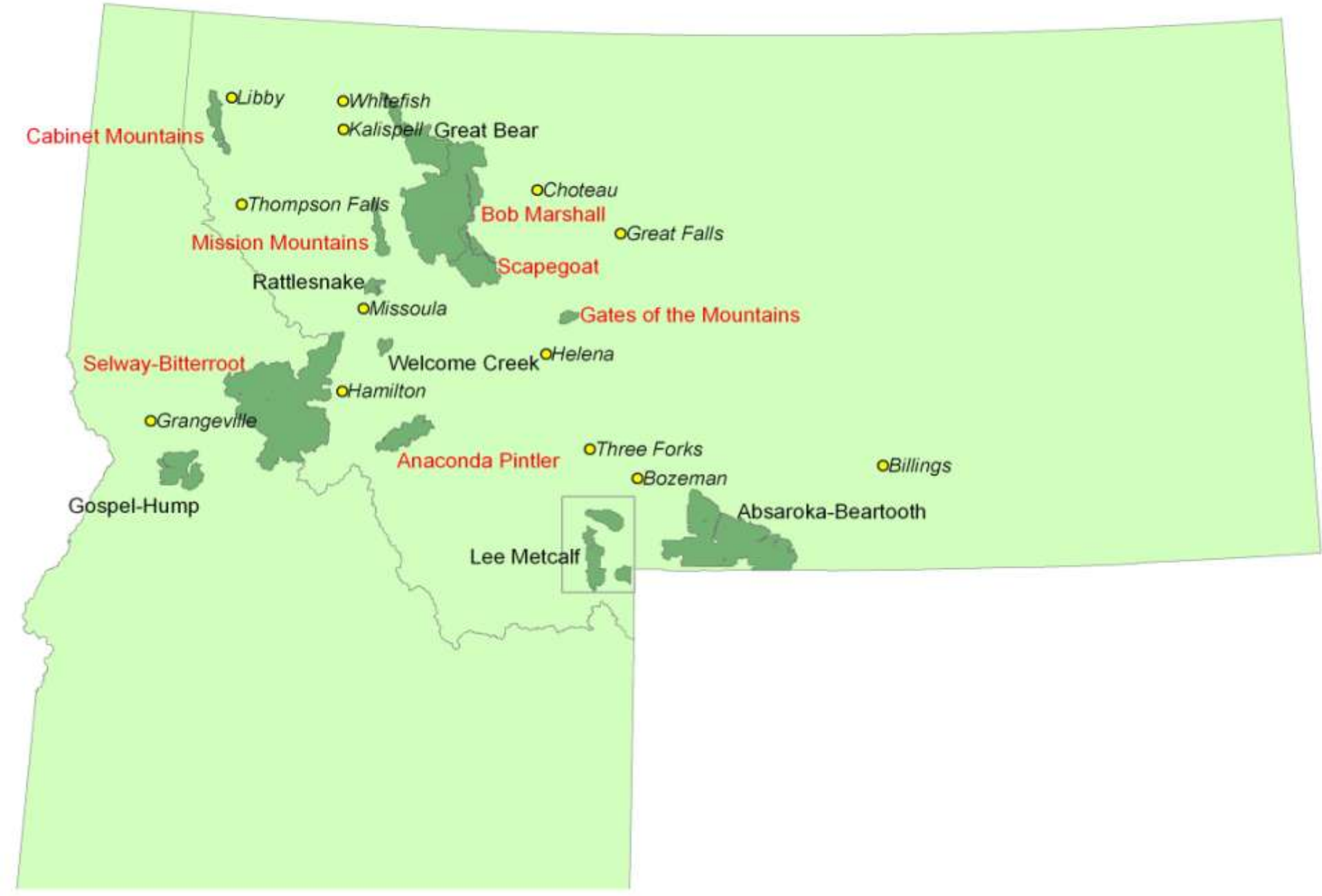
Region 1 Lake Monitoring

Thomas Dzomba – Air Fire & Aviation
Mark Story – Gallatin NF
Jill Grenon – Bridger Teton NF (R4)

Objectives

- **Overview of Region 1 Air Program**
- **Lake Monitoring & Results – purpose, approach, when, where, lake selection, parameters, analysis, conclusions, management difference, lessons**
- **Unknowns and questions?**


Libby
Whitefish
Kalispell
Great Bear
Cabinet Mountains
Choteau
Thompson Falls
Bob Marshall
Great Falls
Mission Mountains
Scapegoat
Rattlesnake
Missoula
Gates of the Mountains
Selway-Bitterroot
Welcome Creek
Helena
Hamilton
Grangeville
Anaconda Pintler
Three Forks
Billings
Bozeman
Gospel-Hump
Absaroka-Beartooth
Lee Metcalf

Bob Marshall Wilderness

Selway Bitterroot Wilderness

Lee Metcalf Wilderness

AQRV/WAQV Monitoring

- **Particulate Matter**
- **Visibility**
- **Lakes**
- **Lichens**
- **Snow**
- **Precipitation**

Wilderness Air Quality Value (WAQV) Class 2 Monitoring Plan
Absaroka Beartooth Wilderness
Lee Metcalf Wilderness
Gallatin, Custer, Beaverhead, Shoshone NF, Butte District BLM

prepared by Mark Story, Kimberly Schlenker, and Jill Grenon, Gallatin NF

January 8, 2008

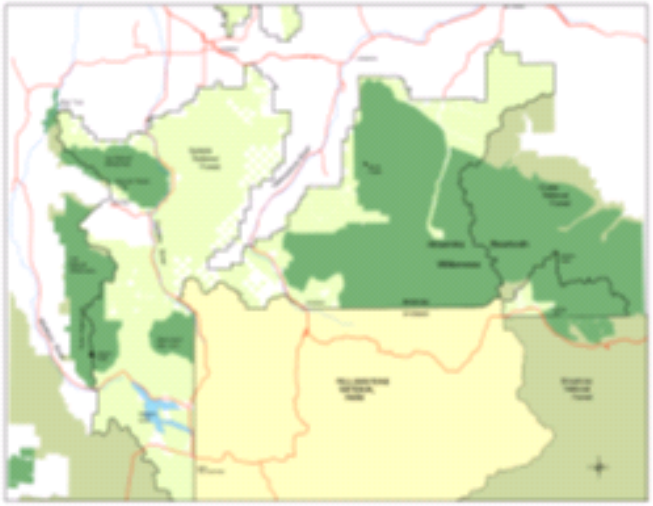
This Wilderness Air Quality Value (WAQV) Class 2 Plan was prepared to:

1. Summarize the wilderness characteristics of the Absaroka Beartooth (ABW) and Lee Metcalf Wilderness (LMW).
2. Explain the legal framework for air quality protection,
3. Identify wilderness air quality values, and
4. Provide a monitoring plan for Wilderness Air Quality Values (WAQVs).

The ABW and LMW are Class 2 for the Clean Air Act Prevention of Significant Deterioration (PSD) regulations. Air quality protection authority (beyond ambient air quality standards and PSD increments) for this wilderness area therefore relies primarily upon the Wilderness Act, although the adjacent Yellowstone NP and North Absaroka Class I Airsheds provide some defacto air quality protection. This plan is designed to specify appropriate monitoring to protect the Class 2 WAQVs and to meet the Wilderness Stewardship Challenge to achieve the objectives of the Air Element #3 http://www.wilderness.net/index.cfm?fuse=toolboxes&sec=air

1) Location

The Absaroka Beartooth Wilderness (ABW) is located in south central Montana (Gallatin and Custer NF's) with a small portion in northern Wyoming (Shoshone NF), just north and east of Yellowstone National Park. The ABW is a contiguous unit of 943,626 acres with 23,288 acres in Wyoming. The ABW includes the 12,799 feet Granite Peak, the highest point in Montana.



USFS R1 Wilderness Air Quality Monitoring Plan

Mark Story - Gallatin National Forest
Thomas Dzomba - USFS R1/R4 Air Fire & Aviation
Jill Grenon - Gallatin National Forest & Montana State University
February 1, 2008

	USFS R1 Class 1 Wilderness Areas – AQRV's						
monitoring item	BMW	SGW	CMW	SBW	APW	GMW	MMW
Phase 3 Lakes			Upper & Lower Libby Lakes	North Kootenai & Shasta Lakes			
IMPROVE visibility	MONT1 & GLAC1* IMPROVE site	MONT1 IMPROVE site	CABI1 & GLAC1* IMPROVE site	SULA1 & SAWT1* IMPROVE site	SULA1 IMPROVE site	GAMO1 IMPROVE site	MONT1 & GLAC1* IMPROVE site
Lichens	12 reference sites – 2002 & 2003, 2010		3 reference sites – 1992, 2010	16 reference sites – 1992 - 1994, 2008	10 reference sites – 1992, 2008	3 reference sites – 2000 - 2001, 2008	4 reference sites – 2002, 2010
NADP	Glacier NP MT05 NADP site*	Glacier NP MT05* and Clancy MT07* NADP sites	Glacier NP MT05* and Priest River ExpFst ID02* NADP sites	Lost Trail Pass MT97 NADP site	Lost Trail Pass MT97 NADP site	Clancy MT07* NADP site	Glacier NP MT05 NADP site
Snow Chemistry	USGS snow chemistry sites*	USGS snow chemistry sites*	USGS snow chemistry sites*	USGS snow chemistry sites*	USGS snow chemistry sites*	USGS snow chemistry sites*	USGS snow chemistry sites*

USFS R1 Class 2 Wilderness Areas – WAQV's

monitoring item	ABW	LMW	GBW	RW	WCW	GHW
Lakes	Twin Island & Stepping Stone Phase 3 lakes	3 lakes (2007)		8 lakes (2007)		5 lakes (2007) 3 lakes (2008)
IMPROVE visibility	YELL2* & NOAB1* IMPROVE sites	YELL1* & NOAB1* IMPROVE sites	GLAC1* IMPROVE site	MONT1 & SULA1 IMPROVE sites	MONT1 & SULA1 IMPROVE sites	SULA1 HECA1* SAWT1* IMPROVE sites
Lichens						2 reference sites – 2008
NADP	Yellowstone Pk WY08* NADP site	Lost Trail Pass MT97 and Yellowstone Pk WY08* NADP sites	Glacier NP MT95* NADP site	Lost Trail Pass MT97 NADP site	Lost Trail Pass MT97 NADP site	Lost Trail Pass MT97, Priest River Exp Fst ID02*, Palouse WA24* NADP sites
Snow Chemistry	USGS snow chemistry sites*	USGS snow chemistry sites*	USGS snow chemistry sites*	USGS snow chemistry sites*	USGS snow chemistry sites*	USGS snow chemistry sites*

BMW – Bob Marshall Wilderness
SGW – Scapegoat Wilderness
CMW – Cabinet Mountains Wilderness
SBW – Selway Bitterroot Wilderness
APW – Anaconda Pintler Wilderness
GMW – Gates of the Mountains Wilderness
MMW – Mission Mountains Wilderness
sites monitored by USFS R1

ABW – Absaroka Beartooth Wilderness
LMW – Lee Metcalf Wilderness
GBW – Great Bear Wilderness
RW – Rattlesnake Wilderness
WCW – Welcome Creek Wilderness
GHW – Gospel Hump Wilderness
* operated by non-USFS agencies

U.S. Forest Service Region 1 Lake Chemistry, NADP, and IMPROVE Air Quality Data Analysis

Jill Grenon
Mark Story

United States Department of Agriculture / Forest Service
Rocky Mountain Research Station
General Technical Report RMRS-GTR-230
September 2009

USDA Forest Service
Region 1 Air Quality

- Home
- Monitoring
- Guidance
- Reports
- GYACAP
- AQ Plans
- Contacts
- Links

Welcome...

