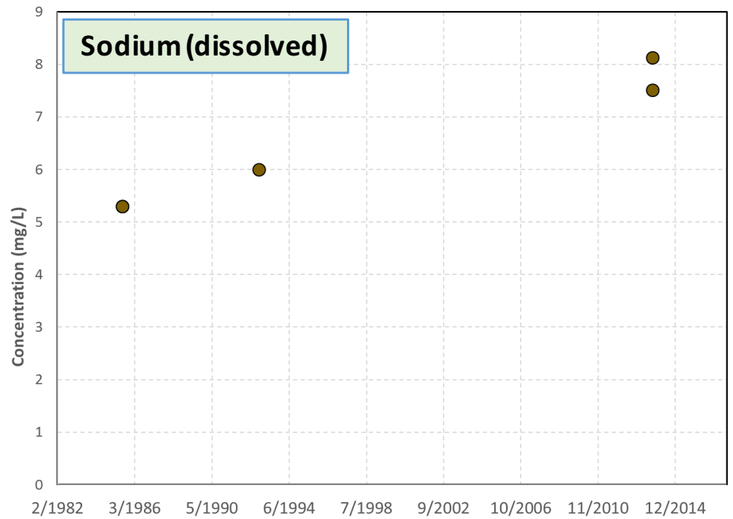
CDWQG: 1 mg/L

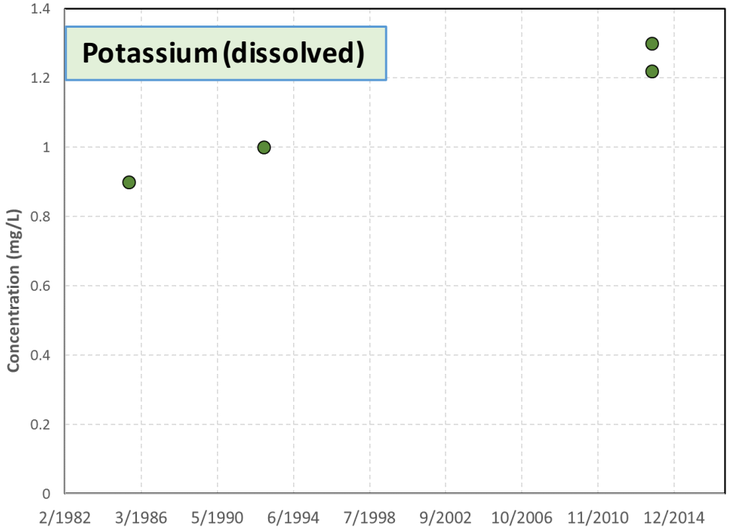
Groundwater - Barium Concentration Station 5 (BC MoE ObsW # 286)

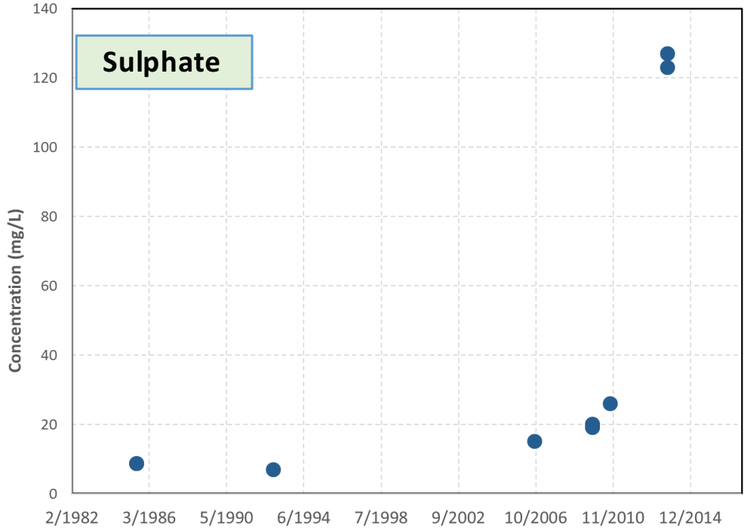


Groundwater - Cl, Na, K, and SO4 concentrations Station 5 (BC MoE ObsW # 286)

