

Pebble Project

Surface Water Quality Program

Streams, Seeps, and Ponds



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SLR International
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Outline

- Stream Program

 - Overview

 - Results and discussion

 - Spatial trends
 - Temporal trends

- Seeps Program

 - Overview

 - Results

- Ponds Program

 - Overview

 - Results



Objectives

- Collect baseline data in streams, lakes, and seeps to provide scientific documentation of naturally occurring constituents:
 - Identity
 - Concentrations
 - Variability
- Identify the number of seeps and their location
- Characterize seep flow and water chemistry under specific flow conditions and time of year
- Provide a database of mine study area water chemistry

Program Team

SLR Alaska evaluated the data and prepared the Water Quality Section of the EBD



R2 Consultants oversaw and advised the Water Quality Program for 2007/2008



HDR was the primary field consultant



Shaw Alaska managed sample processing\shipping



Alaska Peninsula Corporation
also manages the collection of samples
for 3 stations located in lower UT

Analytical Lab Team

SGS North America

SGS CEMI, Lakefield

Columbia Analytical Services

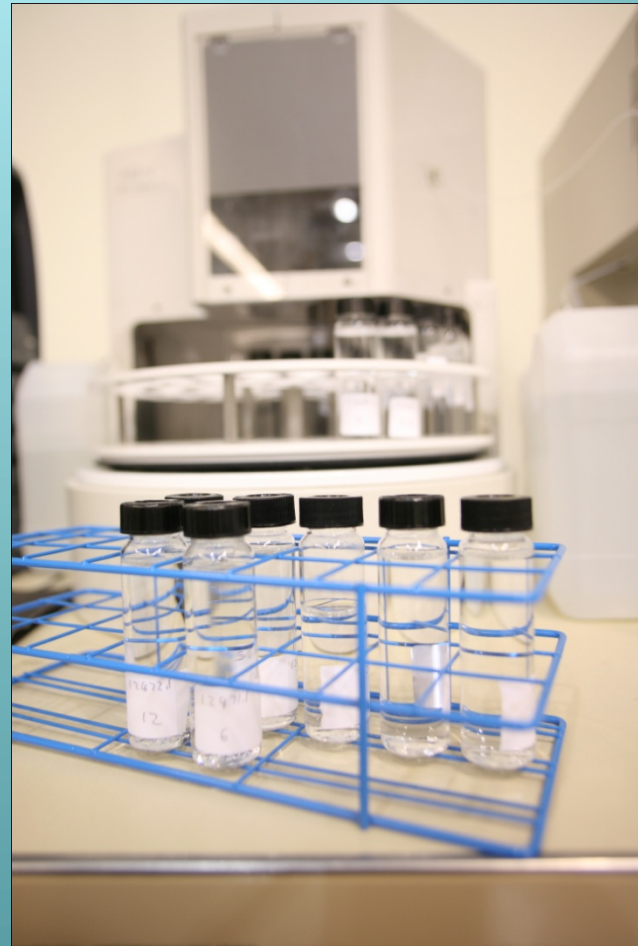
TestAmerica

University of Waterloo

ACZ Laboratories

Texas A&M University

Frontier GeoSciences



Program History and Scope

Mine Study Area

- 8 years of water quality data (2004-2008 data in EBD)
- 134 stream sampling events (about half included in EBD)
 - Up to 44 locations sampled; currently 26 are regularly sampled.
- Stream sampling frequency:
 - Initially (2004 through early 2006) sampling was monthly between May and October with 2 winter sampling events
 - Frequency was changed to monthly year-round in late 2006
- Over 130,000 parameter results for rivers, and over 55,000 results for seeps
 - Includes 1,850 river samples and 780 seep samples

Program History and Scope Continued

Transportation Corridor

- Two year sampling effort (2004-2005)
- 340 samples, 32,000 parameter results
- 6 stations were sampled on 12 occasions
- Another 18 stations were sampled 1 – 6 times each
- Goal was to characterize the general area along the transportation corridor



Water Quality Lab Analytes

Routinely Analyzed:

25 Total and dissolved trace metals

9 Major cations and anions

pH, TDS, TSS, alkalinity, hardness

Cyanides (total, weak acid dissociable (WAD))

Dissolved Organic Carbon was added in June of 2007

Isolated Analyses:

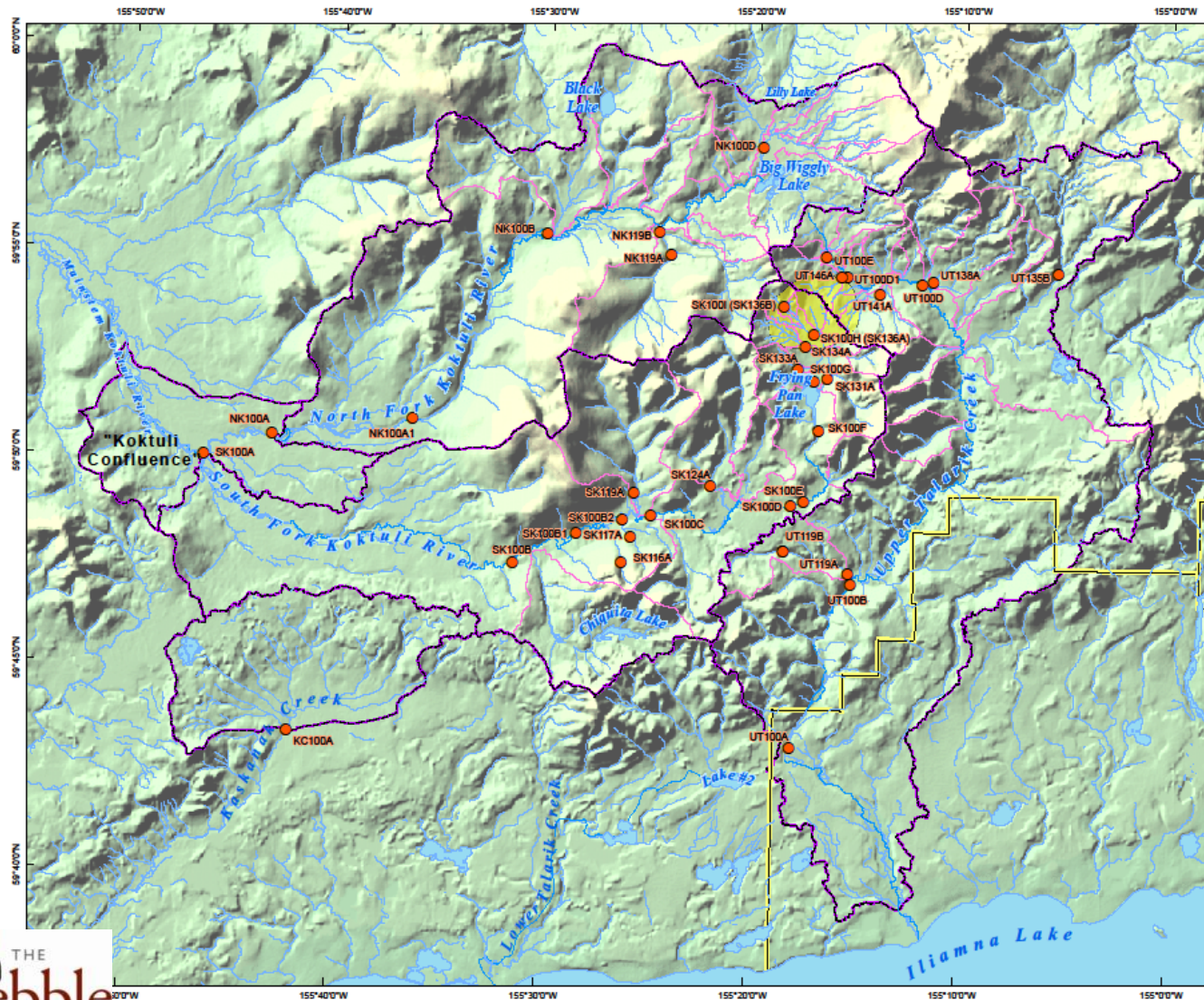
Organics (Semi-volatile Organic Compounds (SVOC), VOCs, and pesticides)

Subset of locations and sampling events, confirmed no presence

DRO/GRO/BTEX: 2 stations in each river, June 2007

Discontinued based on confirmation of no presence

Water Quality Stream Sampling Locations



General Stream Water Quality

Overview



Spatial Consistencies in Data

- **pH**
 - Near neutral across all drainages
- **Temperature**
 - Low at all sites except where summer flow is very low (SFK)
- **Hardness**
 - Low across all drainages, but some spatial variability among drainages
- **Fluoride, Ammonia, Antimony, Mercury, CN (total, WAD)**
 - Low at all sites, predominantly non-detect
- **Little spatial variation**