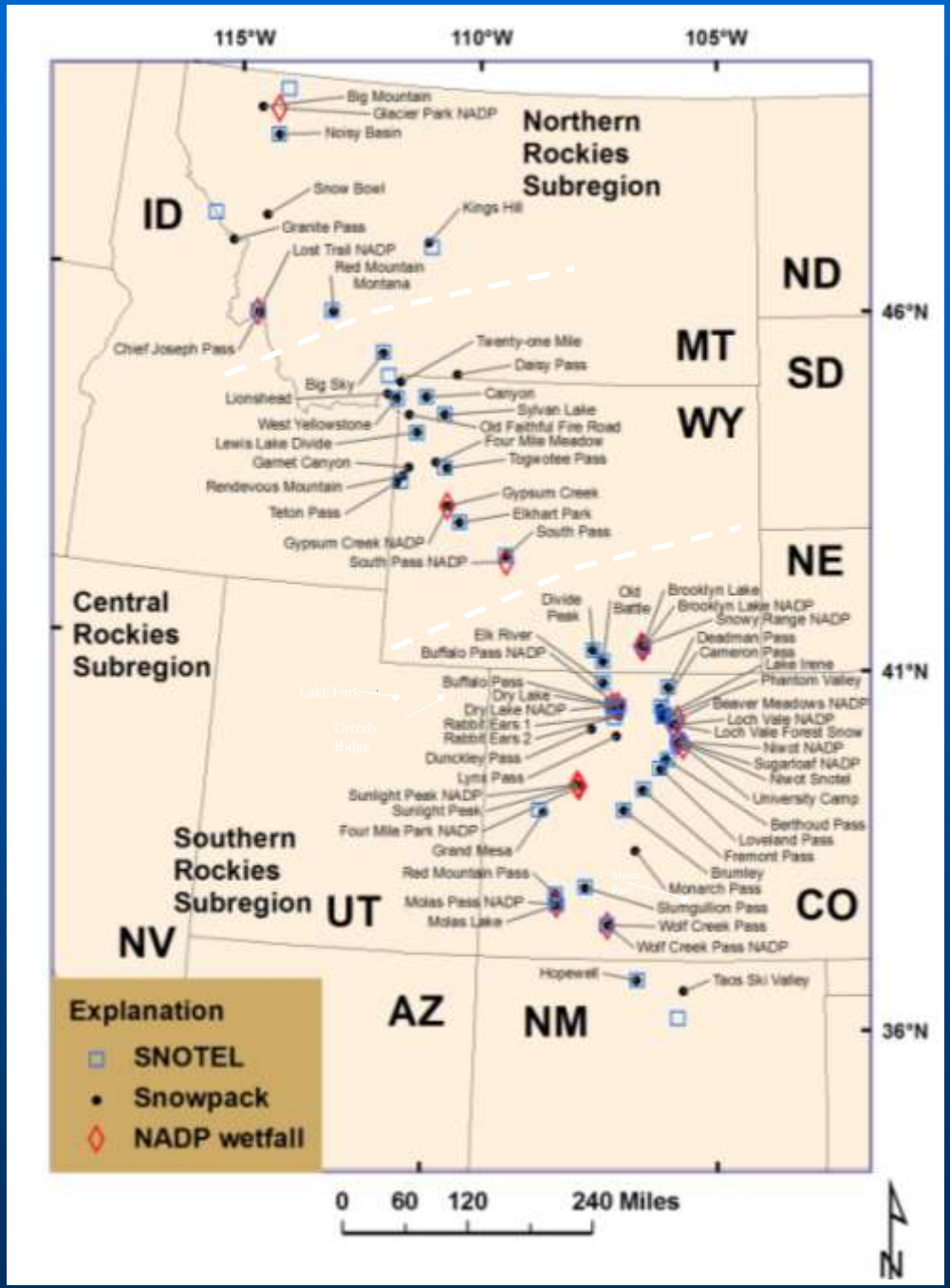
Welcome to the Northern Region's Air Resource Management Program. Air Resource managers advise regulatory and resource management officials in the mitigation of society's air pollutant impacts to forest resources, like reduced visibility, damage to vegetation, or high lakes acidification. Air resource managers advise forest land managers about how to reduce the amount of air pollutants generated by Forest Service activities such as prescribed burning, road construction, oil and gas production, or even ski area development. Air resource managers work with all people to increase the effectiveness of air quality regulations in providing clean air.

www.fs.fed.us/r1/gallatin/resources/air/index.shtml

Please contact us for more information

Rocky Mountain Snowpack Network

- Complements network of NADP wetfall sites
- Collocated with SNOTEL Stations reporting SWE, Air temp max, mins



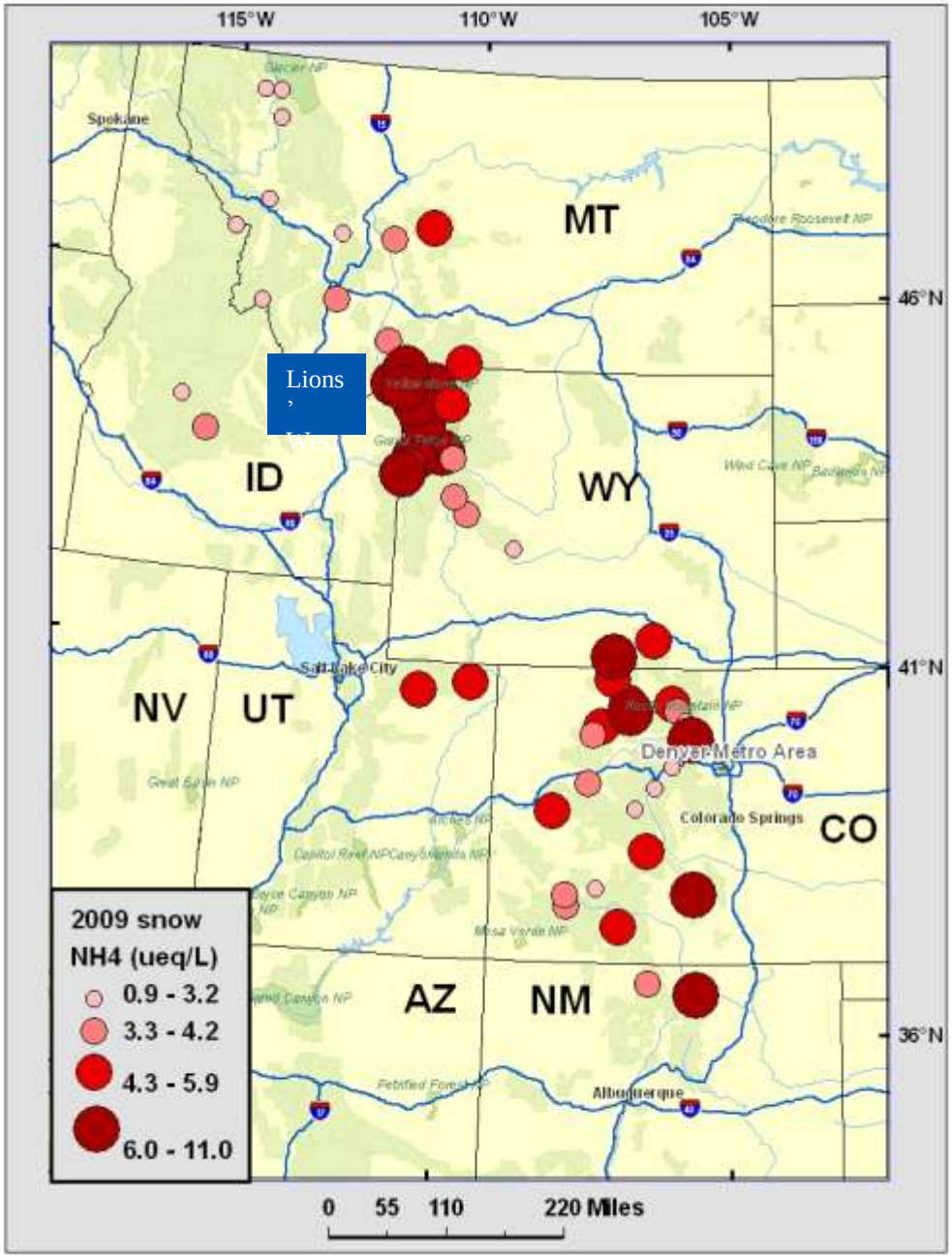
Dissolved Ammonium

•Highest levels of ammonium generally in Central Subregion—esp Targhee Pass Yellowstone, and the Tetons

Lionshead (11.0 ueq/L)
West Yellowstone, offroad (12.1 ueq/L)

•Highest NH4 in region from snowpacked roadway at local-source site (over-snow veh., West Yellowstone, 15.6 ueq/L).

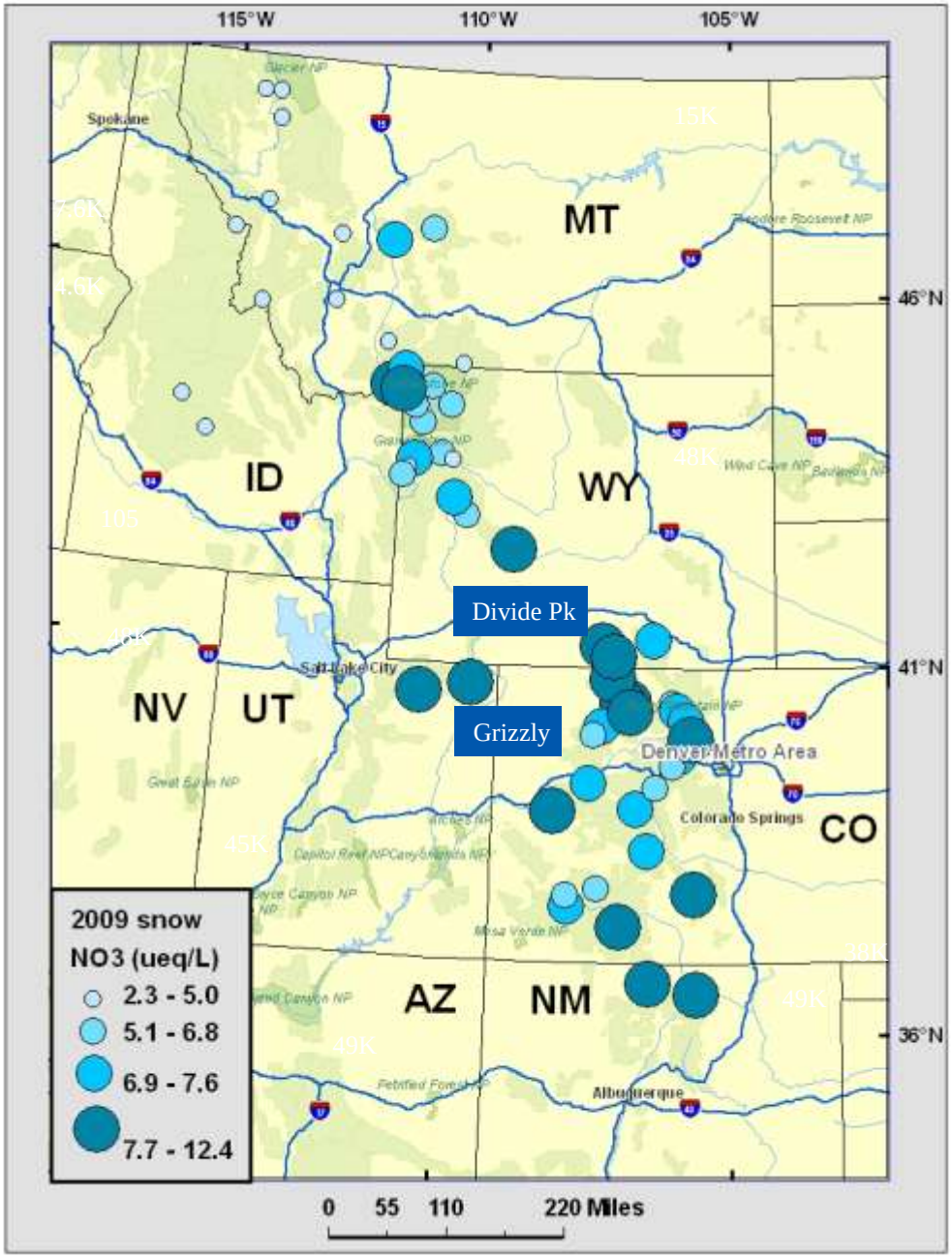
•Other Ag areas: North-central Colo. Mts, Sierra Madre, S. Colo. and northern New Mex.