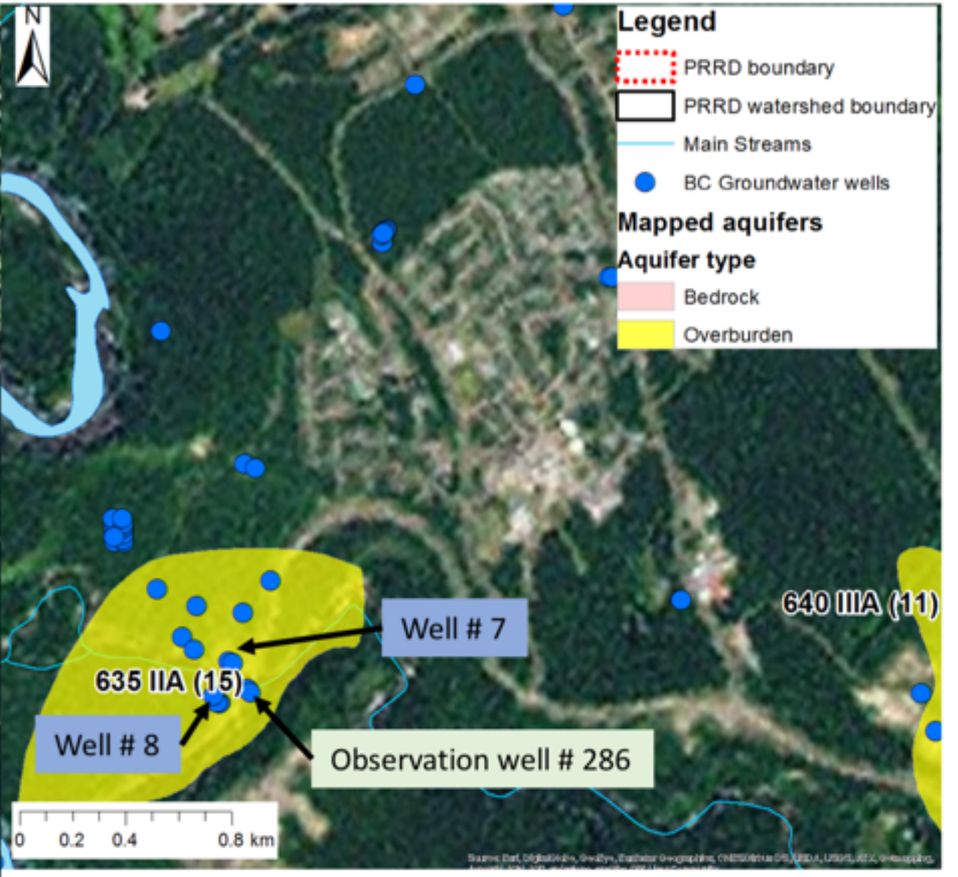








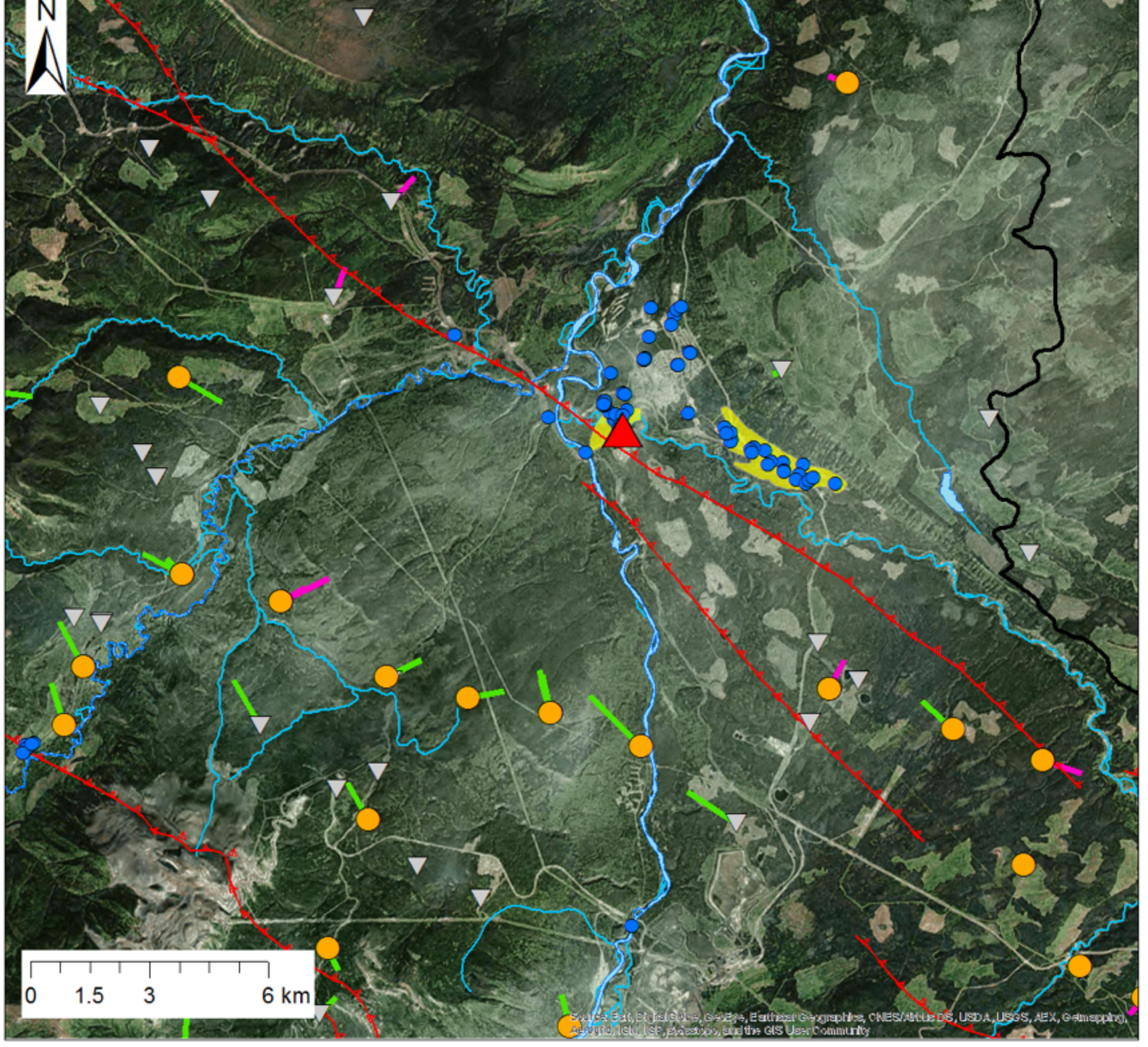
Note: BCMoE DW guideline: 500 mg/L for sulphate



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.



Legend

- PRRD boundary
- PRRD watershed boundary
- Main Streams
- Thrust fault
- BC Groundwater wells

Oil and Gas wells

Operation type

- Disposal
- Injection
- Observation
- Production
- Source (water)
- undefined
- XXXX