DO

Nitrate+nitrite

Chromium

Manganese

Nitrate

Total phosphorus

Cobalt

Silicon

Nitrite

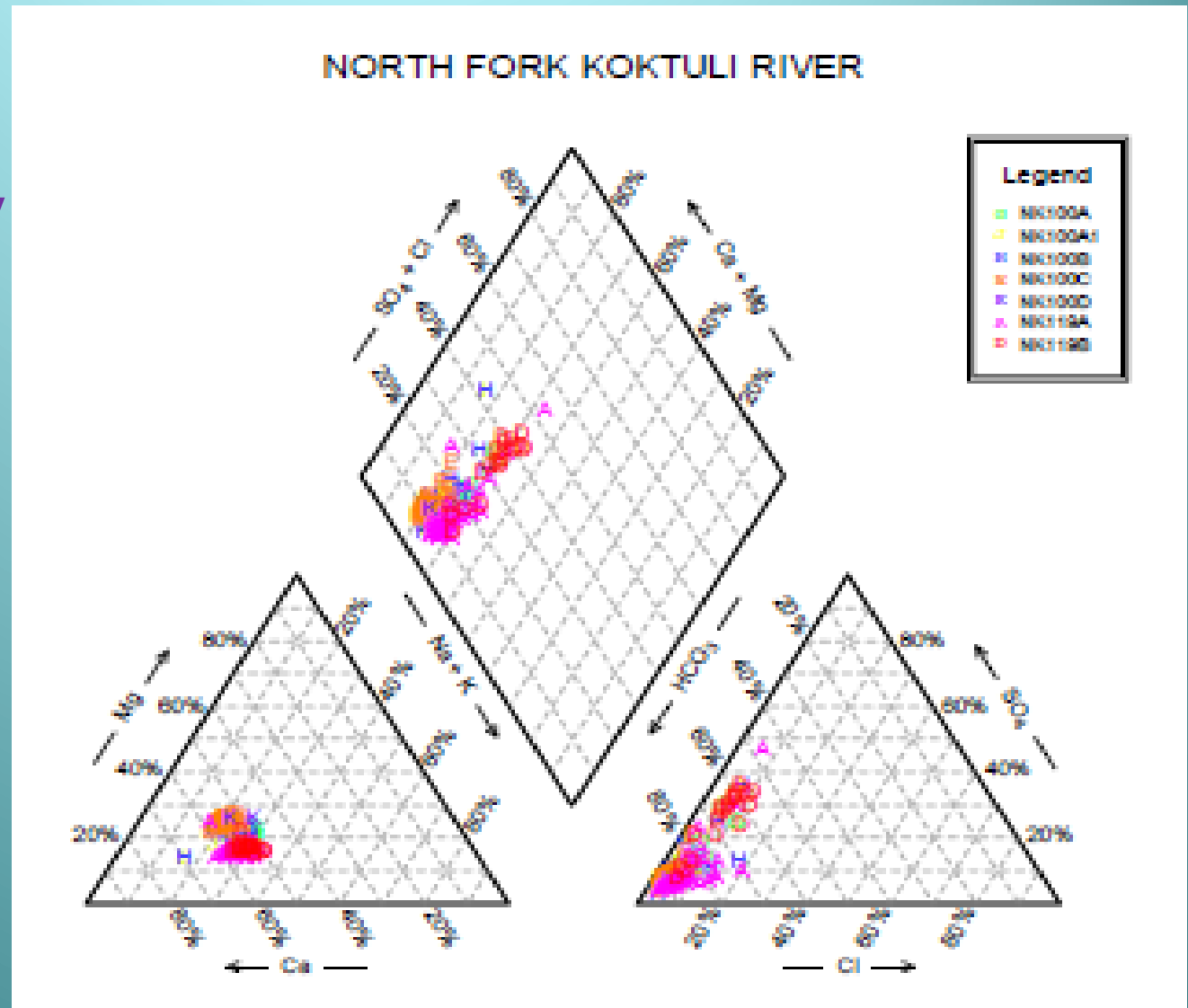
Aluminum

Lead

Zinc

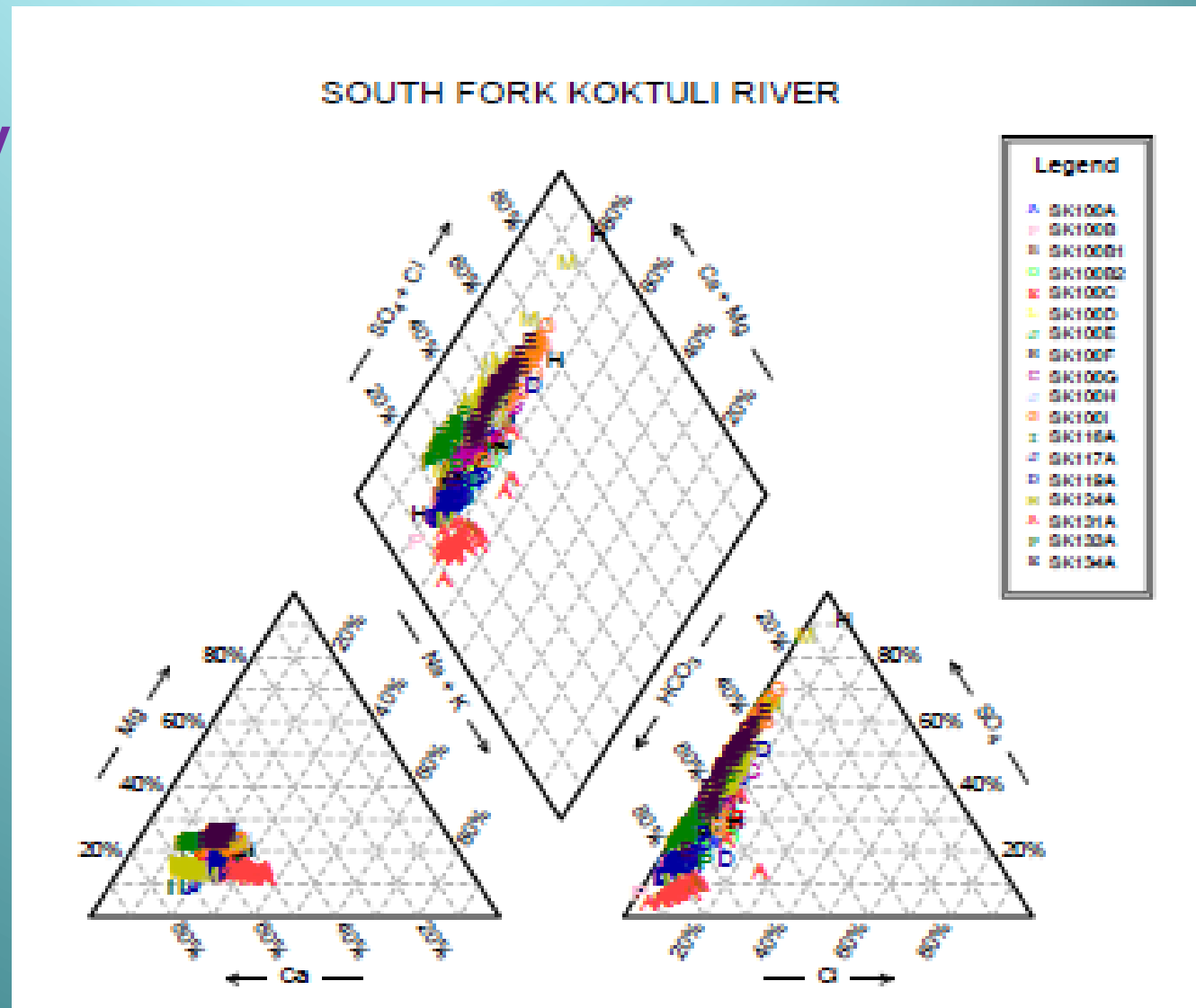
Water Quality: Piper Plots

Predominantly
calcium
bicarbonate-
sulfate



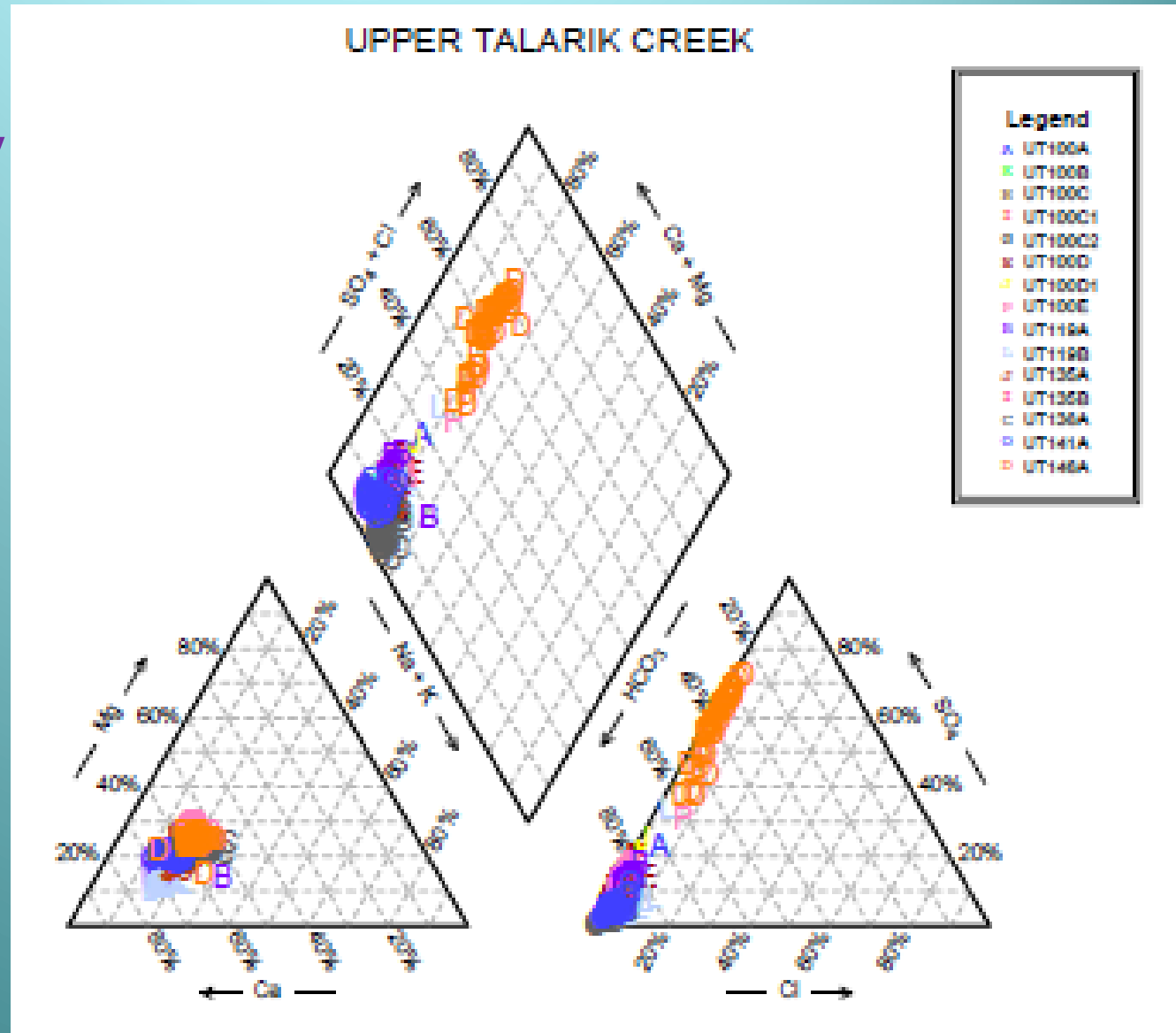
Water Quality: Piper Plots

Predominantly
calcium
bicarbonate



Water Quality: Piper Plots

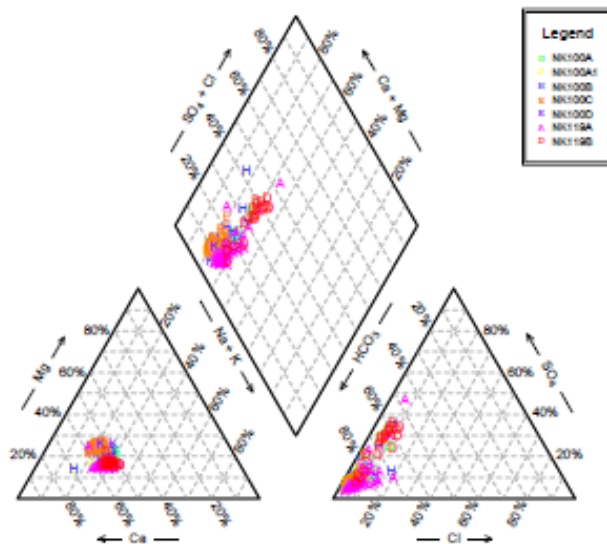
Predominantly
calcium
bicarbonate



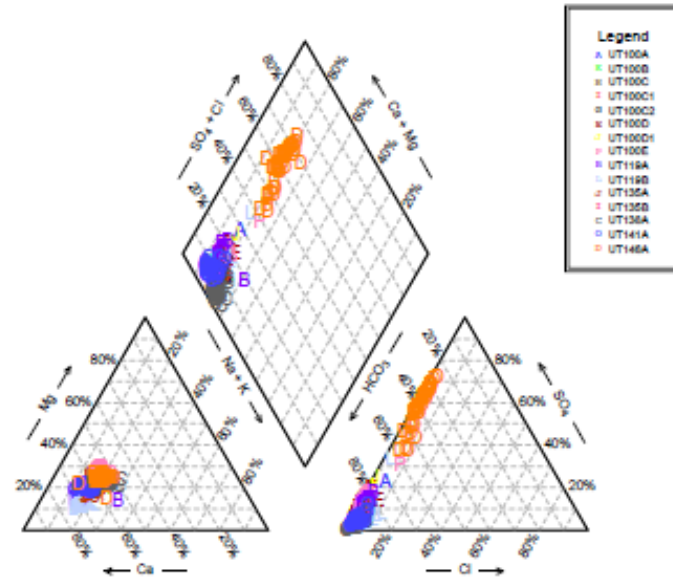
Water Quality: Piper Plots

Predominantly calcium bicarbonate or calcium bicarbonate-sulfate

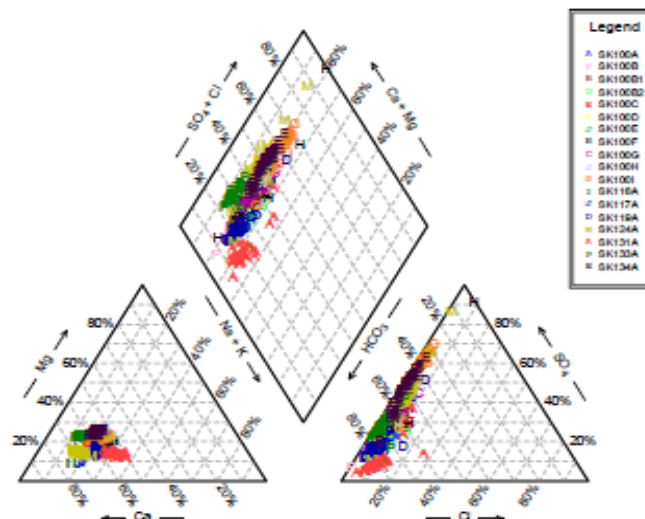
NORTH FORK KOKTULI RIVER



UPPER TALARIK CREEK



SOUTH FORK KOKTULI RIVER



Spatial Variation

Spatial variation in contribution of constituents from water sources can vary in proportion and quality dependent on