Dissolved Nitrate

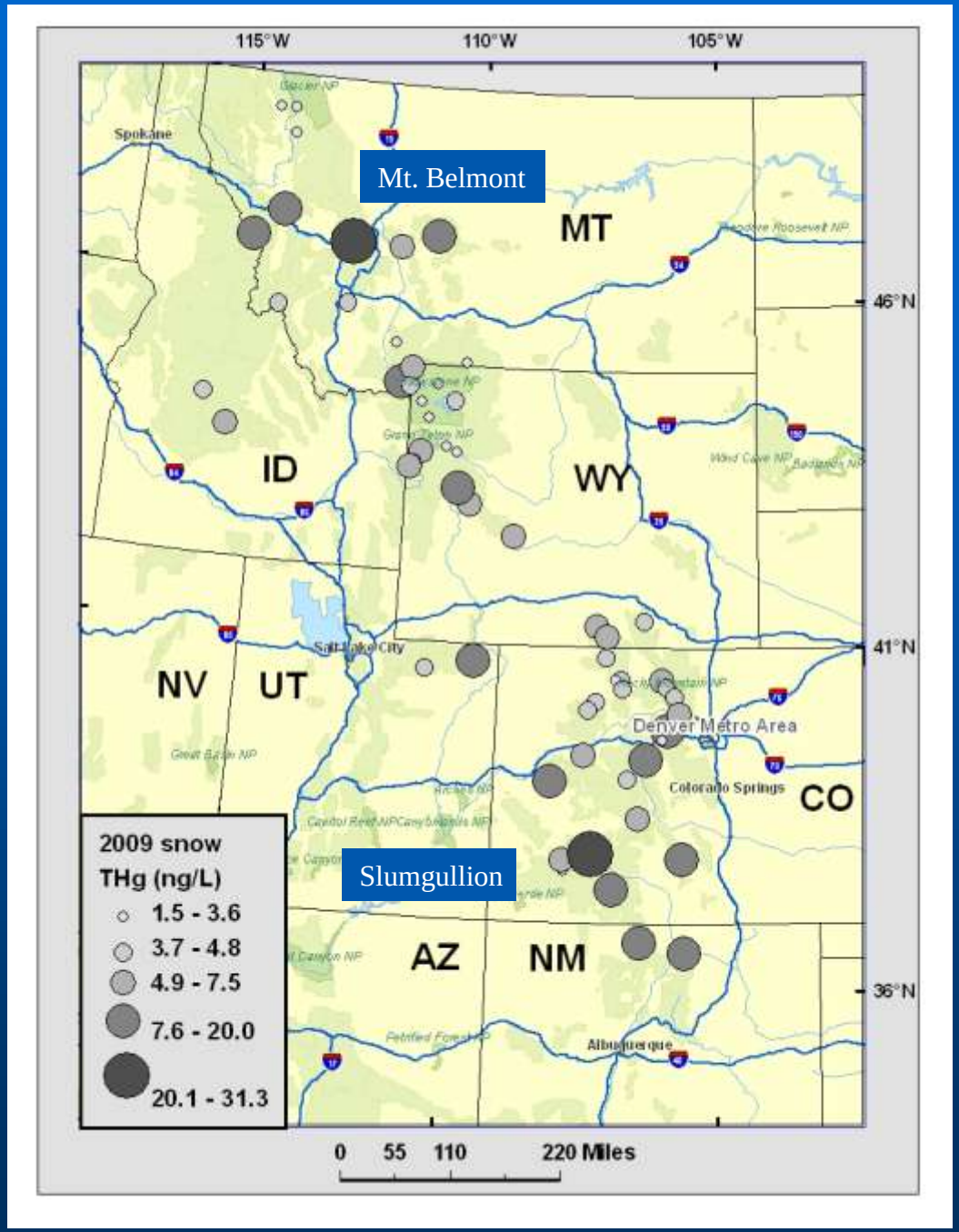
- Highest levels of nitrate generally in Southern Subregion—esp North-central Mts, Sierra Madre, NW Colo., and northern New Mex.
- Also in Uintas, Targhee Pass, and S. Pass at lower end of Wind River Mts

- Divide Peak (12.4 ueq/L)
- Grizzly Ridge (12.1 ueq/L)

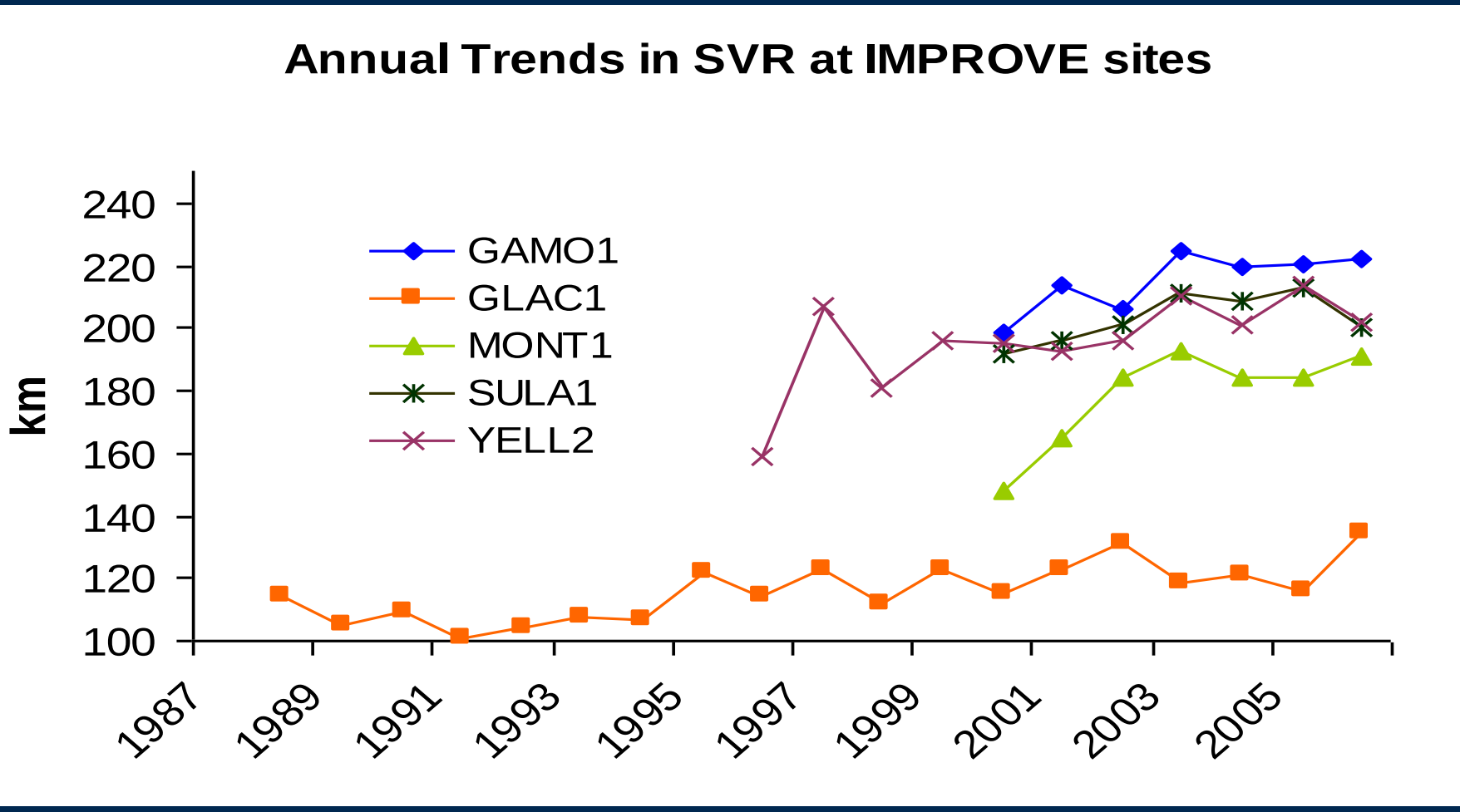


Total Mercury

- Highest levels of mercury (dissolved + particulate) generally in Southern Subregion—esp near 4 Corners
- Other distinct signals appear in Montana from Chief Joe Pass eastward past Helena to Kings Hill, and at Targhee Pass
- Slumgullion Pass (31.3 ng/L)
- Mt. Belmont (20.3 ng/L)



Annual Trends in SVR at IMPROVE sites



Parameter	CABI1	GAMO1	GLAC1	MONT1	SULA1	YELL2	HECA1
SO_4^{2-}			95↓				
NO_3^-	(95↓)	(95↓)		(95↓)	(99.9↓)		
EOMC					(99.9↓)		
Esoil							
ECM			90↓		(99↓)	95↓	
ELAC			90↓		(99.9↓)		
salt							(90↑)
Rb_{ext}			90↓		(99.9↓)	90↓	
SVR		(90↑)	99↑	(95↑)	(99↑)	95↑	
DV			99↓		(99.9↓)	90↓	
MF			99↓			95↓	
MT			95↓		(99.9↓)	95↓	

Table 27. Mann-Kendall p-values for annual data at Region 1 IMPROVE sites. Yellow highlighted cells indicate statistically significant seasonality trends using $p < 0.1$. The Grey cells indicate parameters that were not available. Pink cells are possible trends that are not validated/ statistically sound because there are less then 10 observations.

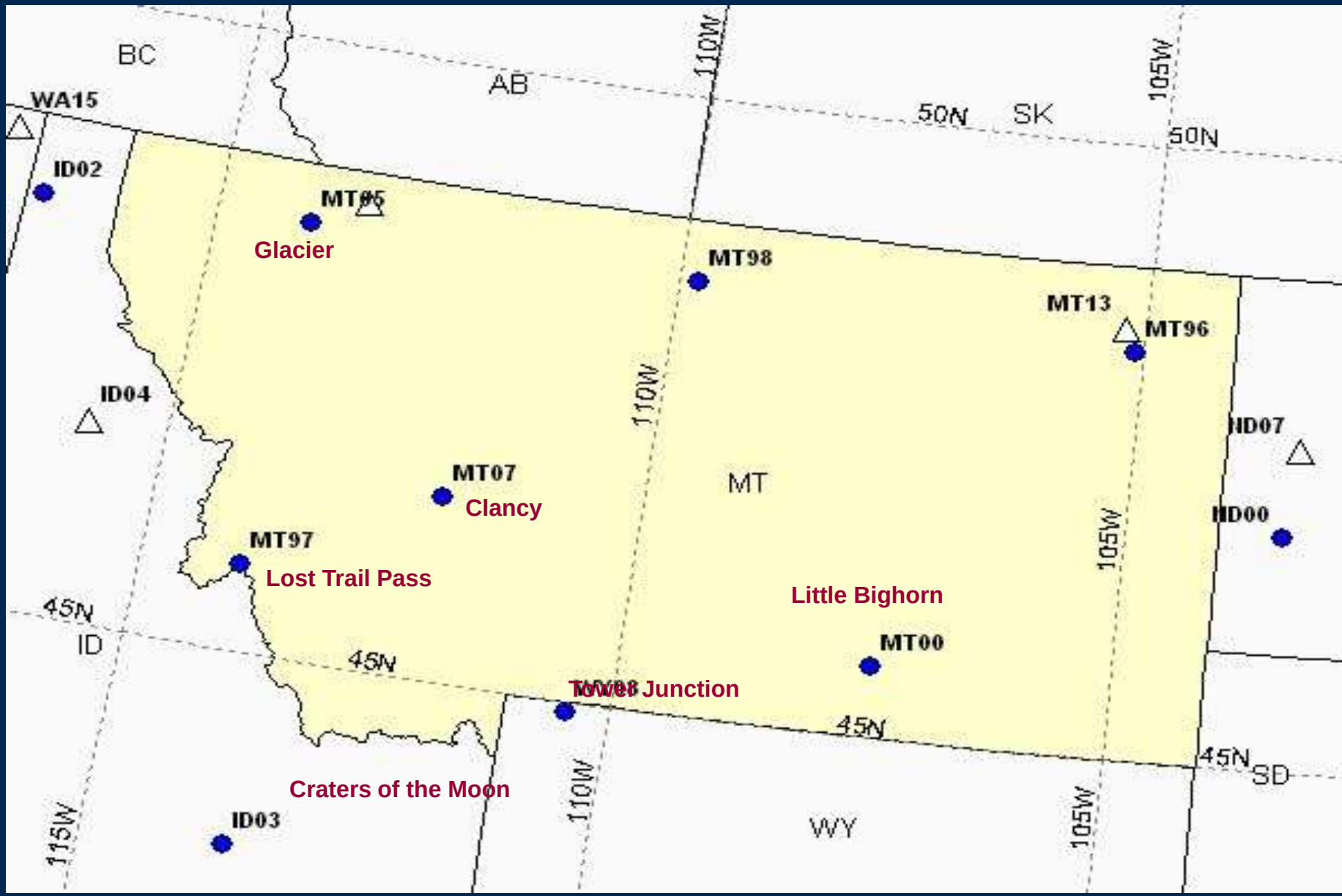
Parameter	CABI1	GAMO1	GLAC1	MONT1	SULA1	YELL2	HECA1
SO_4^{2-}	(0.230)	(1)	0.042	(0.764)	0.200	0.640	(0.368)
NO_3^-	(0.036)	(0.016)	0.441	(0.016)	(<0.001)	0.276	(0.230)
EOMC	(0.548)	(1)	0.726	(0.764)	(<0.001)	0.533	(0.764)
Esoil	(1)	(1)	0.624	(0.548)	0.855	0.120	(0.548)
ECM	(0.368)	(0.548)	0.059	(0.230)	(0.002)	0.012	(0.764)
Salt	(0.133)	(1)	0.780	(0.230)	0.428	0.756	(0.072)
R_{bext}	(0.368)	(0.764)	0.050	(0.133)	(<0.001)	0.087	(0.764)
SVR	(0.133)	(0.072)	0.001	(0.036)	(0.003)	0.029	(0.133)
dv	(0.133)	(0.230)	0.004	(0.133)	(<0.001)	0.062	(0.230)
MF	(0.230)	(0.230)	0.003	(0.133)	0.360	0.020	(0.764)
MT			0.017	(0.133)	(<0.001)	0.029	(0.548)