Grounwater quality trend analysis

Trend designation

- Increasing
- Decreasing
- No trend
- Ambiguous

Oil and gas wells fracking footprint

Completion type

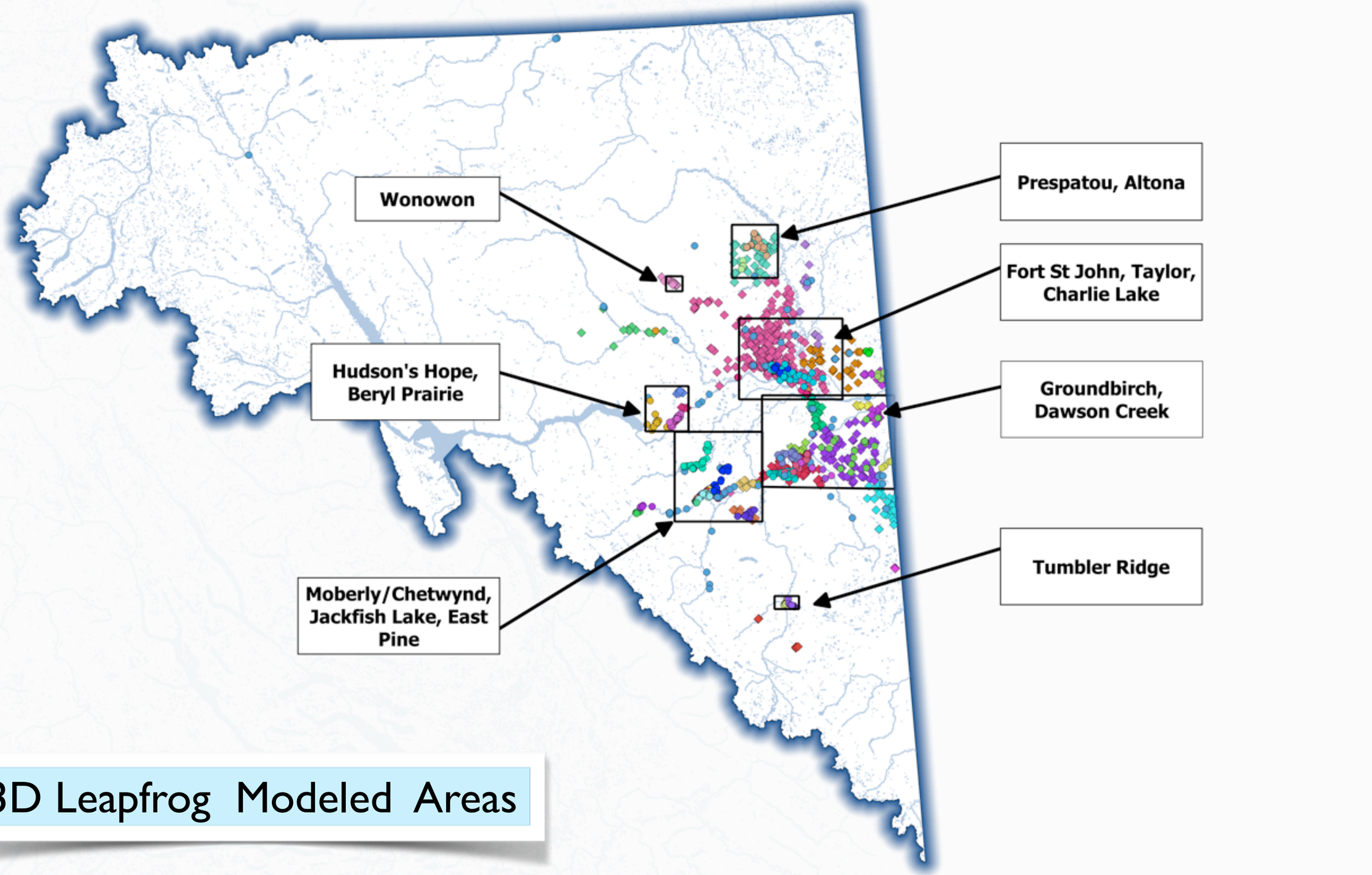
- Not specified
- Fracked

Mapped aquifers

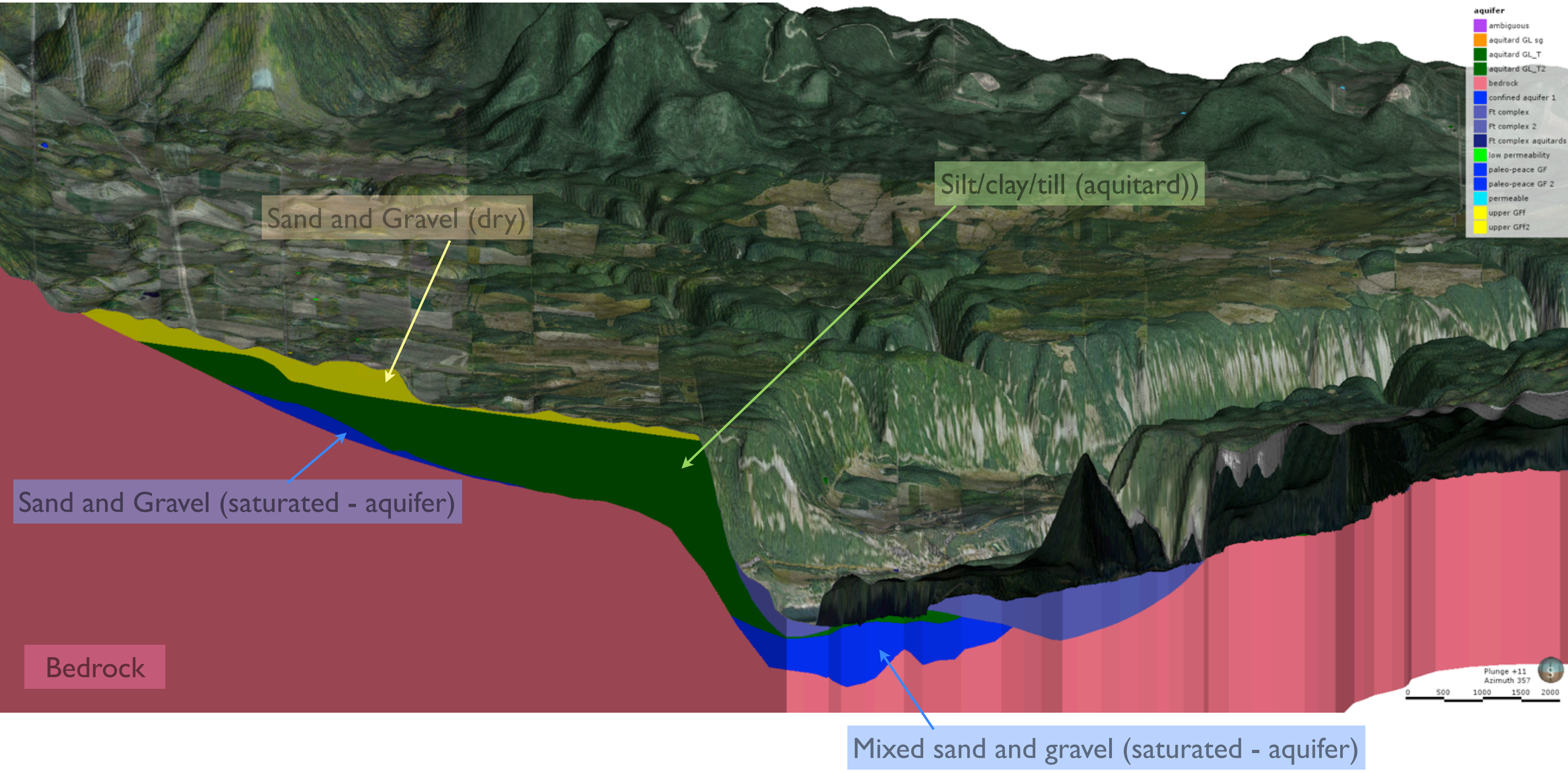
Aquifer type

- Bedrock
- Overburden

3D HYDRO-STRATIGRAPHIC MODELING



3D Leapfrog Modeled Areas


aquifer
ambiguous
aquitard GL sg
aquitard GL_T
aquitard GL_T2
bedrock
confined aquifer 1
Ft complex
Ft complex 2
Ft complex aquitards
low permeability
paleo-peace GF
paleo-peace GF 2
permeable
upper GFf
upper GFf2
Sand and Gravel (dry)
Silt/clay/till (aquitard))
Sand and Gravel (saturated - aquifer)
Bedrock
Mixed sand and gravel (saturated - aquifer)
Plunge +11
Azimuth 357
0
500
1000
1500
2000

CONCLUSIONS

CONCLUSIONS - GENERAL

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.

CONCLUSIONS - SURFACE WATER (SW2)

- The change in WQI has been used to estimate the improvement or worsening of the water quality over time. Produced maps appear to indicate a general worsening of the water quality versus time.
- After 2000 we observe an increasing presence of chloride, sodium and sulphate in surface water.

CONCLUSIONS - GROUNDWATER

- 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.

RECOMMENDATIONS

RECOMMENDATIONS

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

RECOMMENDATIONS

- 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.

- 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.

- 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

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