Groundwater contributions
by rock chemistry and
rock formation

Aquifer characteristics

Macro & micro climate patterns

Surface soil characteristics

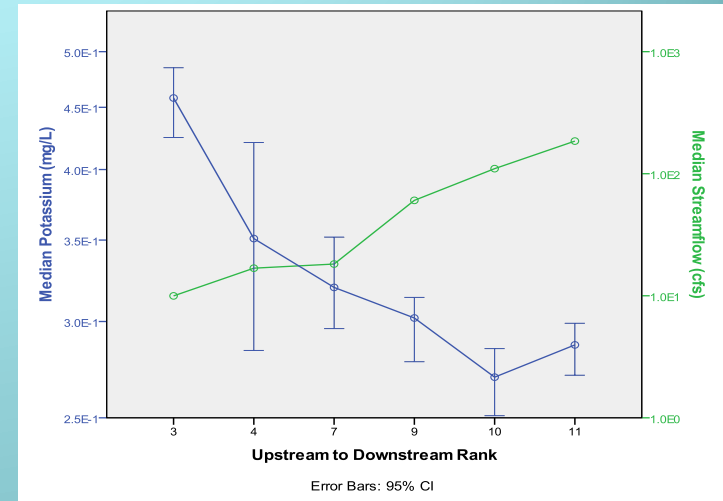
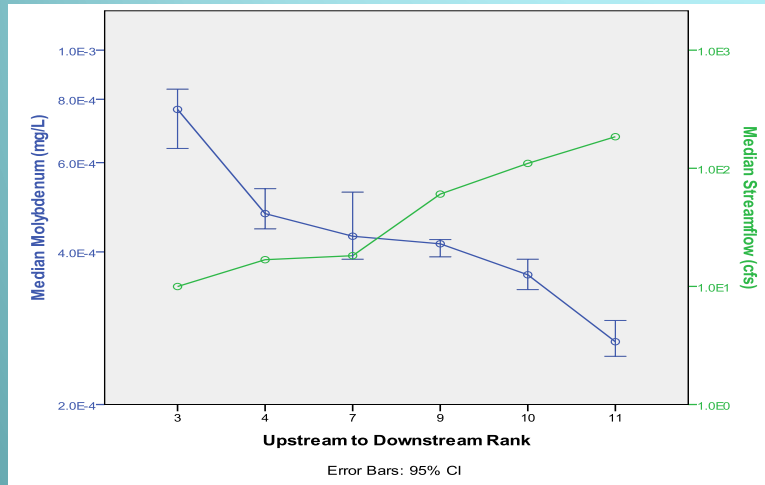
Areas where sediments deposit
and may be re-suspended



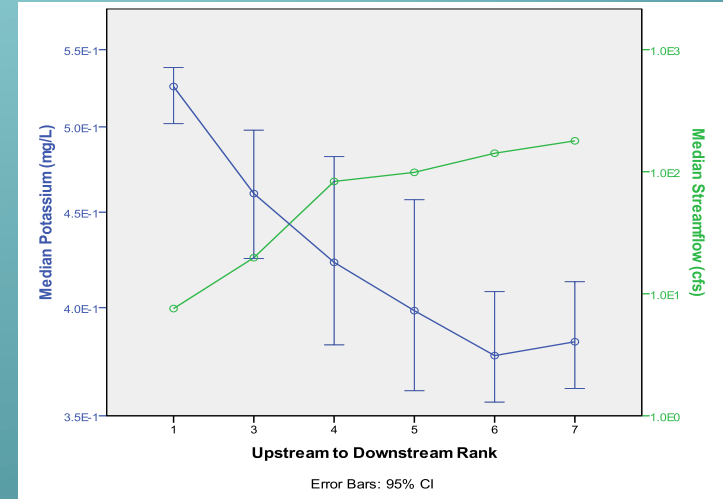
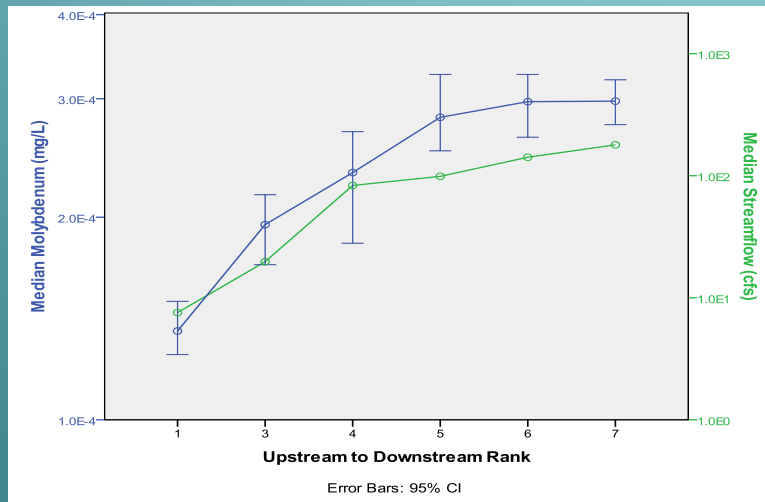
Within Drainage Variation

- Many constituents are inversely proportional to flow in the river main stems (i.e., concentrations get lower as flow increases downstream)
 - TDS, potassium, sodium, nickel, sulfate
- Few constituents are directly proportional to flow in the river main stems (i.e., concentrations get higher as flow increases downstream)
 - Arsenic, chloride
- Less noticeable in the North Fork Kaktuli River since it does not drain or traverse the general deposit area

Effects of Flow on Concentrations



Molybdenum in SFK



Molybdenum in UT

Potassium in UT

Comparison Across River Systems

Four field and physical parameters differed significantly across river systems

TDS

TSS

pH

Alkalinity

Five major ions differed significantly across river systems

Sodium

Sulfate

Chloride

Fluoride

Hardness (as CaCO_3)

One nutrient (total nitrate+nitrite [as N]) differed significantly across river systems

All analyzed trace elements differed significantly across river systems (except for cadmium and lead)



Characterization of Drainages



North Fork Koktuli



Drainage Sampling Overview

North Fork Kaktuli

241 samples from 6 main stem and 1 tributary sampling locations

Between 2004 and 2008

All locations at least one mile from the general deposit area



Drainage Characteristics

North Fork Koktuli

Highest of all drainages

Cadmium

Lead

Values increase downstream

pH

Values decrease downstream

Potassium

Nickel

TDS

South Fork Koktuli



Drainage Sampling Overview

South Fork Koktuli

612 samples from 11 main stem and 7 tributary
sampling locations

Between 2004 and 2008



Drainage Characteristics

South Fork Koktuli

Drains general deposit area

Intermittent stretch mid stream

Highest of all drainages in

Copper

Molybdenum

Sulfate

Nickel

TSS

Selenium

Lowest of all drainages in

TDS

Concentrations decline downstream for many constituents:

TDS

Sodium

Iron

Potassium

Sulfate

Nickel

Fluoride

Hardness

Copper

Molybdenum

Cyanide

Upper Talarik Creek



Drainage Sampling Overview

Upper Talarik

509 samples from 8 main stem and 7 tributary
sampling locations

Between 2004 and 2008



Drainage Characteristics

Upper Talarik Creek

Drains a portion of the mineral deposit

Highest of all drainages

TDS

Alkalinity

Calcium

Magnesium

Nickel

pH

Hardness

Sodium

Nitrogen (total nitrate+nitrate)

Decreases downstream and with distance from mineral deposit

TDS

Potassium

Sulfate

Sodium

Alkalinity

Hardness

Increases downstream

Arsenic

Molybdenum

Chloride

Kaskanak Creek



Drainage Characteristics

Kaskanak Creek

Only one station – no spatial trends within the drainage

Highest of all drainages

TSS

Potassium

Chloride

Iron

Arsenic

WAD Cyanide

Lowest of all drainages for

Flow

Sulfate

Naturally Occurring Concentrations Above Criteria

Water quality data can be compared to

State of Alaska Chronic Aquatic Life Criteria (CALC) (18 AAC 70)
EPA Drinking Water Standards (DW)

Naturally Occurring Elevated Concentrations

The term “naturally occurring elevated concentrations” is used to indicate concentrations of an analyte that are above water quality criteria

All drainages in the study area exhibit multiple parameters with naturally occurring elevated concentrations

Parameters with Naturally Occurring Concentrations Above Criteria

There are naturally elevated concentrations above CALC and/or drinking water criteria in surface water in all three major drainages for:

Physical parameters

pH, DO

Alkalinity

WAD Cyanide

Metals

Al	Fe
Cu	Pb
Cd	Mn

Zn (NFK and SFK only)



Temporal Trends

The contribution of sources vary in proportion and quality temporally

During open water season (late April-October) stream flow is a combination of groundwater, snowmelt and precipitation

Seasonal high flows may contribute

Greater dilution from snow melt or precipitation

Greater erosion

Re-suspension of sediment

Flushing of near-surface groundwater

Temporal Trends

During freezing conditions stream flow is generally groundwater fed

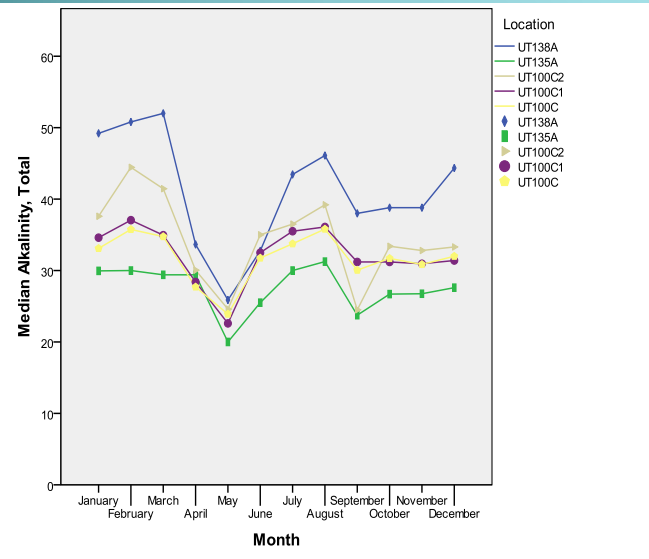
Iced-over conditions prevent contribution from precipitation.

As water freezes, other components are precipitated.

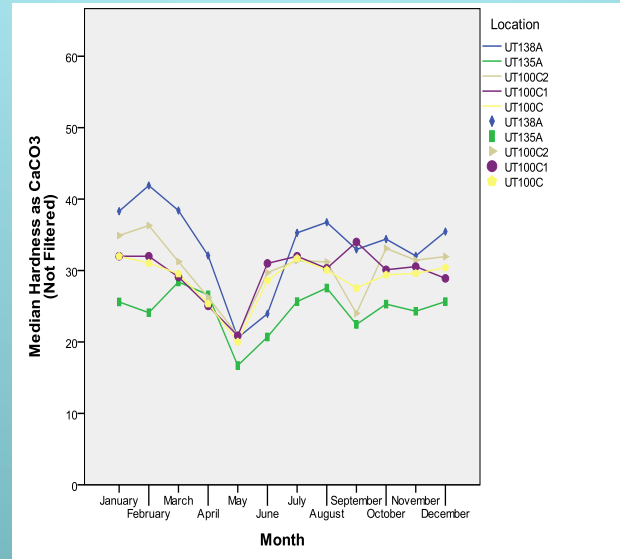
This creates higher concentrations in the underlying liquid portion – particularly in areas of ice dams.