National Atmospheric Deposition Program (NADP)

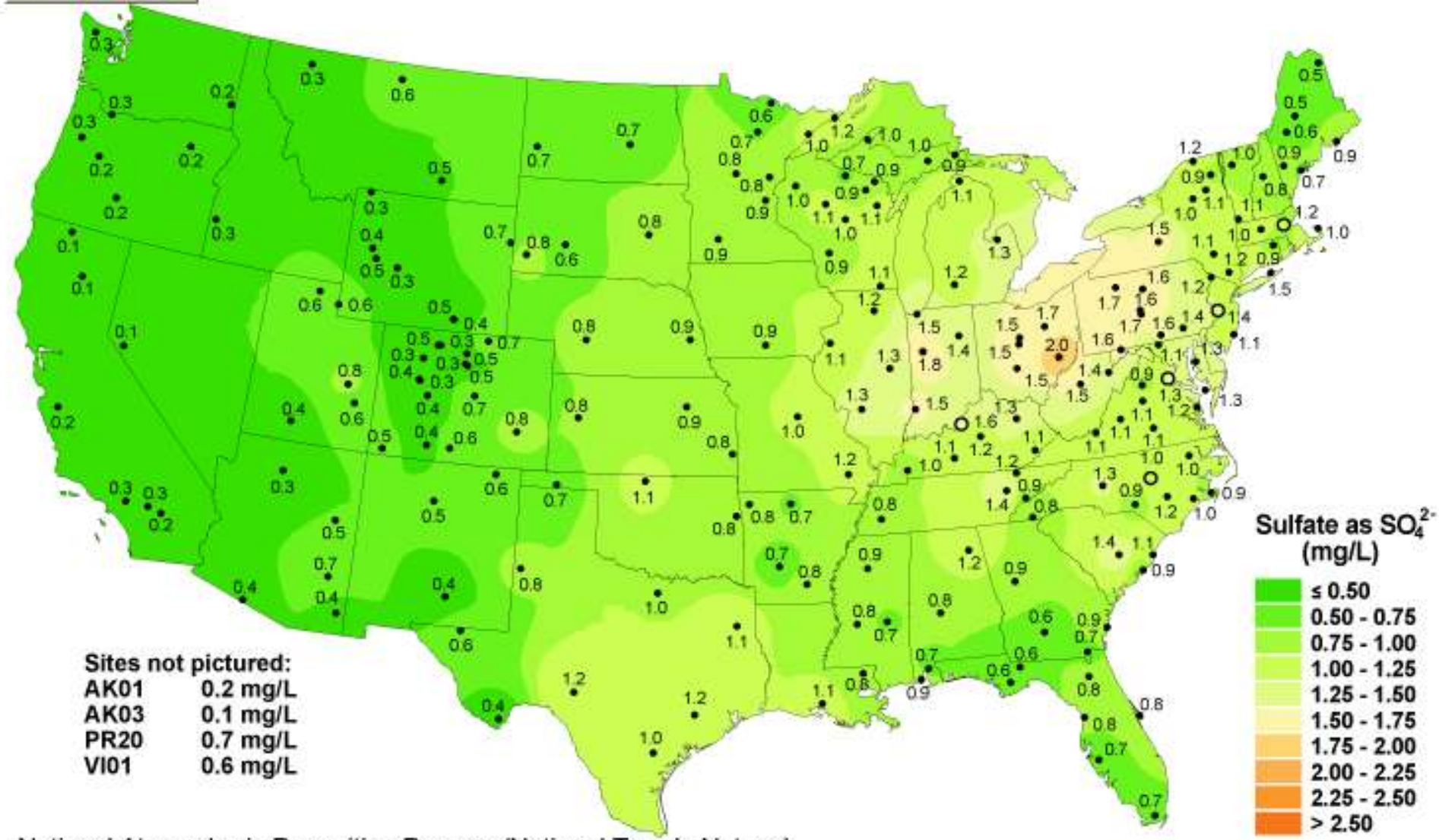
- **Chemistry of rain and snow**
- **Lost Trail Pass**

  MT97

NADP sites in and around MT



Sulfate ion concentration, 2008

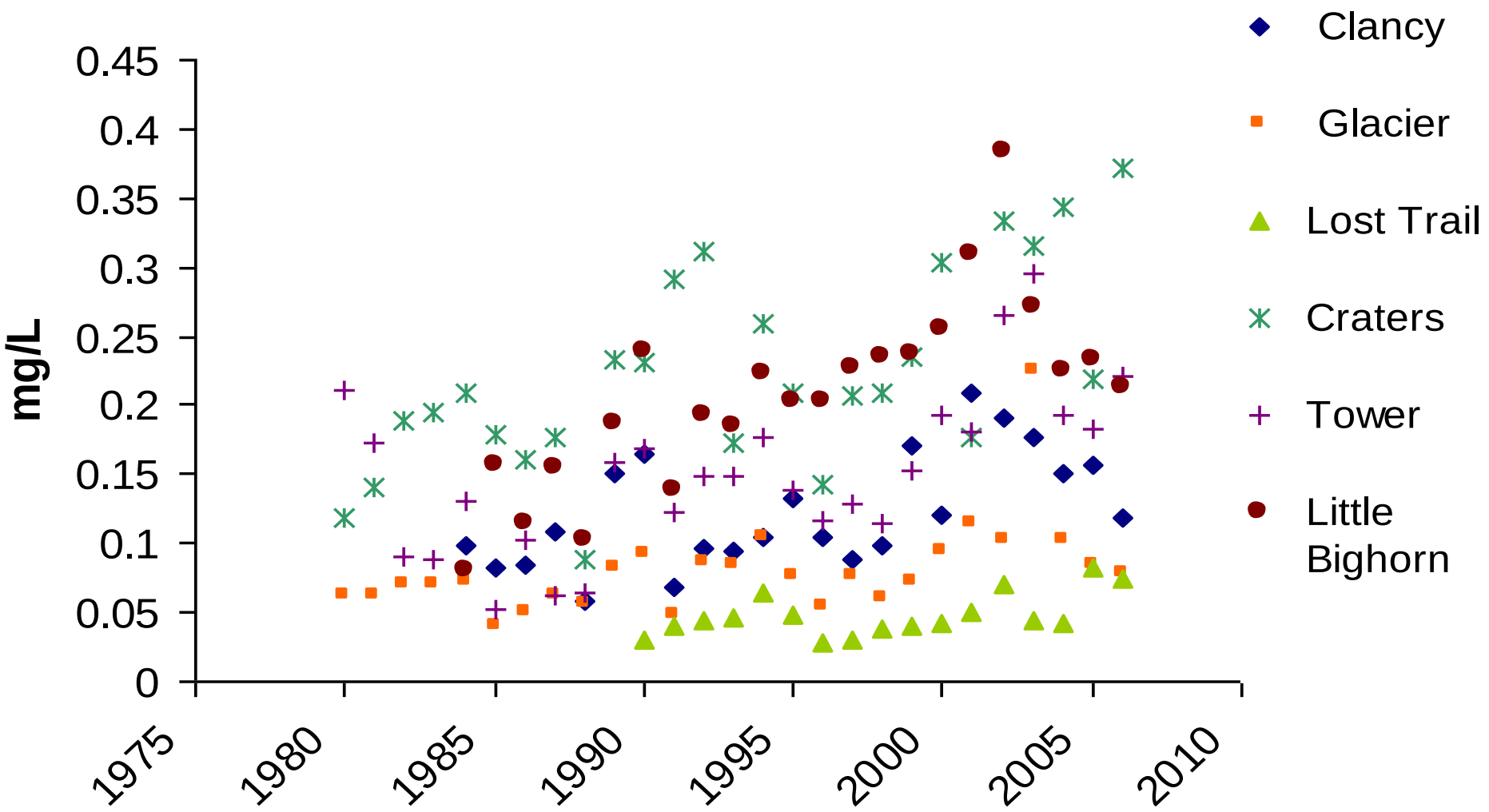


Sites not pictured:

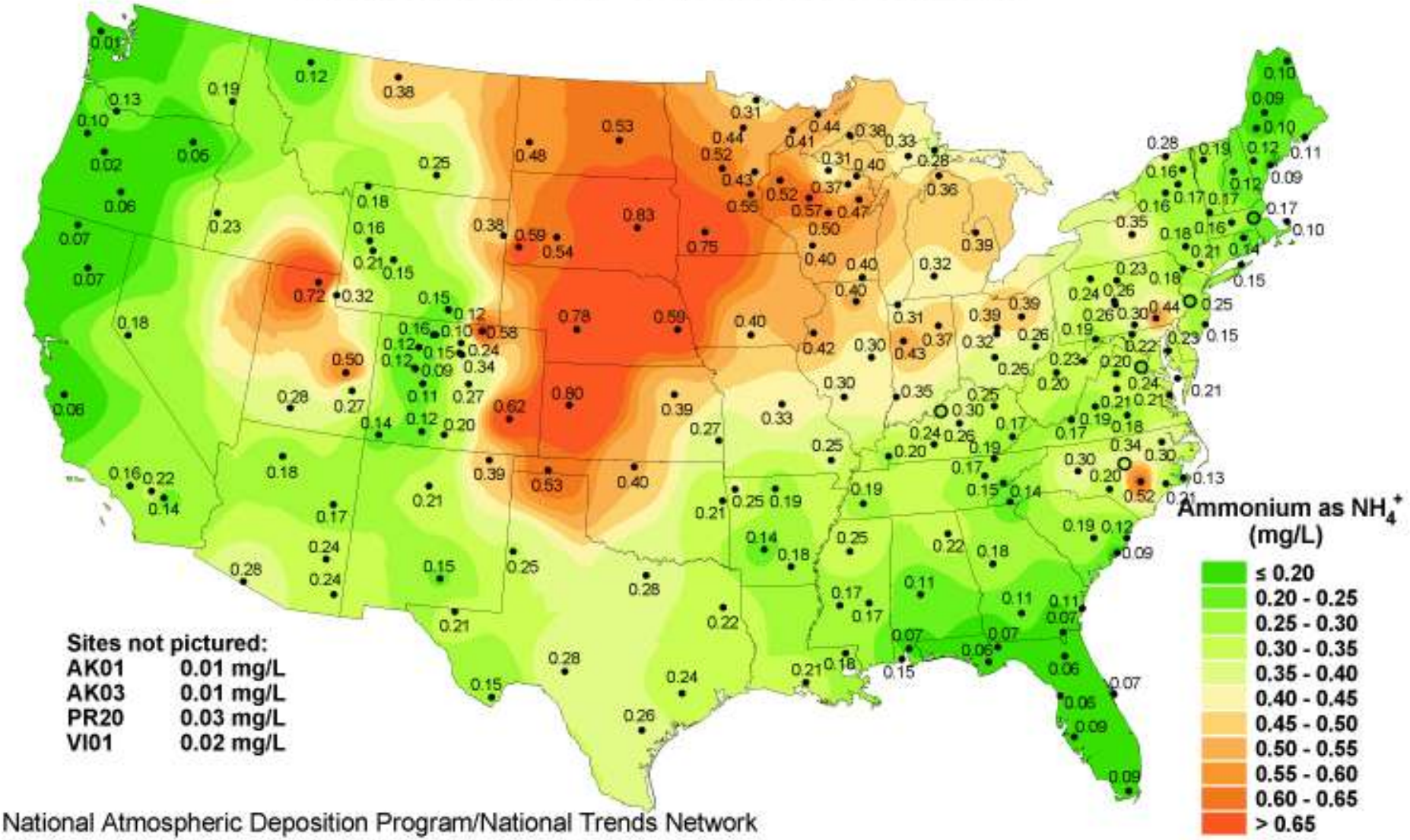
AK01	0.2 mg/L
AK03	0.1 mg/L
PR20	0.7 mg/L
VI01	0.6 mg/L

National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Annual NH4+ at NADP sites



Ammonium ion concentration, 2008



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

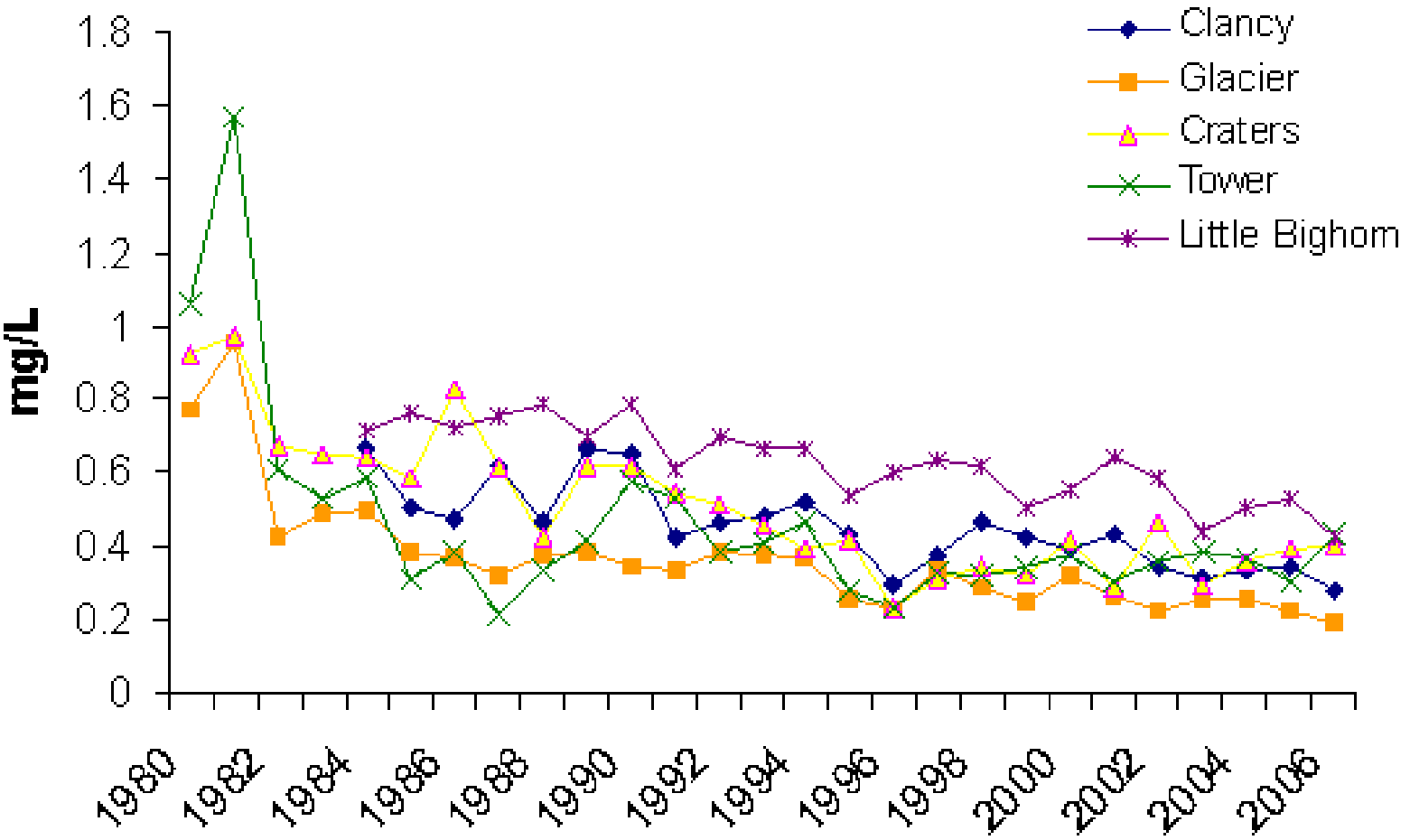


Fig. 12. Annual trends in sulfate concentration at NADP sites.

Table 11. Percent Confidence levels and trend direction of selected parameters (mg/L) annual data at Region 1 NADP sites. The ↑ symbolizes an increasing trend and the ↓ marks a decreasing trend. The numbers equal the percent confidence that a trend of statistical significance exists. 99 also means $\alpha = 0.01$, 95 means $\alpha = 0.05$, etc.

mg/L	Clancy	Glacier	Lost Trail Pass	Craters of the Moon	Little Bighorn	Tower
NO_3^-	**95** ↑				**90** ↑	
NH_4^+	**99** ↑	**99** ↑	**95** ↑	**99.9** ↑	**99.9** ↑	**99** ↑
cond		**95** ↓	**90** ↑	**99** ↓		
pH						
SO_4^{2-}	**99.9** ↓	**99.9** ↓		**99.9** ↓	**99.9** ↓	**95** ↓
Ca		**99** ↓	**95** ↑	**95** ↓		**90** ↓
Cl	**99** ↓	**99.9** ↓		**99.9** ↓	**99.9** ↓	**99.9** ↓
Na	**99** ↓	**99.9** ↓		**99** ↓	**99.9** ↓	**99** ↓
K		**95** ↓	**95** ↑	**99** ↓	**90** ↓	
Mg	**95** ↓	**99.9** ↓		**99.9** ↓	**99** ↓	**99** ↓

Table 12. Mann-Kendall p-values for parameter (mg/L) annual data at Region 1 NADP sites. Highlighted cells indicate statistically significant trends using $p < 0.1$.

mg/L	Clancy	Glacier	Lost Trail Pass	Craters of the Moon	Little Bighorn	Tower
NO_3^-	0.027	0.297	0.322	0.707	0.068	0.189
NH_4^+	0.006	0.003	0.029	<0.001	<0.001	0.003
cond	0.328	0.012	0.052	0.002	0.355	0.588
pH	0.542	0.315	0.433	0.348	0.771	0.646
SO_4^{2-}	<0.001	<0.001	0.343	<0.001	<0.001	0.013
Ca	0.979	0.003	0.016	0.011	0.132	0.095
Cl	0.003	<0.001	0.322	<0.001	<0.001	<0.001
Na	0.007	<0.001	0.173	0.003	<0.001	0.002
K	0.671	0.013	0.020	0.002	0.075	0.144
Mg	0.043	<0.001	0.800	<0.001	0.001	0.003

- Bob Marshall Wilderness – 1989-1994 15 lakes U. Montana
- R1 Screening Procedure 1991
- Phase 1 sampling 200 lakes 1991
- Phase 2 sampling 108 lakes 1992
- APW lake sediment CERCLA 1992 46 lakes MT Tech & U. Montana
- Phase 3 sampling 6 lakes 1993 – present
- Phase 3 sampling of phytoplankton, periphyton , 2 samples/year 1993-1996
- MAGIC modeling 6 phase 3 lakes 1996-1998
- Eilers review report 2003
- R1 AQ Monitoring Plan 2008
- SAS Analysis 2008, OC & ON parameters
- GTR 230 R1 AQ 2009

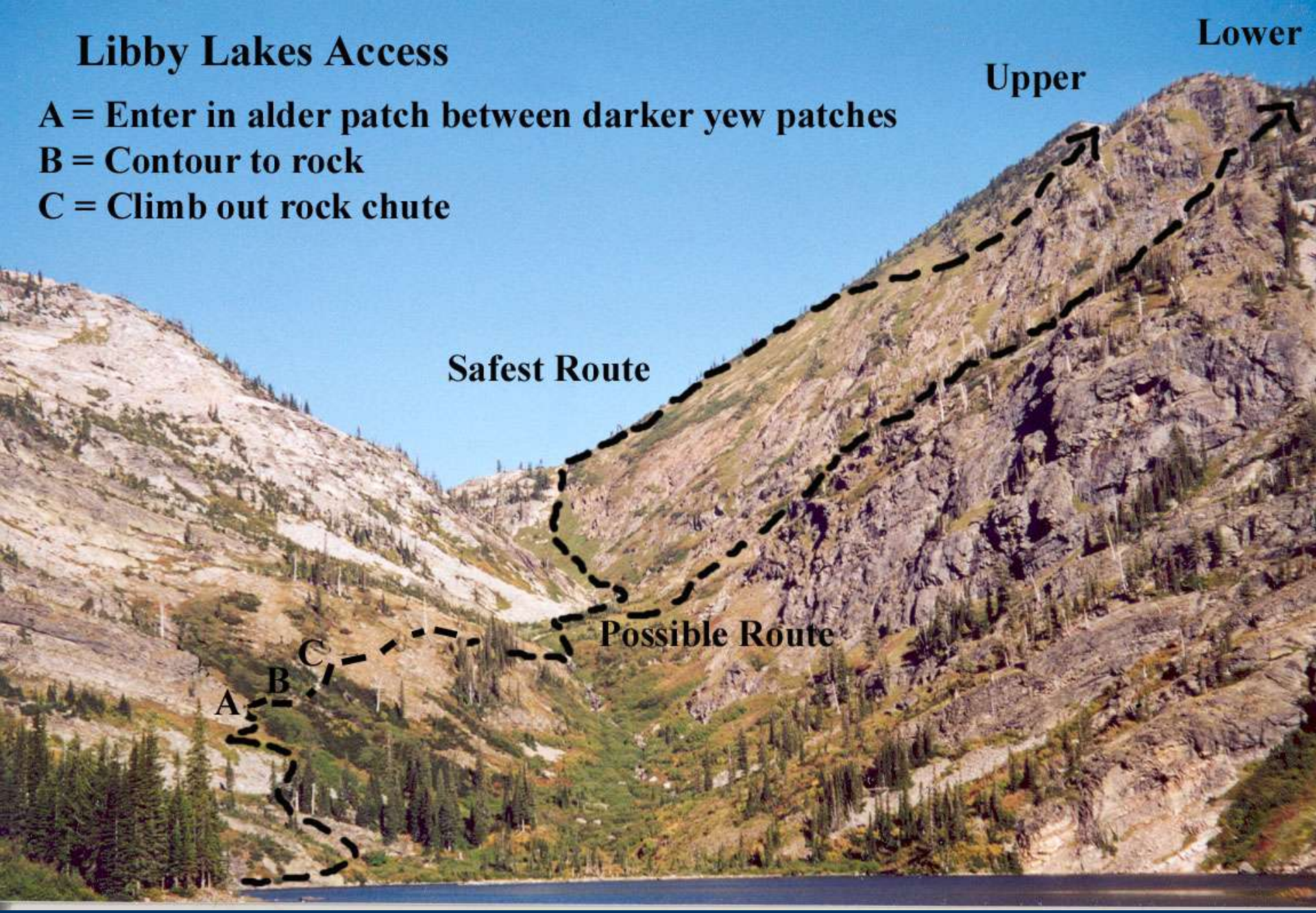
United States Department of Agriculture
Forest Service
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado 80526
General Technical Report RM-GTR-294