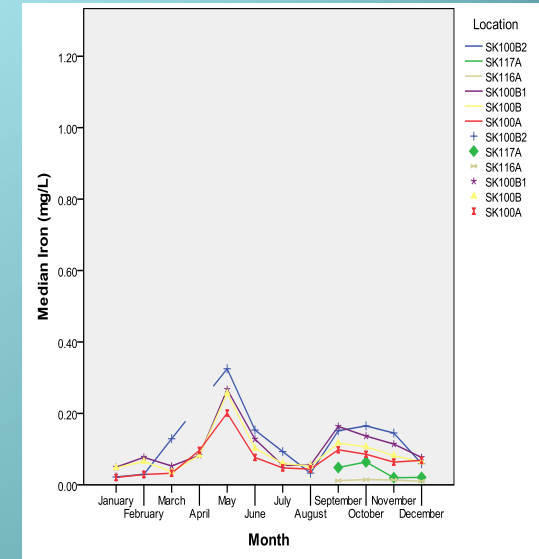
Temporal Trends



Alkalinity, UT



Hardness, UT



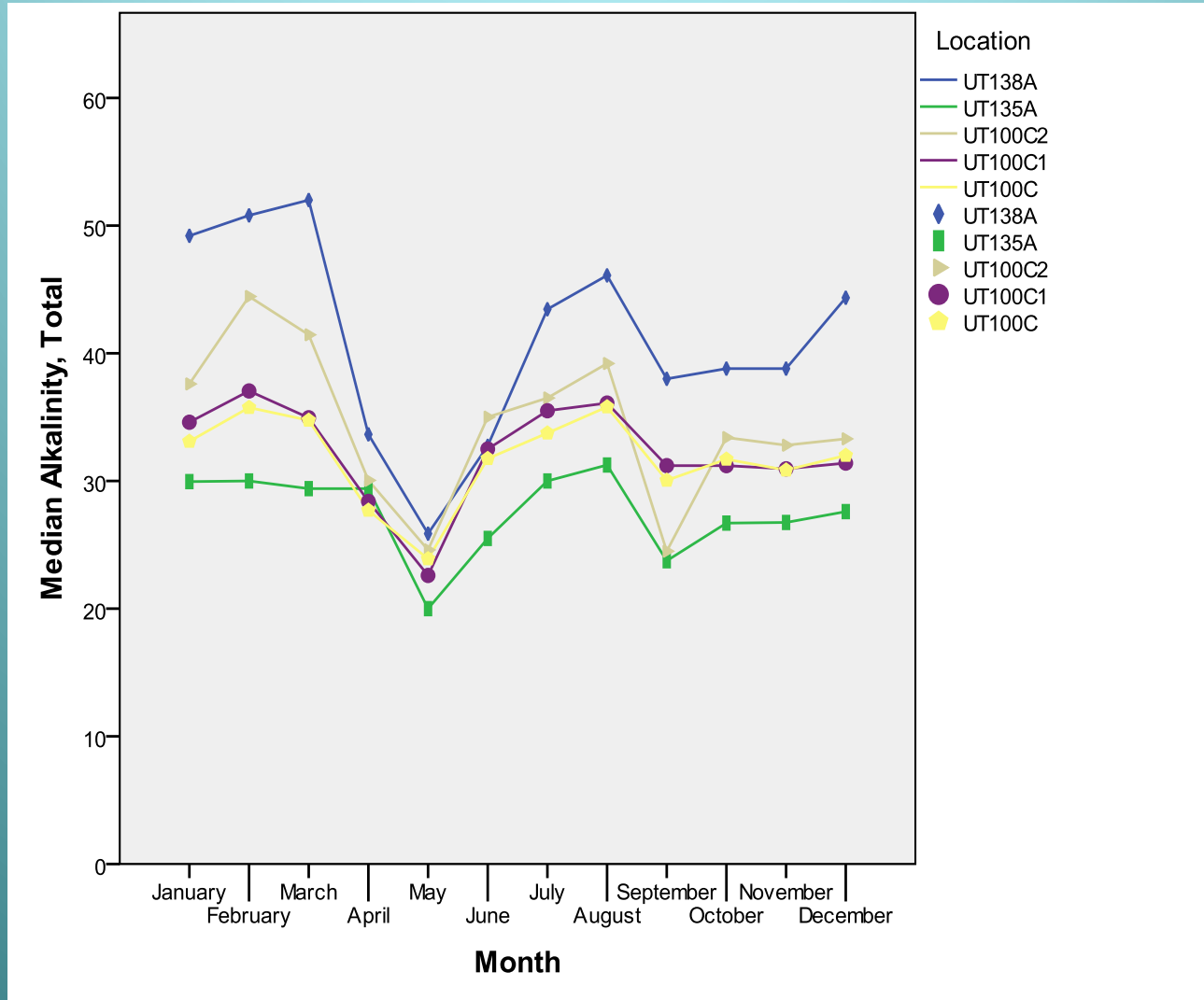
Iron, SFK



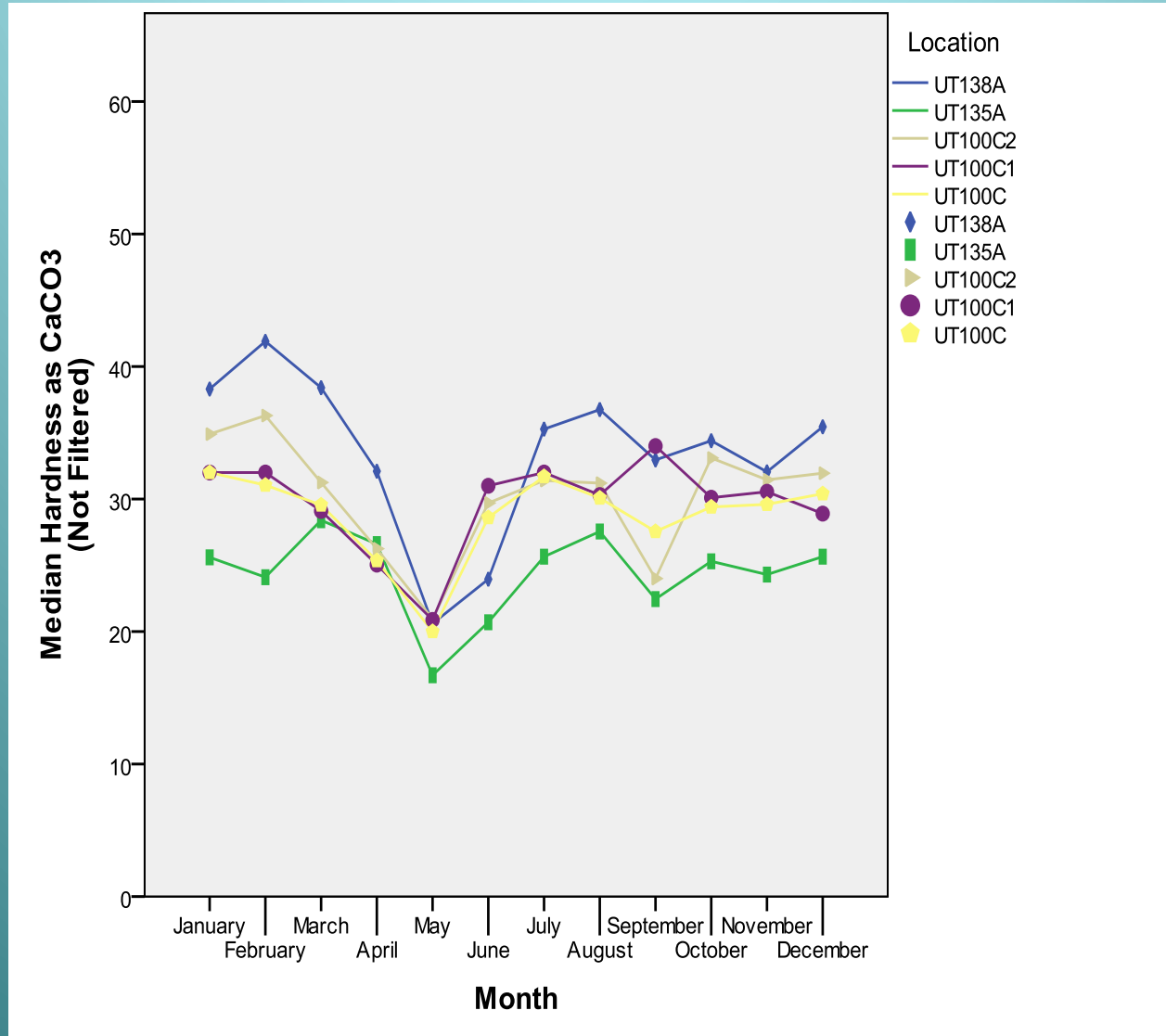
Breakup associated with lower alkalinity and hardness, but higher iron

Most constituents exhibit similar patterns

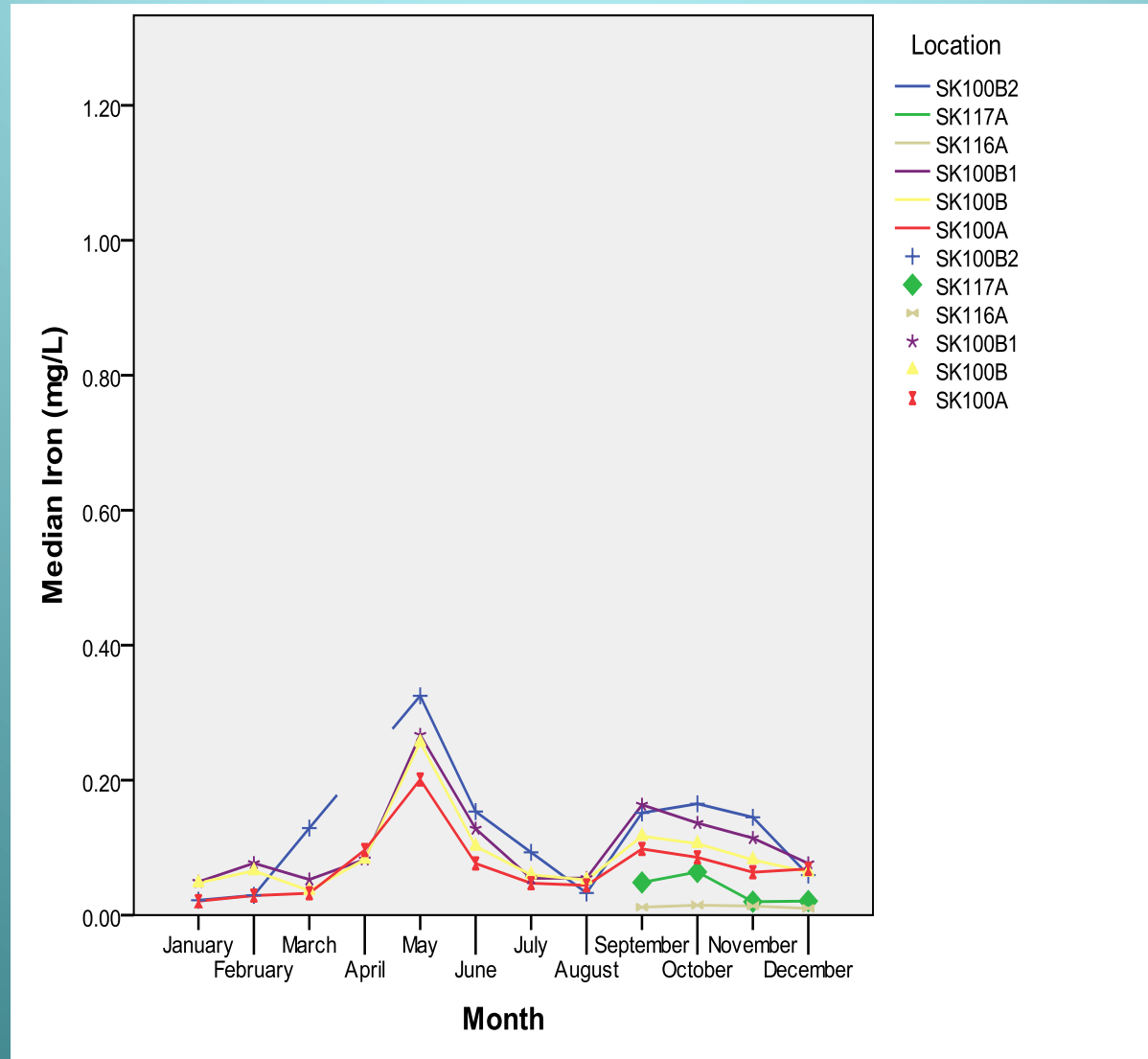
Temporal Trends: Alkalinity in Upper Talarik Creek



Temporal Trends: Hardness in Upper Talarik Creek



Temporal Trends: Iron in South Fork Koktuli River



Five Bullet Summary: Rivers

- Drainages have different signatures of naturally occurring constituents
- Naturally occurring concentrations in rivers typically fluctuate seasonally based on spring snowmelt and fall precipitation
- Background signatures of naturally occurring constituents depend in part on distance from the general deposit area
- Concentrations of several parameters, particularly metals, in surface water are naturally higher than the applicable regulatory-based limits
- Cyanide is naturally occurring in surface water, corroborating results in soil and plants

Seep Program



Seep Program Objectives

- Identify the number of seeps and their locations in the mine study area
- Characterize the flow and water chemistry that are representative of specific flow conditions
- Establish baseline conditions of naturally occurring constituents in seeps within the mine study area
- Identify major factors influencing constituent distribution



Seeps Water Quality: 2004-2008

11 – 127 sampling sites annually

Additional sites added and discontinued over time

28 locations sampled in 2008

Up to 5 sampling events per year:

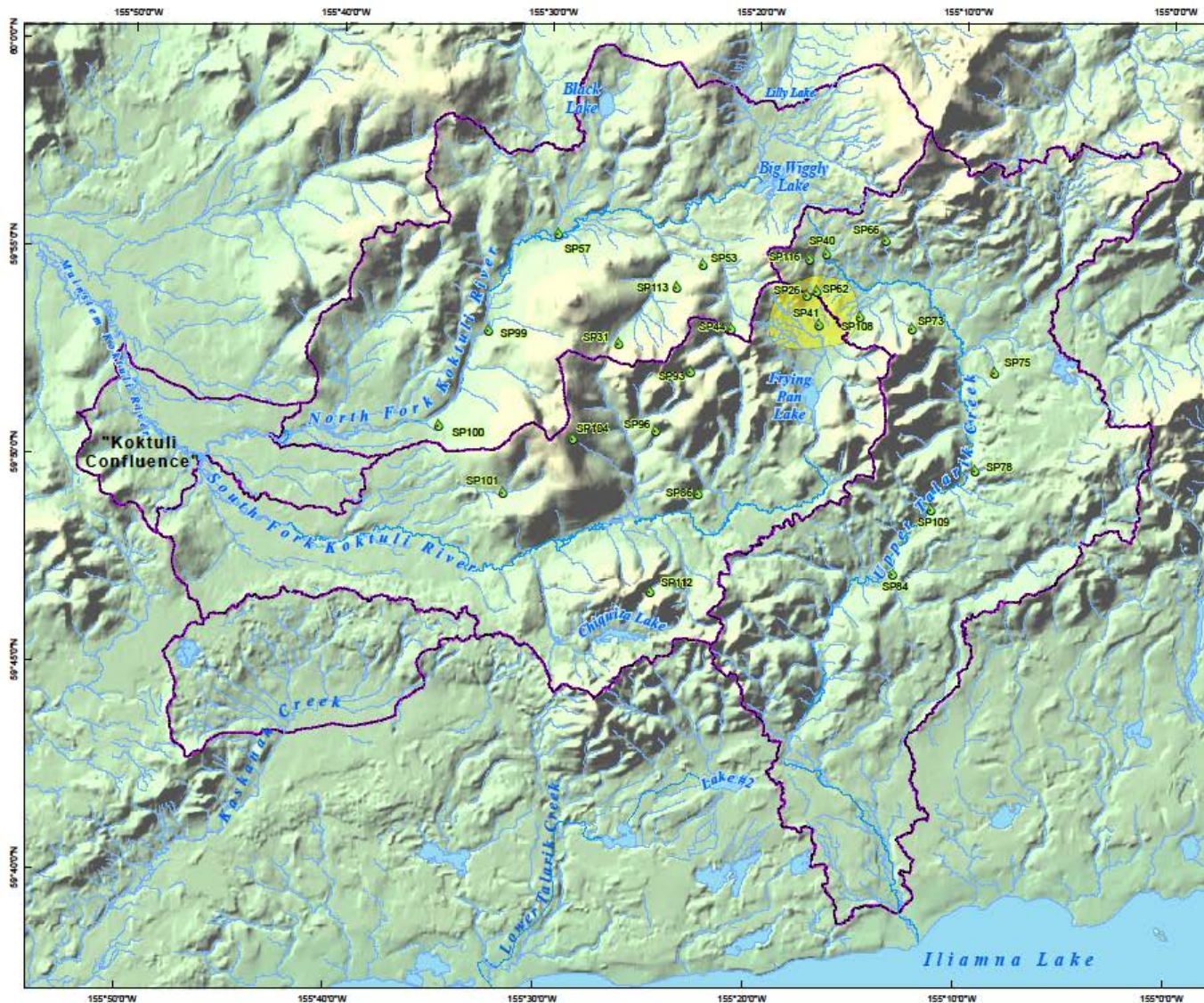
- Winter base flow (March; 2005-2007)
- Spring breakup (May/June; 2004, 2006- 2008)
- Summer low flow (July/August; 2005-2008)
- Fall storm event (Sept/early Oct; 2004, 2007, 2008)
- Late fall (late October, early November; 2005-2008)

650 seep samples collected



Seep Sampling Stations

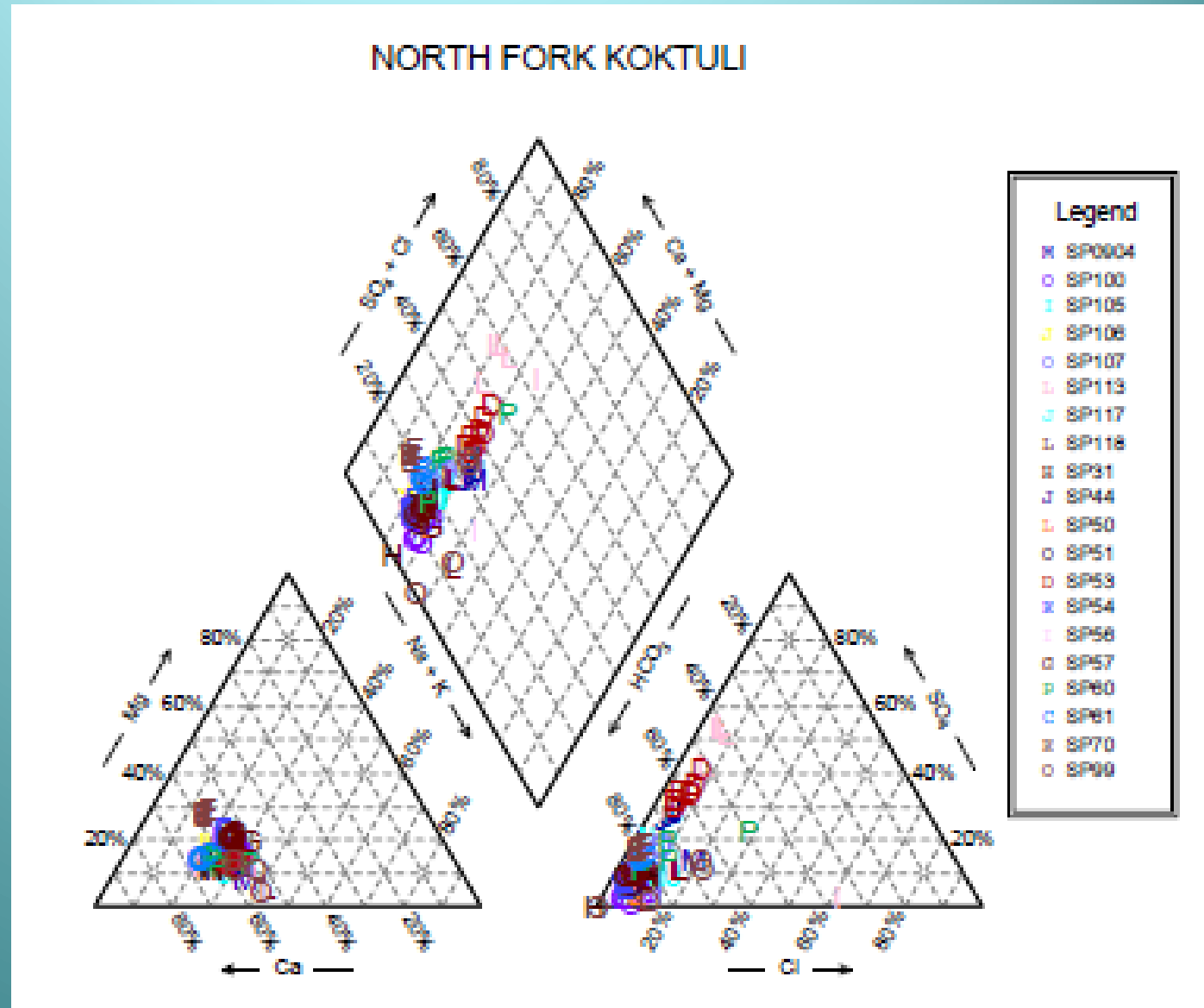
2004 -2008



Seeps Program Results: Piper Plots

Similar to NFK
River

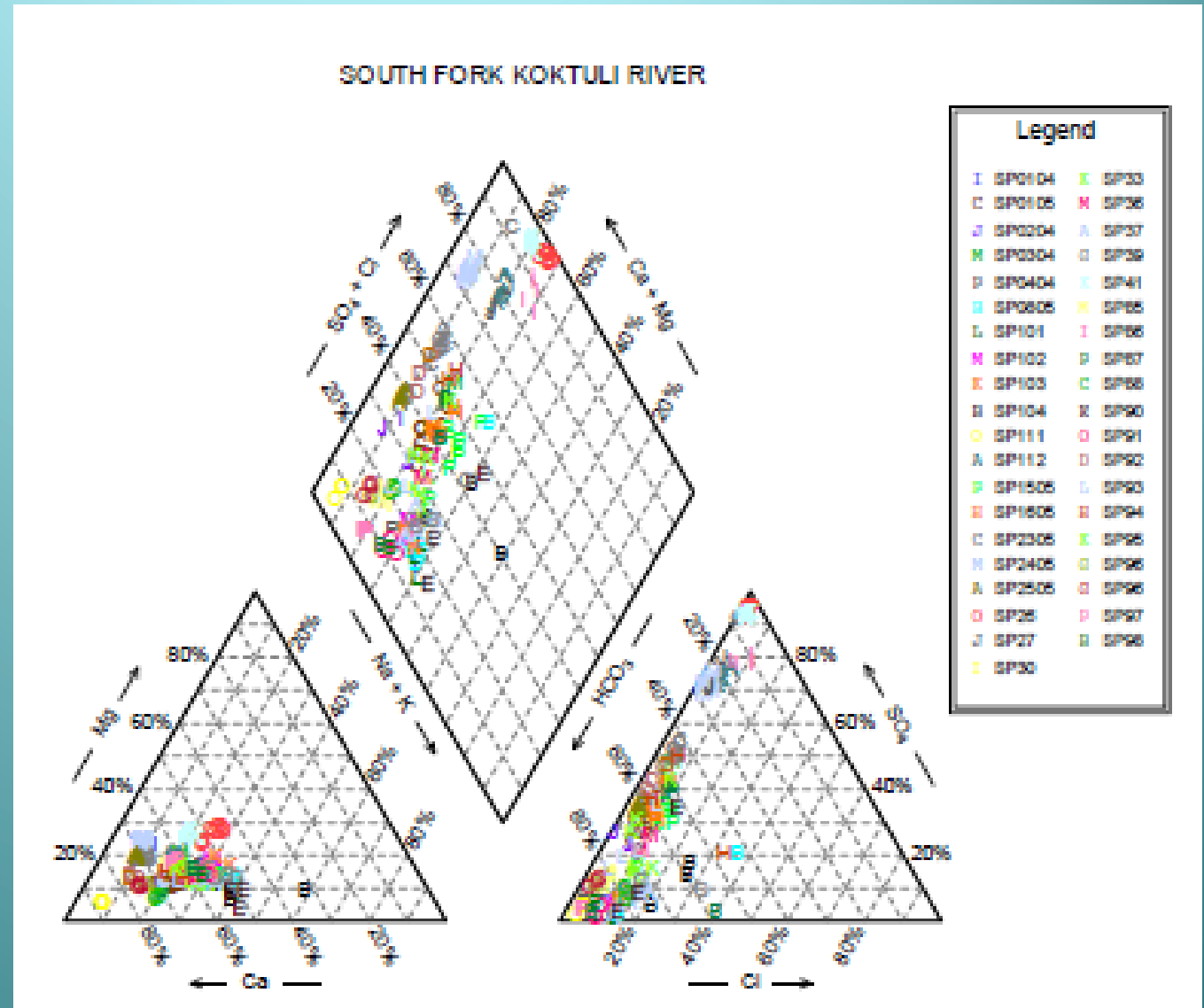
Predominantly
calcium
bicarbonate-
sulfate