A Screening Procedure to Evaluate Air Pollution Effects in Region 1 Wilderness Areas, 1991

Jack Stanford
Ann Acheson
David Brakke
Sharon Eversman
Kristi Savig
Joe Eilers

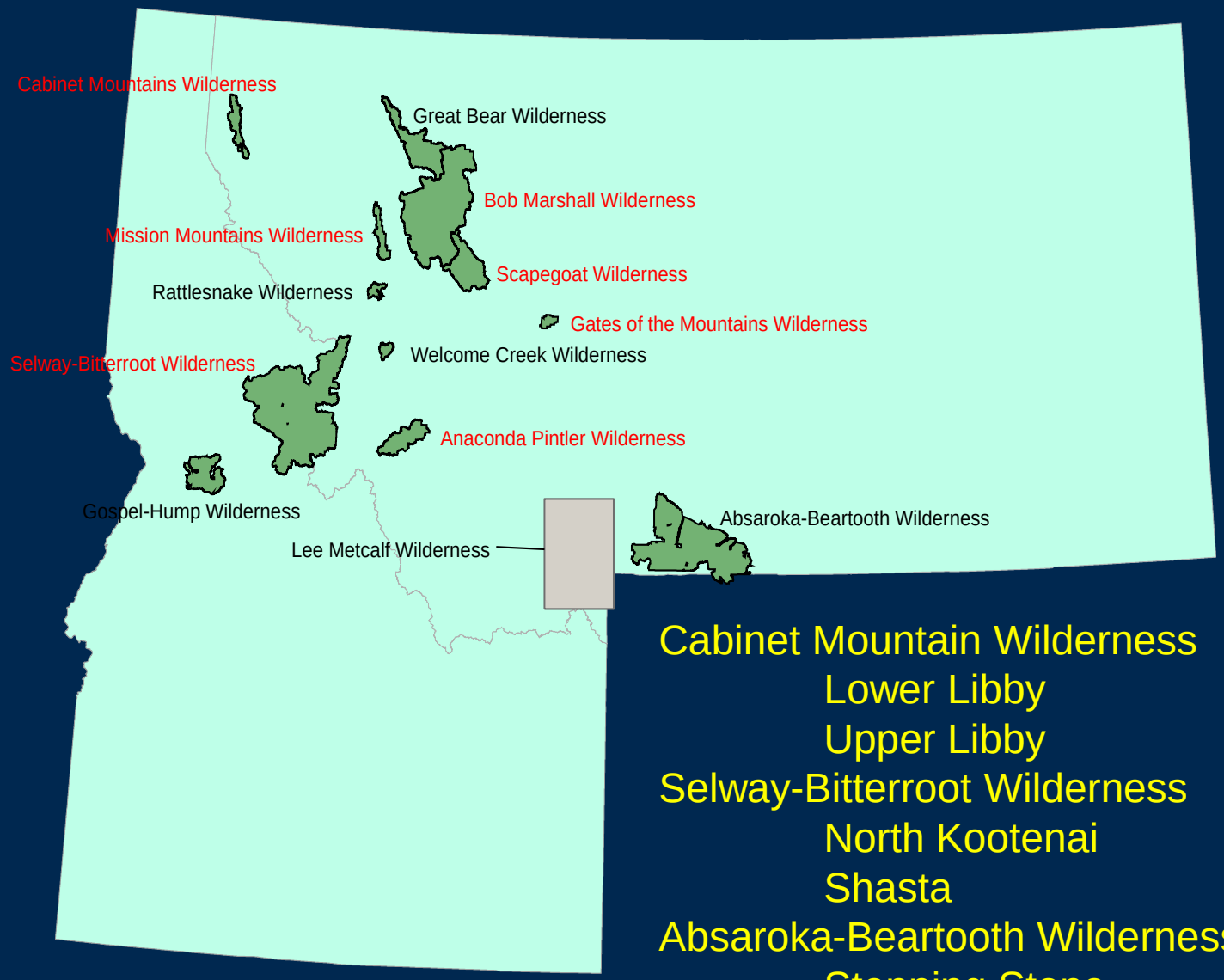
Screening parameter	Criteria (potential sensitivity)
ANC or base cations:	>200 µeq/l, negligible; 100-200, low; <100, moderate; <25, high.
pH:	>7.0, negligible; 6.4-7.0, low; <6.0-6.3 moderate; <6.0, high.
Specific conductance:	>20 µS/cm, negligible; 10-20, low; <10, high.
Anions:	$SO_4^{2-} + NO_3^-$ > 10% total base cation concentrations (µeq/l) may indicate acidic input is occurring.
Water clarity (secci depth, m)[a]:	>5 m, moderate; >10 m, high.
Total P:	<10 µg/l, moderate; <5 µg/l, high.
Al^{+n}	no criteria developed.

Screening parameter	Threshold or range	Description of LAC
ANC[a] (µeq/l)	>100	Not a sensitive indicator.
	100-10	Cumulative change should be <10% of baseline condition.
	<10	Any significant change from baseline will likely damage biota (pH ~6.0); no change allowed.
pH	>pH 7	Not a sensitive indicator.
	pH 7.0-6.0	Cumulative change should be <10% of baseline condition.
	pH 6.0	Any significant change from baseline will likely damage biota (pH ~6.0); no change allowed.
Specific Conductance		No LAC developed
Anions		
$\Sigma (SO_4^{2-}+NO_3^-)$ (µeq/l) should	ANC = 10-100	Cumulative change in anions should be < 10% of baseline concentration of total base cations; $(SO_4^{2-}+NO_3^-)$ not be elevated to >10% of total base cation[b].
Water clarity[c]		Cumulative change should be <10% of baseline condition.
Total P		No LAC developed
Al^{+n} (µg/l)		Should not be elevated to >50 µg/l


Libby Lakes Access
A = Enter in alder patch between darker yew patches
B = Contour to rock
C = Climb out rock chute
Lower
Upper
Safest Route
Possible Route
C
B
A

SAMPLE		uS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ueq/L
ID	pH	Conduct.	Na	NH4	K	Mg	Ca	F	Cl	NO2	NO3	PO4	SO4	ANC
			0.02	0.01	0.01	0.01	0.04	0.01	0.02	0.07	0.03	0.06	0.04	
Shasta Lake	6.046	3.67	0.321	0	0.04	0.048	0.257	0.001	0.029	0.001	0.000	0.000	0.088	25.4
Shasta Lake Dup	6.040	3.62	0.32	0	0.047	0.05	0.255	0.001	0.034	0.001	0.000	0.000	0.106	23.0
Shasta Lake Blank	5.592	1.16	0	0.012	0	0	0	0.001	0.005	0.001	0.000	0.002	0.010	4.0
Lower Libby Lake	6.274	2.45	0.15	0	0.049	0.064	0.256	0.000	0.033	0.000	0.000	0.000	0.138	22.0
Lower Libby Lake Dup	6.287	3.91	0.447	0	0.113	0.061	0.238	0.000	0.302	0.000	0.000	0.000	0.093	19.6
Upper Libby Lake	5.779	1.56	0.098	0	0.054	0.013	0.104	0.000	0.018	0.003	0.000	0.000	0.030	10.5
Upper Libby Lake Dup	5.840	1.7	0.108	0.004	0.067	0.016	0.078	0.000	0.033	0.000	0.000	0.002	0.016	7.6
Upper Libby Lake Blank	5.520	1.19	0	0.006	0	0	0.036	0.000	0.004	0.000	0.000	0.000	0.000	6.4
Twin Island Lake	6.449	5.65	0.199	0.023	0.143	0.101	0.468	0.009	0.084	0.000	0.000	0.003	0.327	34.8
Twin Island Lake Dup	6.501	5.33	0.209	0.019	0.136	0.106	0.473	0.008	0.074	0.000	0.000	0.000	0.311	32.8
Stepping Stone Lake	6.298	3.59	0.079	0.005	0.103	0.077	0.285	0.000	0.043	0.000	0.000	0.000	0.212	19.4
Stepping Stone Lake Dup	6.376	3.37	0.087	0	0.107	0.08	0.316	0.000	0.039	0.000	0.000	0.000	0.182	23.6
Stepping Stone Lake Blank	5.568	1.42	0	0.003	0	0	0.026	0.000	0.005	0.000	0.000	0.000	0.010	5.8
North Kootenai Lake	6.36	4.53	0.366	0	0.142	0.062	0.407	0.010	0.056	0.000	0.000	0.000	0.535	26.7
North Kootenai Lake Dup	6.33	4.34	0.358	0	0.146	0.059	0.409	0.009	0.036	0.000	0.000	0.001	0.505	25.8
North Kootenai Lake Blank	5.54	1.2	0	0.029	0	0	0.008	0.001	0.000	0.000	0.000	0.004	0.007	2.7

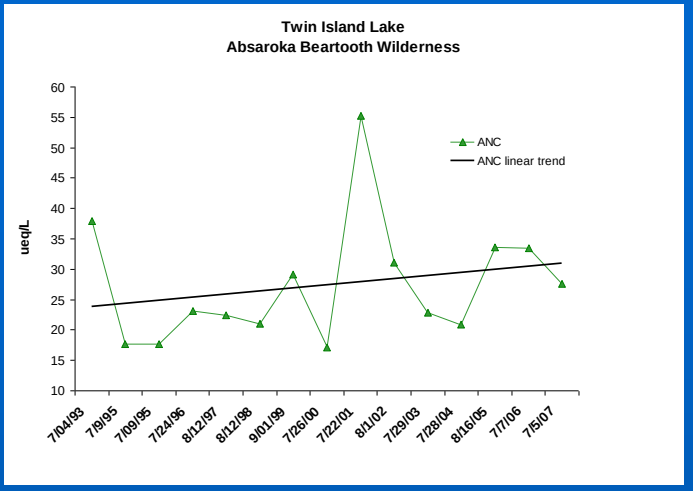
Wilderness Area	# Lakes	Avg. ANC (µeq/l)	Low ANC (µeq/l)
Absaroka-Beartooth	641	83	15
Anaconda-Pintler	100	429	46
Bob Marshall	119	811	154
Cabinet Mountains	88	169	5
Gospel Hump	86	82	24
Great Bear	36	1376	680
Hells Canyon	29	142	28
Lee Metcalf	111	232	68
Mission Mountains	151	449	73
Rattlesnake	52	214	100
River of No Return	21	93	48
Selway-Bitterroot	315	52	18

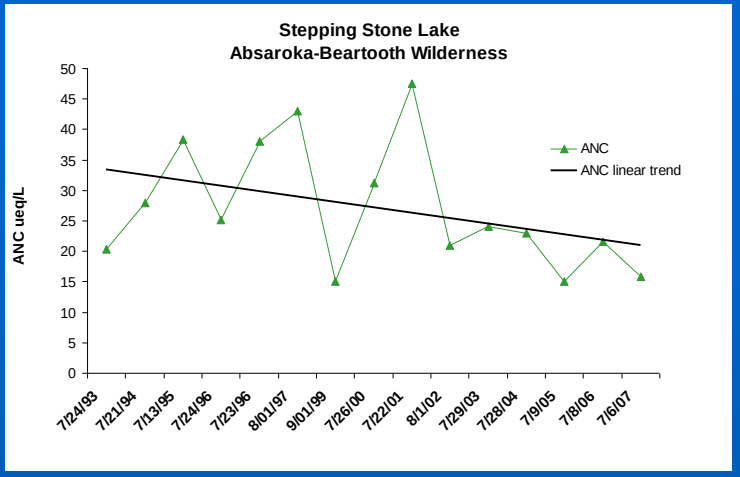


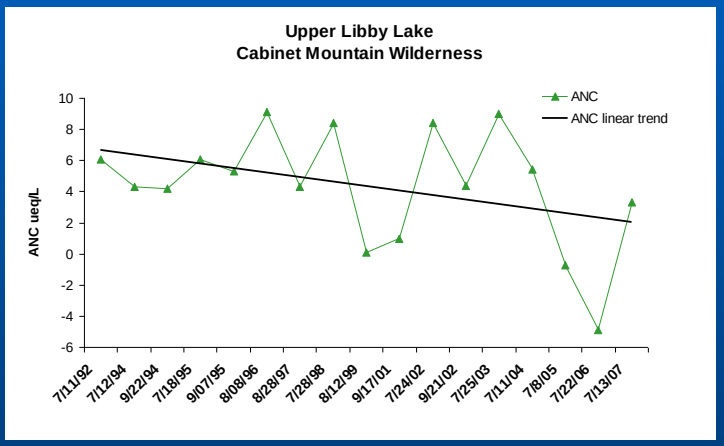
Cabinet Mountain Wilderness
- Lower Libby
- Upper Libby