Seeps Program Results: Piper Plots

Similar to SFK
River

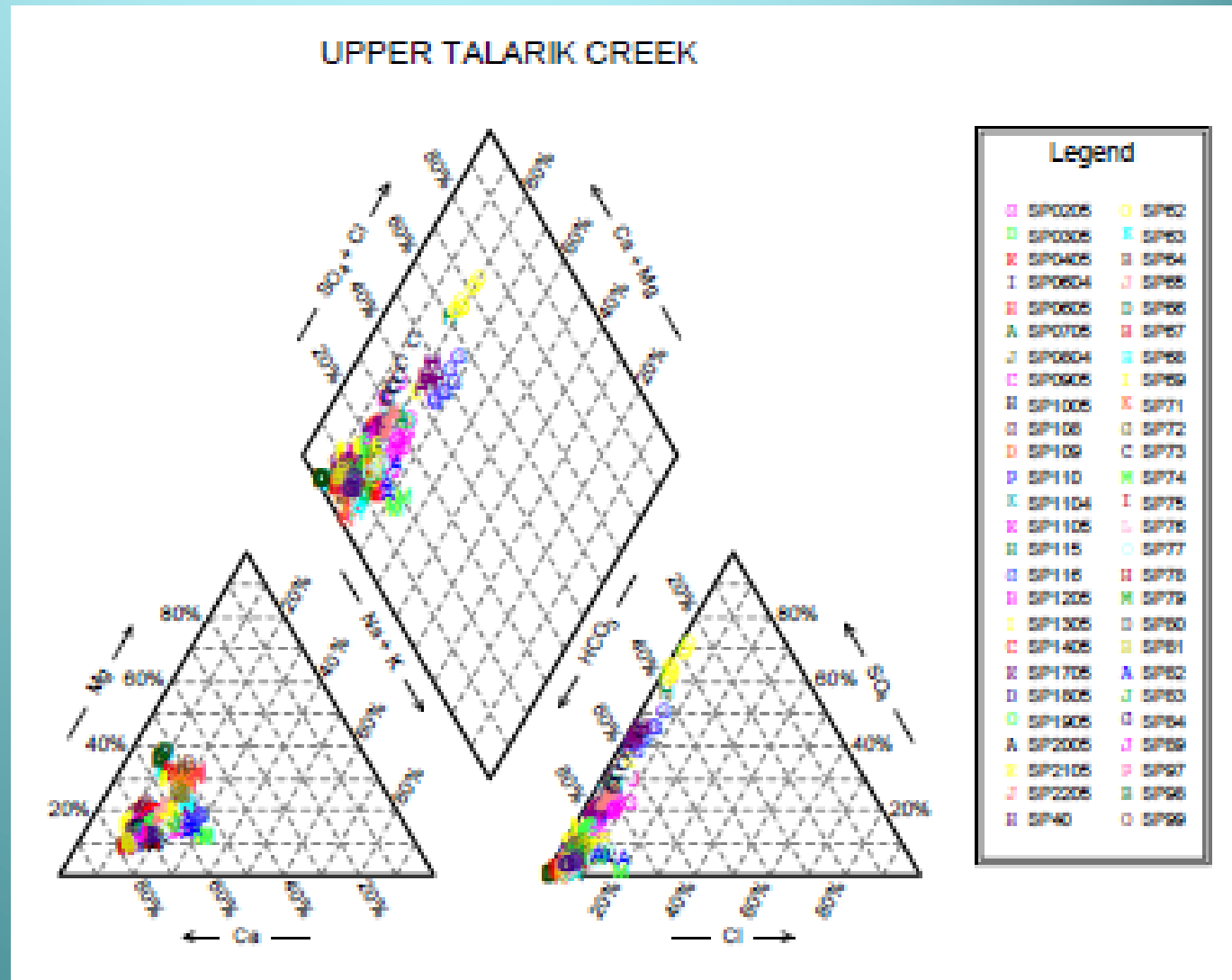
Predominantly
calcium
bicarbonate



Seeps Program Results: Piper Plots

Similar to UT
Creek

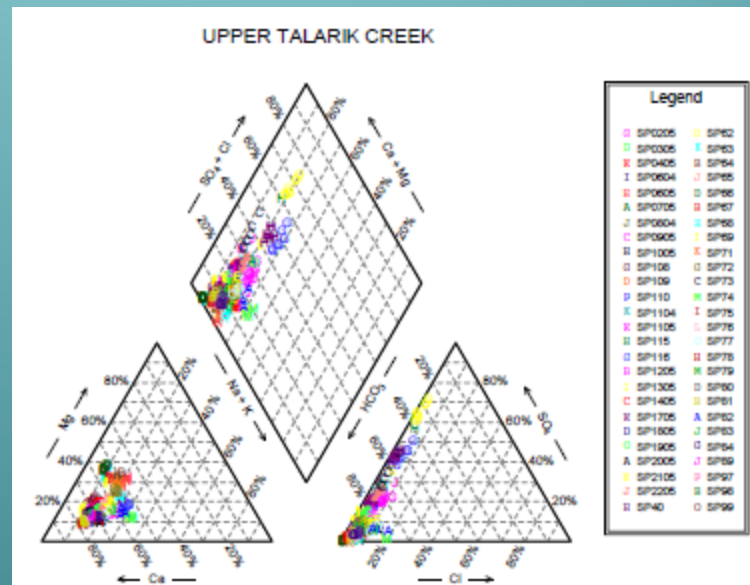
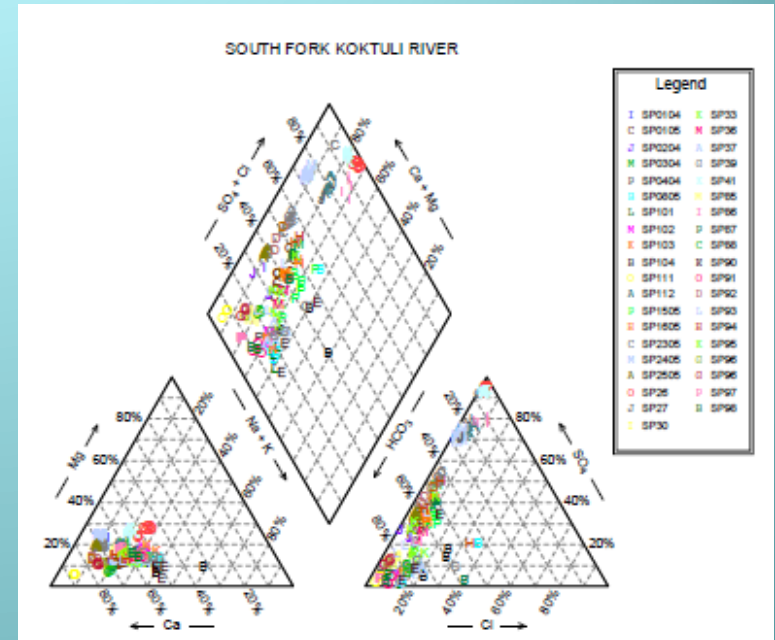
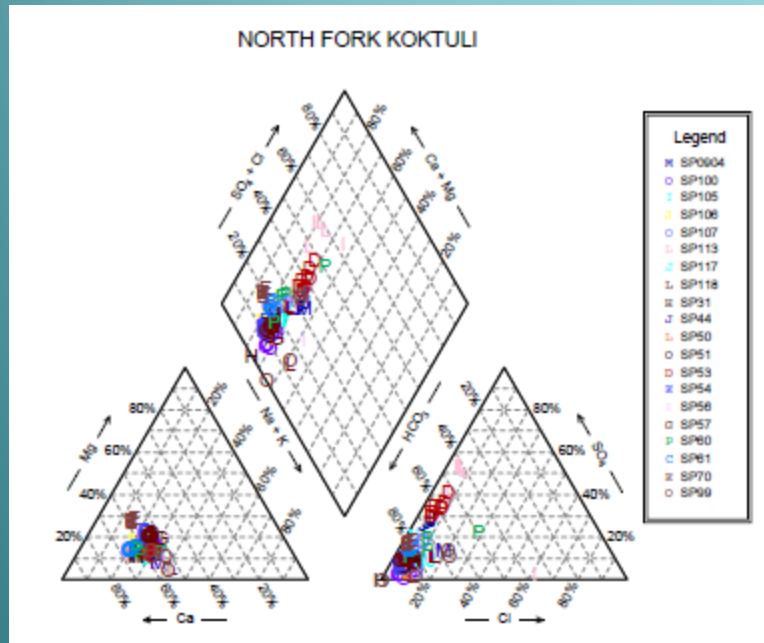
Predominantly
calcium
bicarbonate-
sulfate



Seeps Program Results: Piper Plots

Similar to streams

Predominantly calcium bicarbonate
or calcium bicarbonate-sulfate



Seeps Program Results

North Fork Koktuli drainage

Very low concentrations in March and April, and only from station SP57 (upwelling area in the floodplain)

Concentrations in these samples influenced by surface water as well as groundwater

Concentrations increase for all chemicals and locations beginning in May, but different patterns are evident for different chemicals

South Fork Koktuli drainage

Only one constituent (molybdenum) was not detected from seeps in April and May

Seeps Program Results (cont.)

South Fork Koktuli drainage (cont.)

Several trace elements concentrations were highest at SP26 and SP41 (e.g., copper and nickel)

SP26 and SP41 are within the general deposit area at lower elevation than the ore deposit

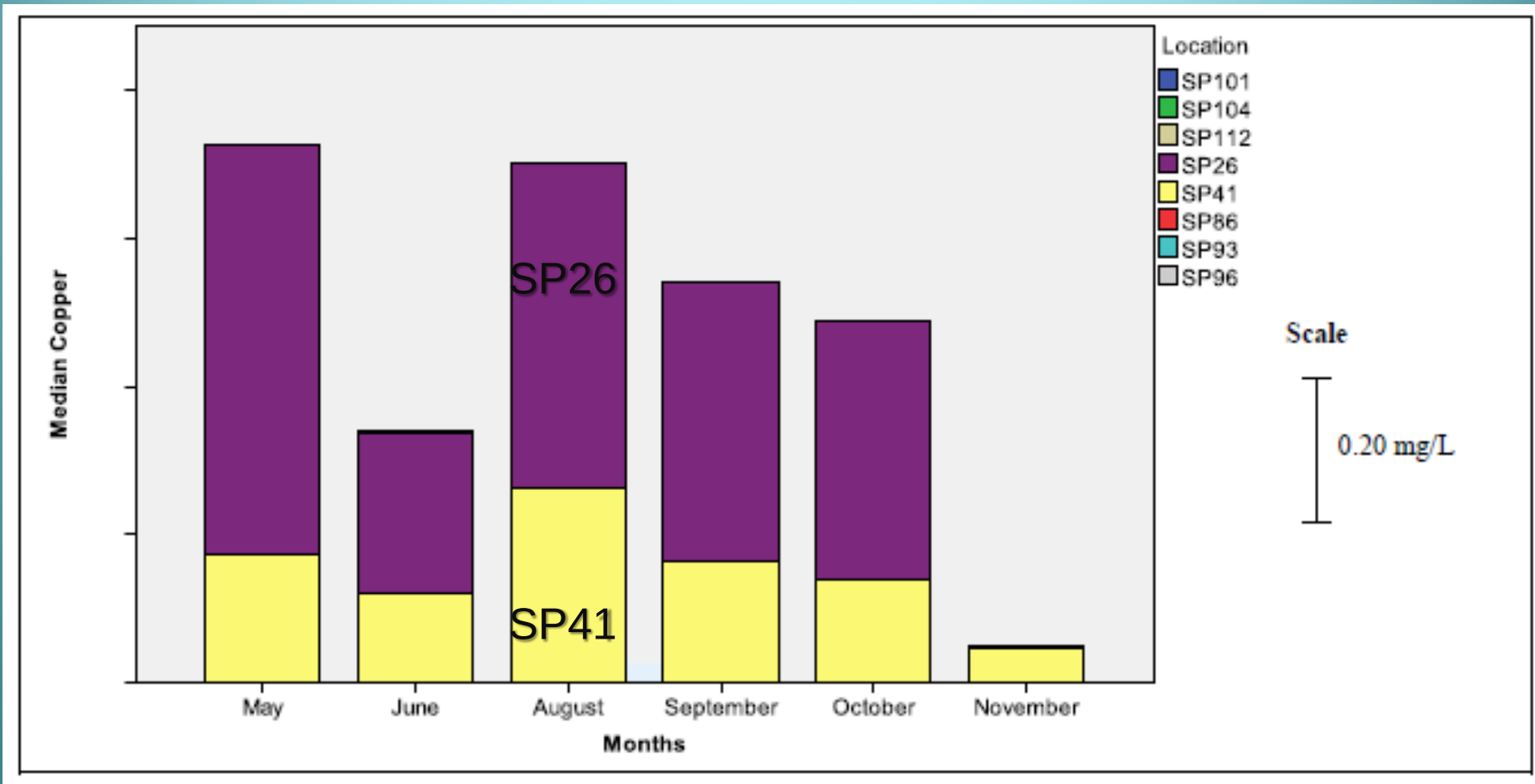
Concentrations in these samples influenced by groundwater associated with the ore deposit