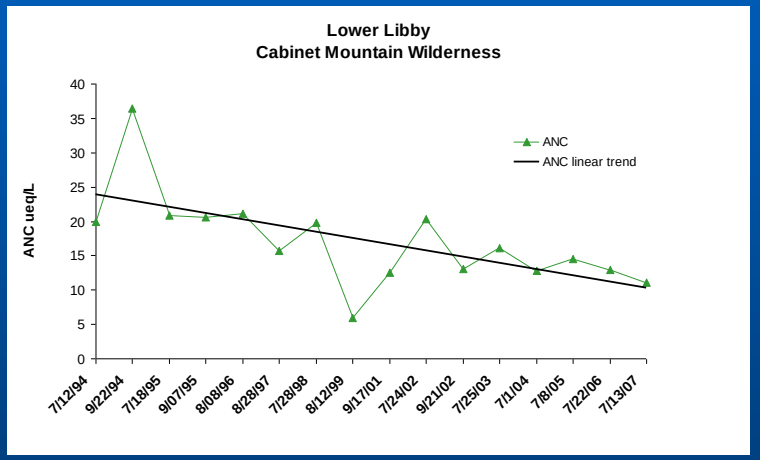
Selway-Bitterroot Wilderness
- North Kootenai
- Shasta

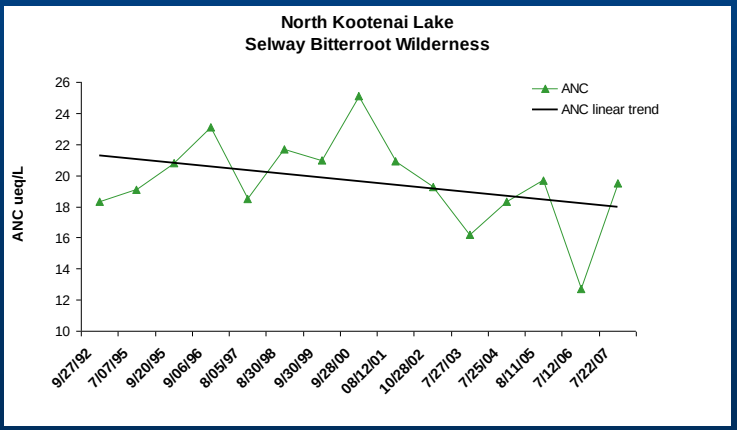
Absaroka-Beartooth Wilderness
- Stepping Stone
- Twin Island


Twin Island Lake
Absaroka Beartooth Wilderness
ueq/L
ANC
ANC linear trend
7/04/93
7/9/95
7/09/95
7/24/96
8/12/97
8/12/98
9/01/99
7/26/00
7/22/01
8/1/02
7/29/03
7/28/04
8/16/05
7/7/06
7/5/07


Stepping Stone Lake
Absaroka-Beartooth Wilderness
ANC ueq/L
ANC
ANC linear trend
7/24/93
7/21/94
7/13/95
7/24/96
7/23/96
8/01/97
9/01/99
7/26/00
7/22/01
8/1/02
7/29/03
7/28/04
7/9/05
7/8/06
7/6/07


Upper Libby Lake
Cabinet Mountain Wilderness
ANC ueq/L
ANC
ANC linear trend
7/11/92
7/12/94
9/22/94
7/18/95
9/07/95
8/08/96
8/28/97
7/28/98
8/12/99
9/17/01
7/24/02
9/21/02
7/25/03
7/11/04
7/8/05
7/22/06
7/13/07


Lower Libby
Cabinet Mountain Wilderness
ANC ueq/L
ANC
ANC linear trend
7/12/94
9/22/94
7/18/95
9/07/95
8/08/96
8/28/97
7/28/98
8/12/99
9/17/01
7/24/02
9/21/02
7/25/03
7/1/04
7/8/05
7/22/06
7/13/07


North Kootenai Lake
Selway Bitterroot Wilderness
ANC ueq/L
ANC
ANC linear trend
9/27/92
7/07/95
9/20/95
9/06/96
8/05/97
8/30/98
9/30/99
9/28/00
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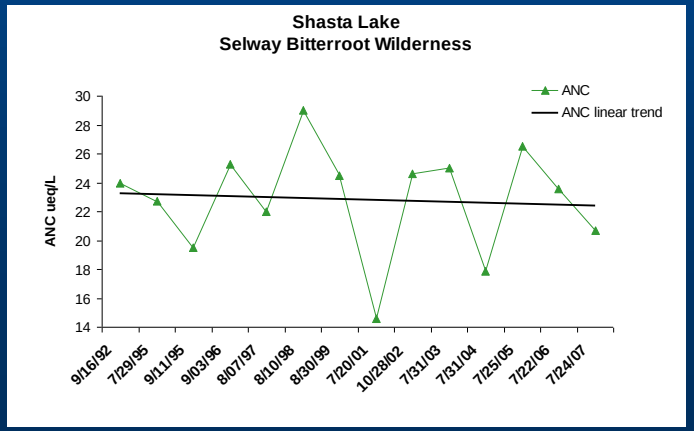
7/25/04
8/11/05
7/12/06
7/22/07

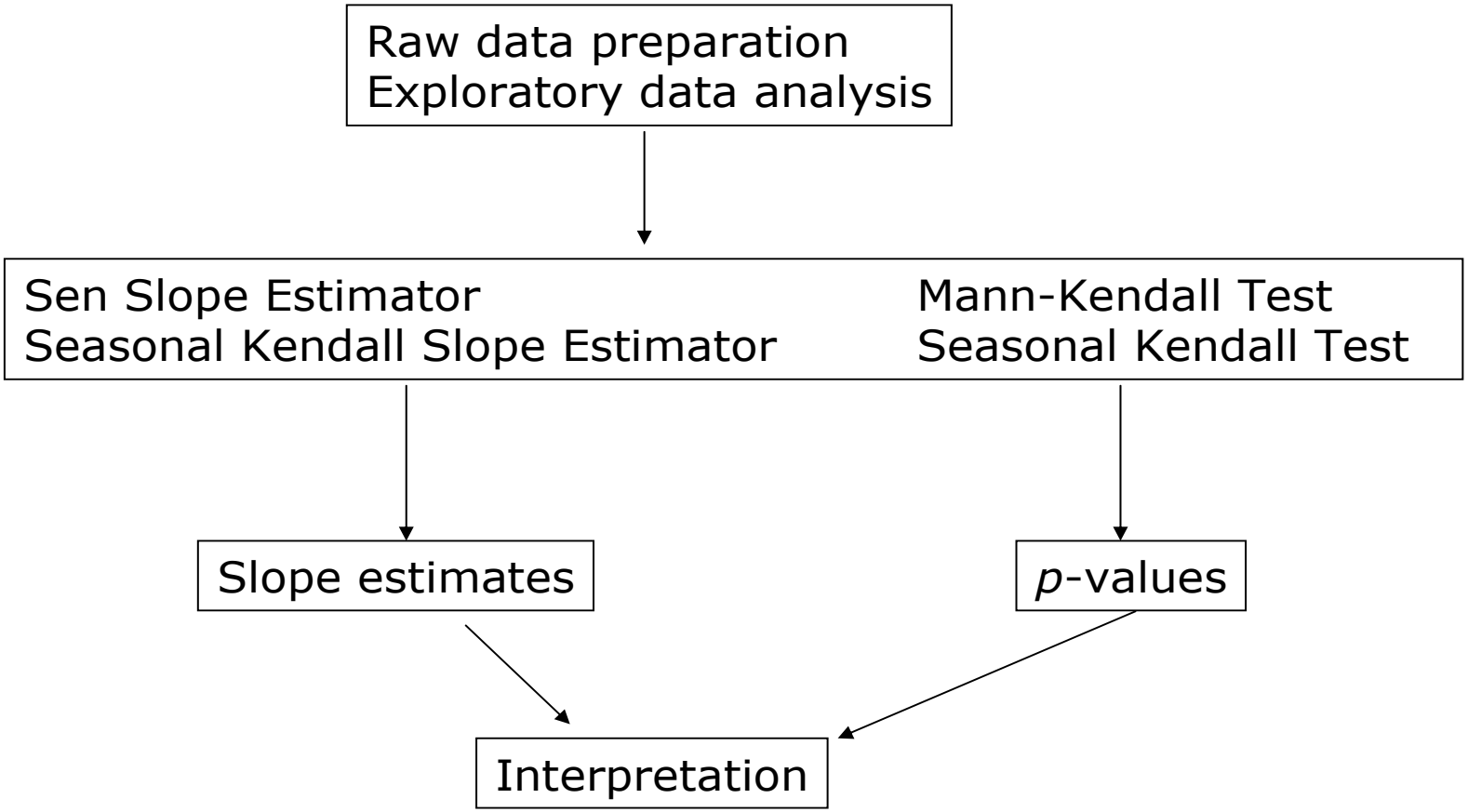

Shasta Lake
Selway Bitterroot Wilderness
ANC ueq/L
ANC
ANC linear trend
9/16/92
7/29/95
9/11/95
9/03/96
8/07/97
8/10/98
8/30/99
7/20/01
10/28/02
7/31/03
7/31/04
7/25/05
7/22/06
7/24/07

Statistics

- SAS Institute statistical software was used to run analyses following draft USFS Data Analysis Protocol (DAP) recommendations in coordination with Lori Porth, RMRS Statistician

- Non-parametric test that can work with non-normal distributions and are not affected by errors, gross outliers, or missing data in the data set.

- A trend is detectable and considered significant if it meets our designated alpha level of $\alpha = 0.1$ also shown as 90% confidence level. Additional confidence levels used were 95 ($\alpha = 0.05$), 99 ($\alpha = 0.01$), and 99.9 ($\alpha = 0.001$). (Salmi et.al 2002).



Flow diagram depicting temporal trend analysis protocol (Gurrieri 2006)

Statistical Tests Used

- Mann-Kendall- run to see if there were significant trends for each parameter
- Kruskal-Wallace- run to see if seasons in the data set were statistically different
- Seasonal Mann-Kendall-run to look for trends while taking seasonality into account
- Sens slope estimator- magnitude of slope

Table 9. Percent confidence level and trend direction for lake sampling data.