Upper Talarik drainage

General trends less apparent

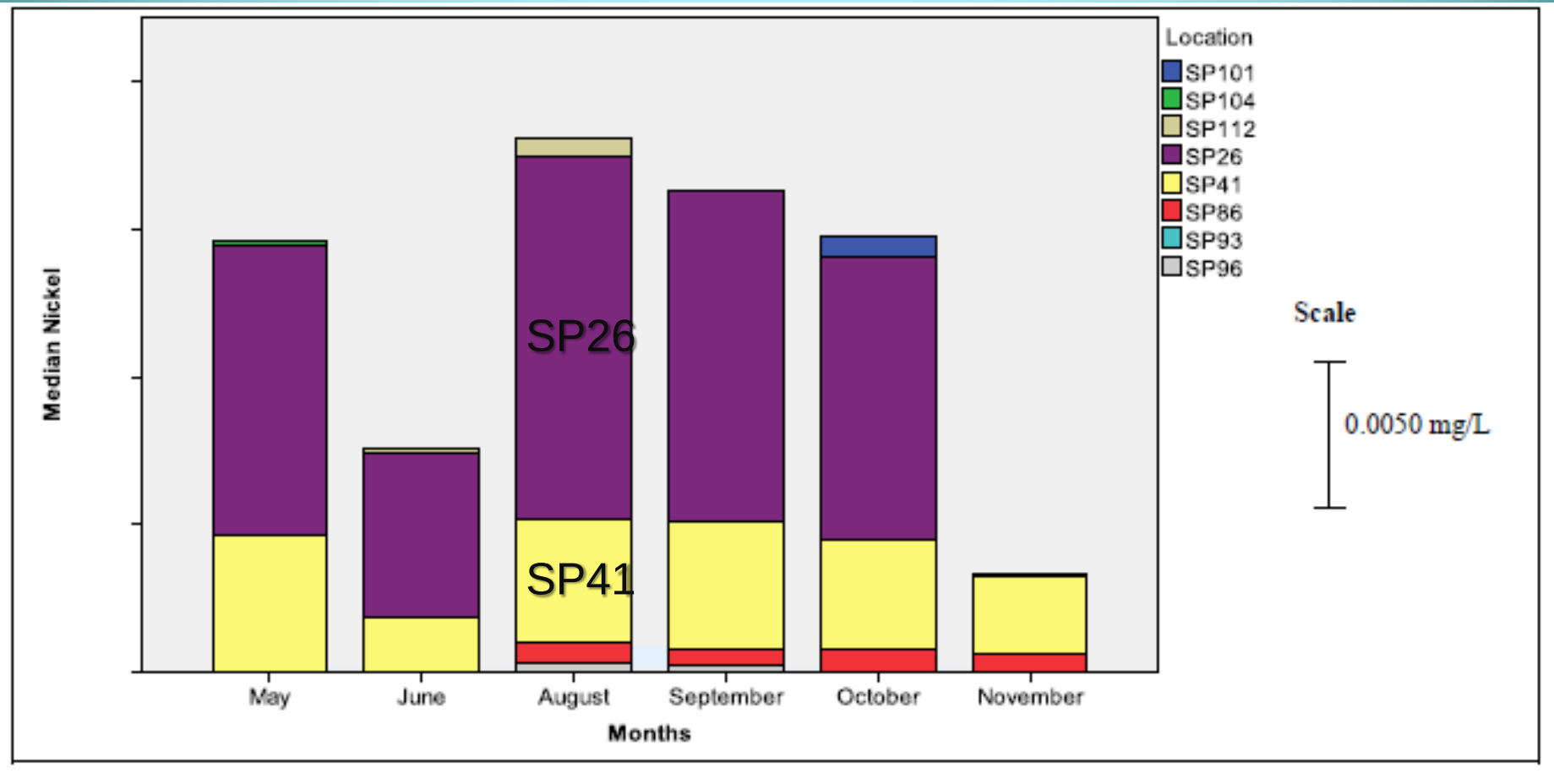
Concentrations of constituents were generally low in March and were only detected in station SP40

Copper in SFK Seeps



Note: Bars are not cumulative but reflect relative concentrations by month.

Nickel in SFK Seeps

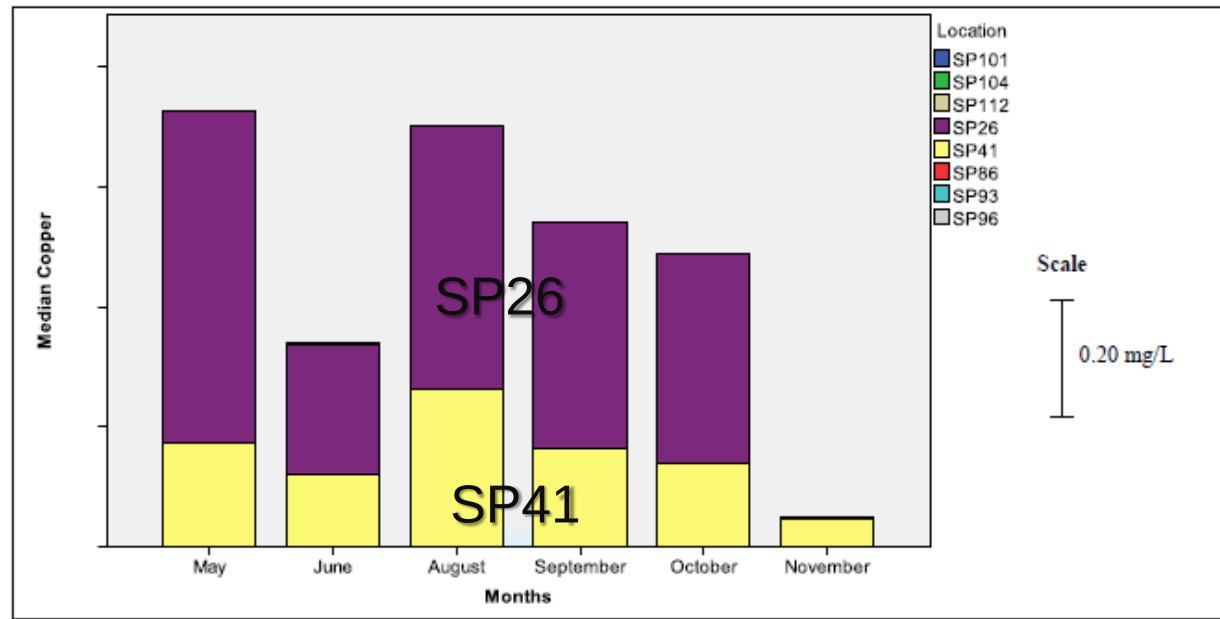


Note: Bars are not cumulative but reflect relative concentrations by month.

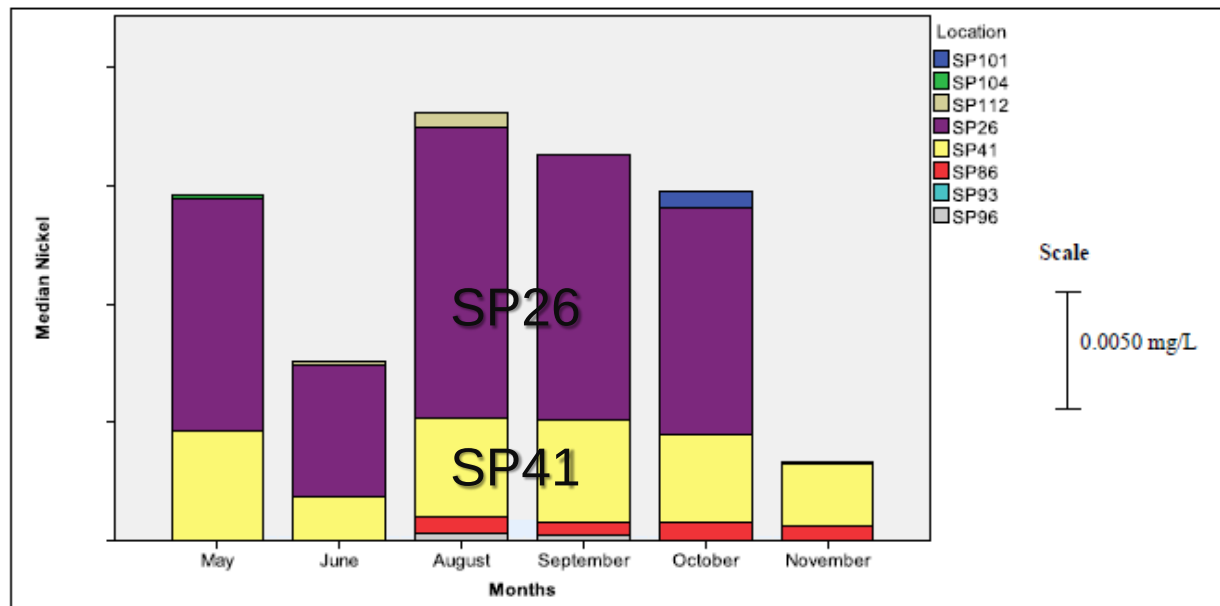
Pebble Project EBD

Copper and Nickel in SFK Seeps

Copper

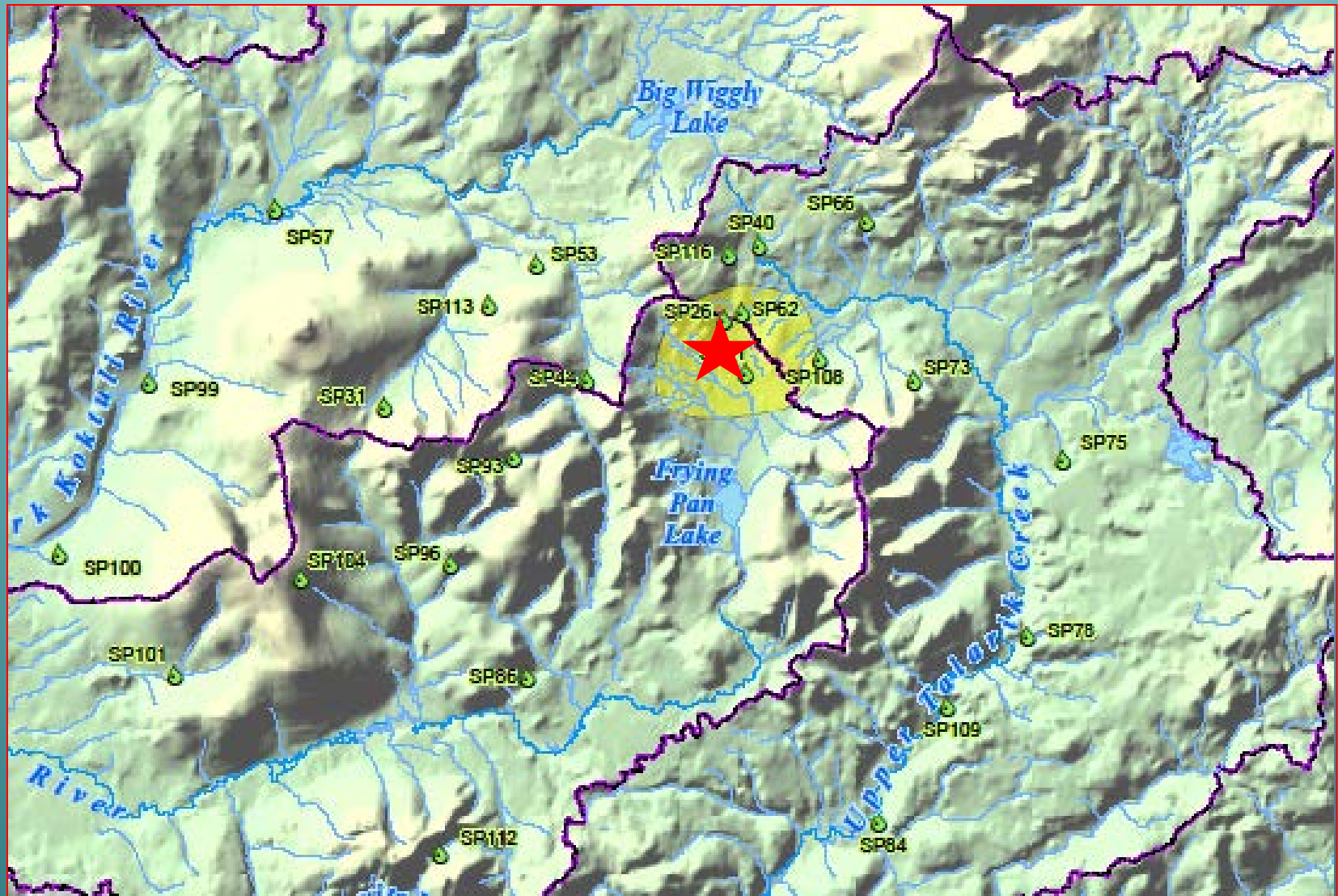


Nickel



Note: Bars are not cumulative but reflect relative concentrations by month.

Seep Stations SP26 and SP41



Spatial Consistencies in Seeps Data

pH

Generally near-neutral

Temperature

Mean of 3.4 °C in all three drainages, generally colder than streams

Major ions exhibited highest concentrations

Na, Mg, K, Ca, sulfate

Discharge

range 0 – 2 cfs (90% are < 0.5 cfs)

Measurable flow varies throughout the year

Varied response to precipitation events



Parameters with Naturally Occurring Concentrations Above Criteria in Seeps

Similar to streams, a few seeps have naturally elevated levels above the CALC and/or DW for:

Physical parameters

pH, DO

Alkalinity

WAD Cyanide

Nitrate+nitrite (as N) (SFK only)

Metals

All three drainages:

Al Cu

Fe Pb

Cd As

SFK and UT drainages only:

Zn Ni

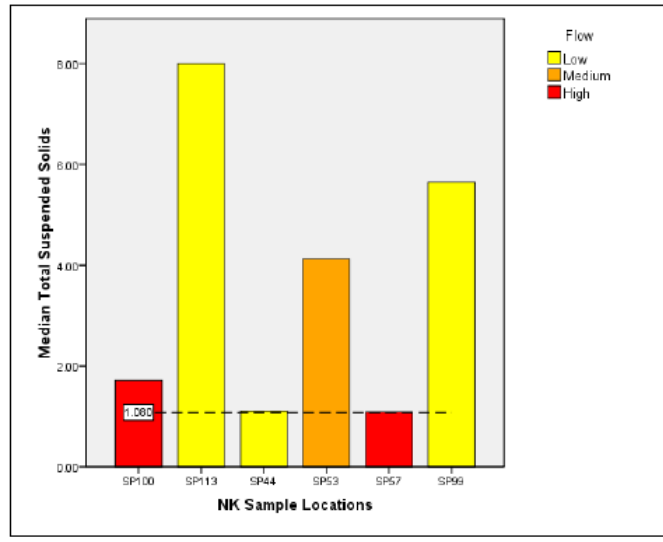
Mn Hg



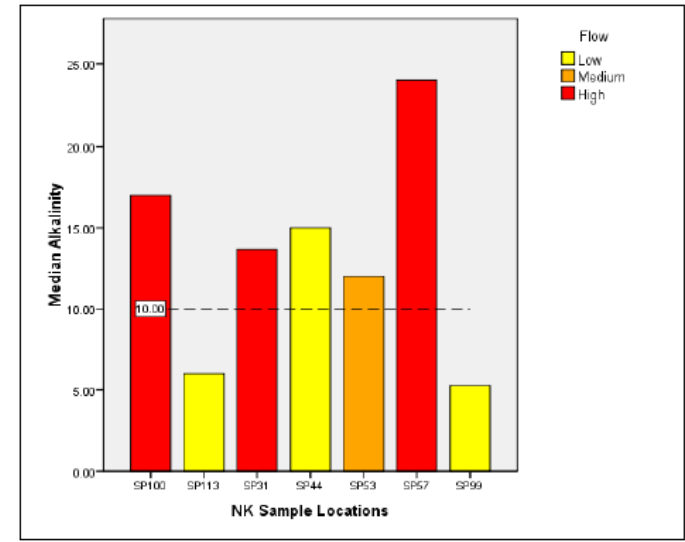
Within Drainage Variation

- Several constituents are inversely proportional to discharge velocity (i.e., concentrations get lower as seep velocity increases)
 - TSS, sulfate, Fe (NFK)
 - TDS, K, Cu, Ni (SFK)
- Several constituents are directly proportional to discharge velocity (i.e., concentrations get higher as velocity increases)
 - Alkalinity (NFK only)
 - TSS, Fe, Pb, Mo (UT)

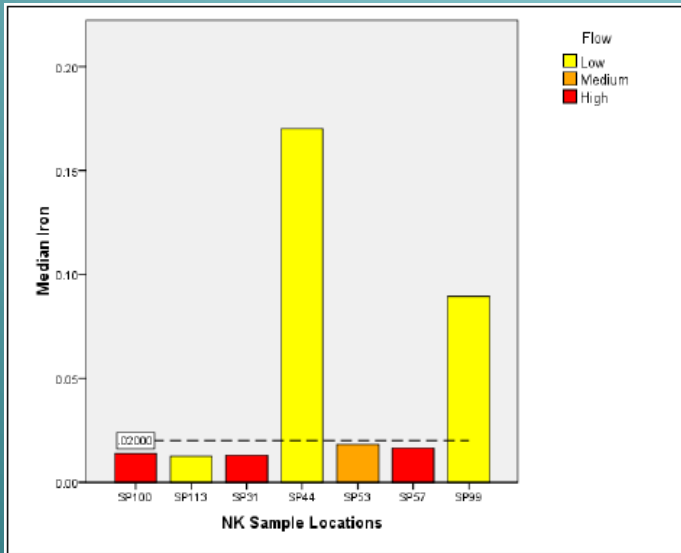
Effects of Seep Flow on Concentrations



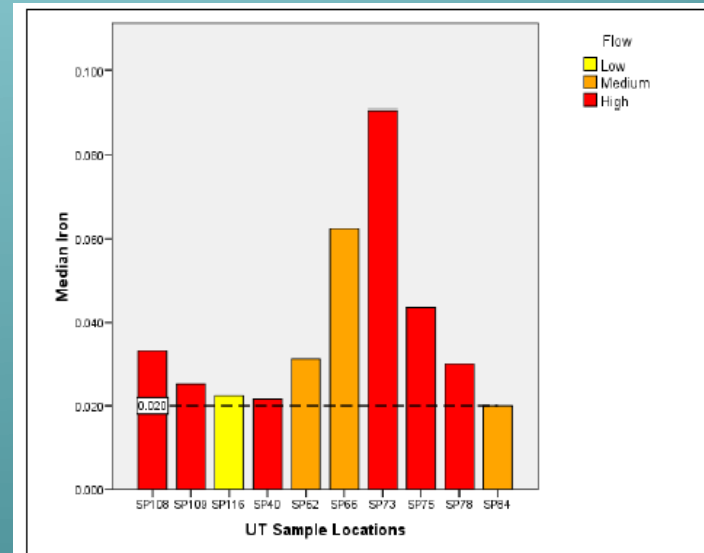
TSS in NFK



Alkalinity in NFK



Iron in NFK



Iron in UT Pebble Project EBD

Comparison Across Seep Drainages

Four field and physical parameters differed significantly across pairs of drainages

TDS

TSS

pH

Alkalinity

Five major ions differed significantly across pairs of drainages

Sodium

Sulfate

Potassium

Fluoride

Hardness (as CaCO_3)

One nutrient (total nitrate+nitrite [as N]) differed significantly across pairs of drainages

Six trace elements differed significantly across pairs of drainages

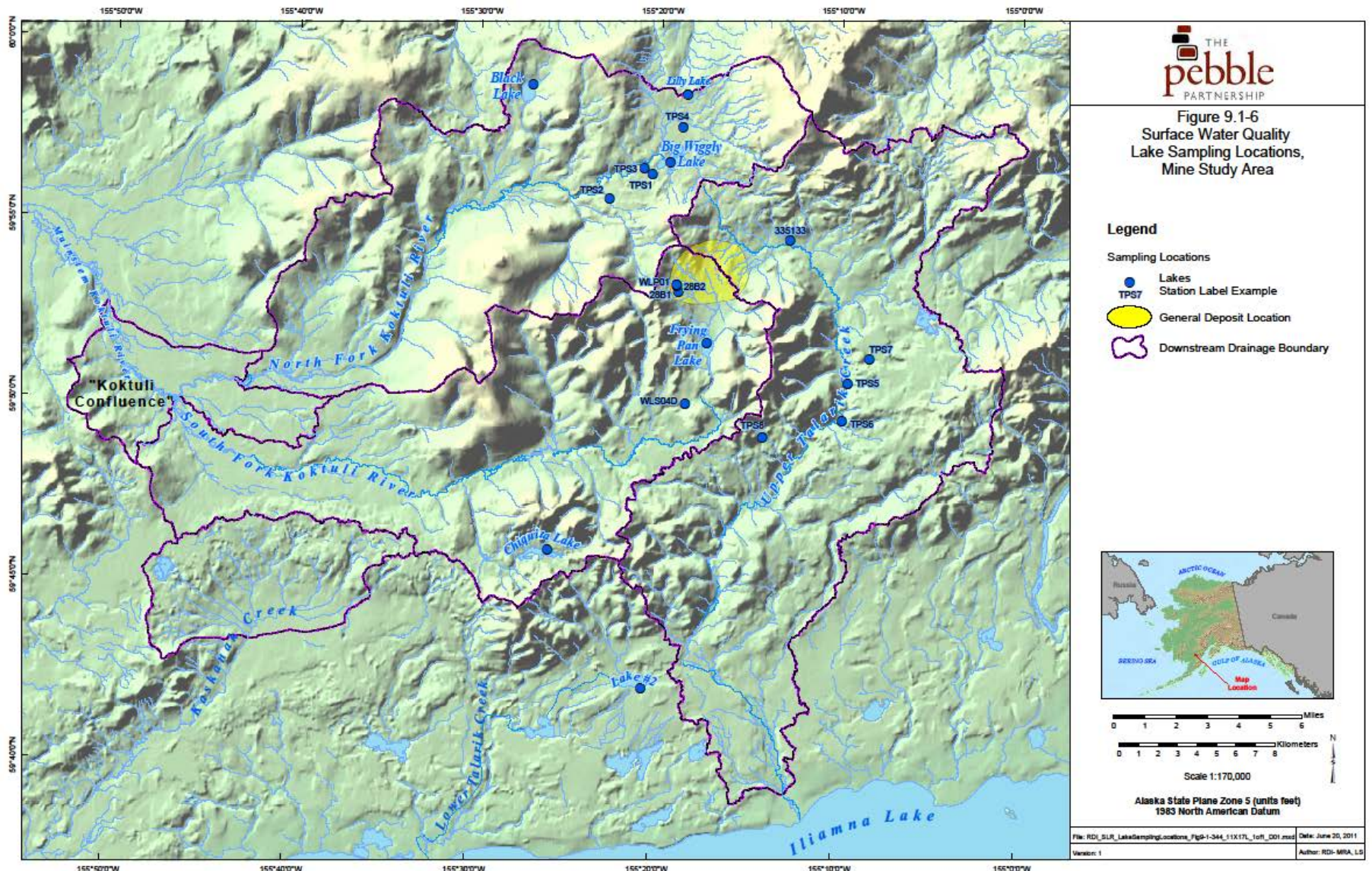
Arsenic, cadmium, copper, iron, nickel, zinc



Four Bullet Summary: Seeps

- Drainages have different signatures of naturally occurring constituents
- Background signatures of naturally occurring constituents depend in part on distance from the general deposit area
- Concentrations of several parameters in seeps are naturally higher than the applicable regulatory-based limits
- Most concentrations are independent of seep velocity, but both direct and inverse relationships are present for a few parameters

Pond Sampling Program



Ponds Water Quality 2006-2007

Objectives are the same as for streams

47 Samples from 28 stations across 19 lakes

1 Sampling event per year (August)

Separate from the “small pools” study



Pond Program Results

Three parameters generally non-detect in ponds

TSS, fluoride, WAD cyanide

Similar to streams and seeps, some lakes have naturally elevated levels above the CALC and/or DW for:

pH, DO, alkalinity (generally all lakes)

WAD cyanide (only detected sample in FPL)

Metals (Al, Cu, Fe, Pb) in FPL only

Frying Pan Lake has a different signature of parameter concentrations than other sampled lakes

This lake incorporates drainage from higher elevations around the general deposit area

Leads to higher concentrations of some parameters (**iron**) and lower values of other parameters (**pH, potassium**) in FPL

Three Bullet Summary: Ponds

- Concentrations of several parameters in ponds are naturally higher than the applicable regulatory-based limits.
- Background signatures of naturally occurring constituents in ponds depend in large part on whether they drain the general deposit area.
- Frying Pan Lake has a different signature of parameters than do the other sampled lakes.

And finally, a two word summary:

Thank you



Special thanks to Charlotte MacCay at PLP for allowing me to steal her old presentation with all these cool photos.