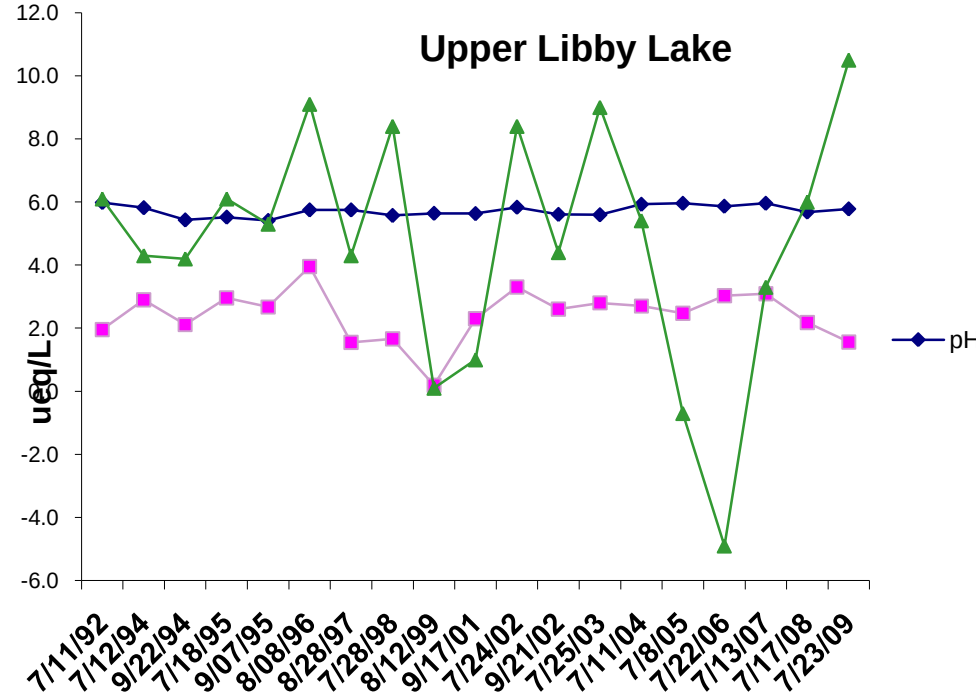
The ↑ symbolizes an increasing trend and the ↓ marks a decreasing trend. The numbers equal the percent confidence that a trend of statistical significance exists. 99 also means $\alpha = 0.01$, 95 means $\alpha = 0.05$, etc.

mg/L	Lower Libby	Upper Libby	N. Kootenai	Shasta	Stepping Stone	Twin Island
ANC					99 ↓	
Cond				95 ↓	95 ↓	
NH_{4+}						
NO_3-				95 ↑		
pH					99 ↑	99 ↑
$SO_{4=}$	95 ↓					
Ca						
Cl			95 ↓		99 ↓	

Table 10. Mann-Kendall p-values for annual lake data

Highlighted cells indicate statistically significant trends using $p < 0.1$.

parameter	Lower Libby	Upper Libby	N. Kootenai	Shasta	Stepping Stone	Twin Island
ANC	0.138	0.428	0.767	0.246	0.002	0.381
Conductivity	0.621	0.882	0.198	0.032	0.042	0.956
NH_{4+}	0.368	0.519	0.714	0.136	0.487	0.442
NO_3-	0.686	0.725	0.313	0.030	0.450	0.856
pH	0.620	0.843	0.373	0.219	0.038	0.010
$SO_{4=}$	0.047	0.113	0.767	0.582	0.843	0.228
Ca	0.552	1	0.692	0.246	0.656	0.274
Cl	0.276	1	0.048	0.583	0.003	0.827


Upper Libby Lake
12.0
10.0
8.0
6.0
4.0
2.0
-2.0
-4.0
-6.0
ueq/L
pH
7/11/92
7/12/94
9/22/94
7/18/95
9/07/95
8/08/96
8/28/97
7/28/98
8/12/99
9/17/01
7/24/02
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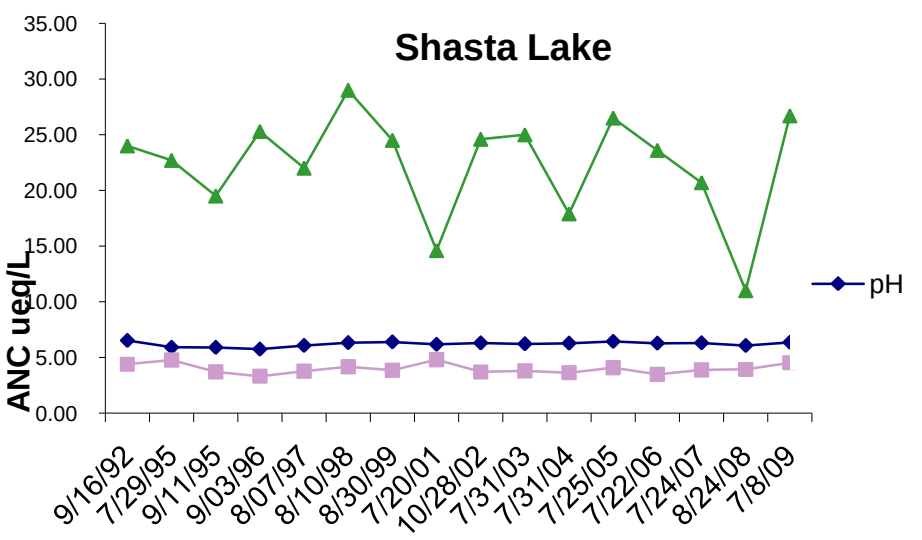
7/22/06
7/13/07
7/17/08
7/23/09


Shasta Lake
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
ANC ueq/L
pH
9/16/92
7/29/95
9/11/95
9/03/96
8/07/97
8/10/98
8/30/99
7/20/01
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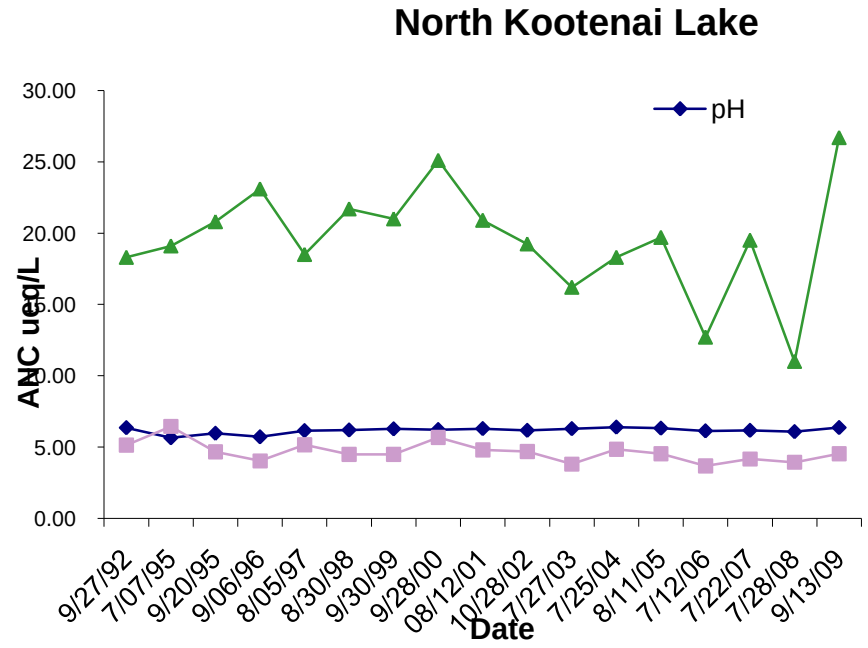
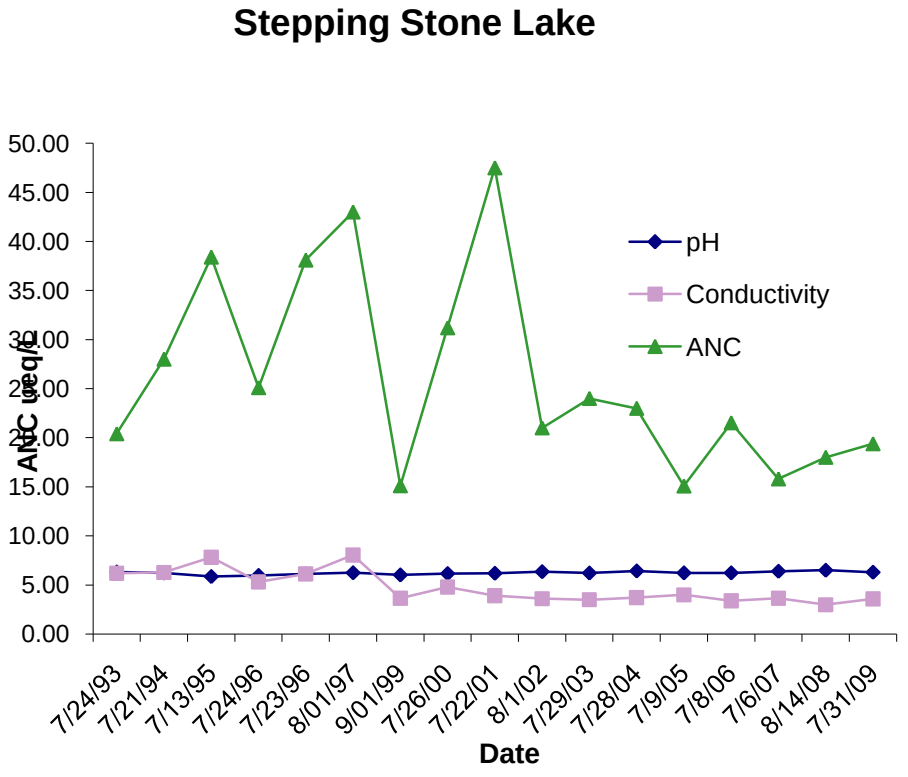
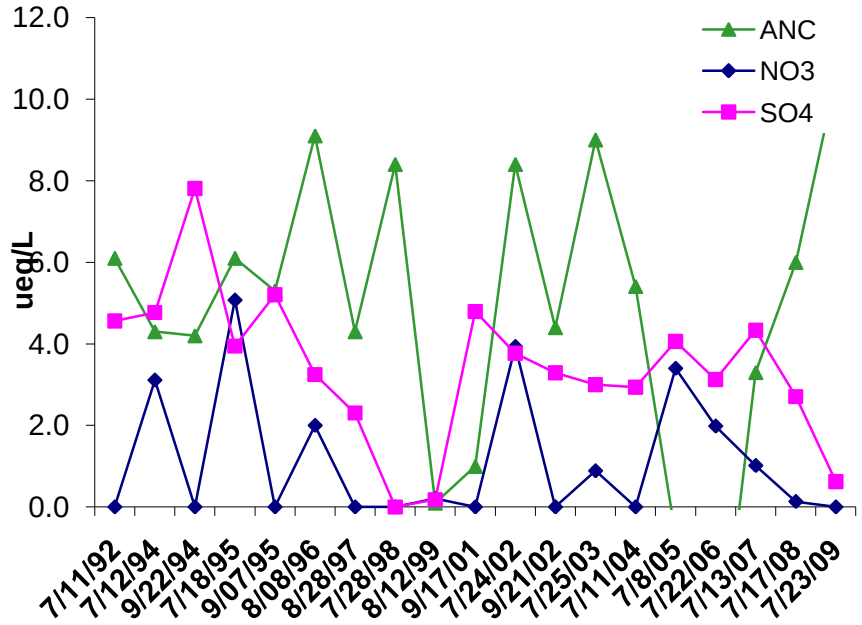
7/22/06
7/24/07
8/24/08
7/8/09

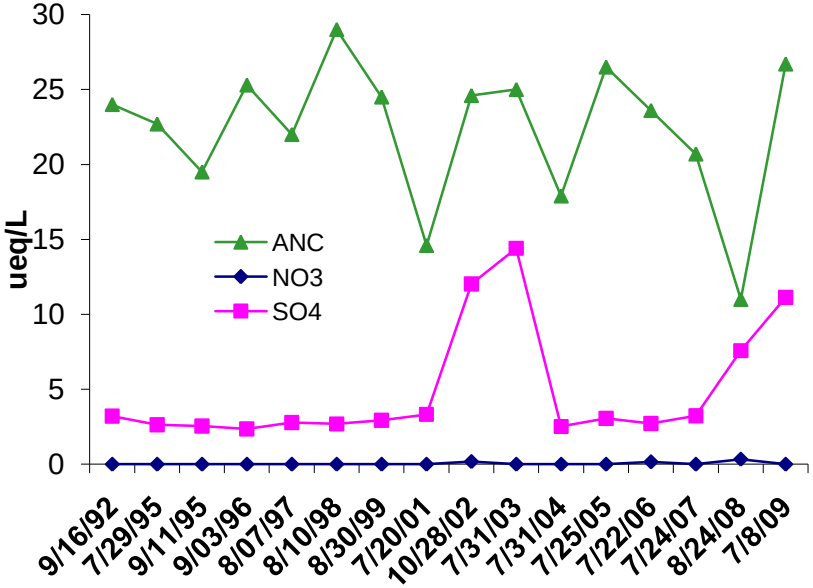

North Kootenai Lake
30.00
25.00
20.00
15.00
10.00
5.00
0.00
ANC ueq/L
pH
9/27/92
7/07/95
9/20/95
9/06/96
8/05/97
8/30/98
9/30/99
9/28/00
08/12/01
10/28/02
7/27/03
7/25/04
8/11/05
7/12/06
7/22/07
7/28/08
9/13/09
Date


Stepping Stone Lake
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
ANC ueq/L
pH
Conductivity
ANC
7/24/93
7/21/94
7/13/95
7/24/96
7/23/96
8/01/97
9/01/99
7/26/00
7/22/01
8/1/02
7/29/03
7/28/04
7/9/05
7/8/06
7/6/07
8/14/08
7/31/09
Date

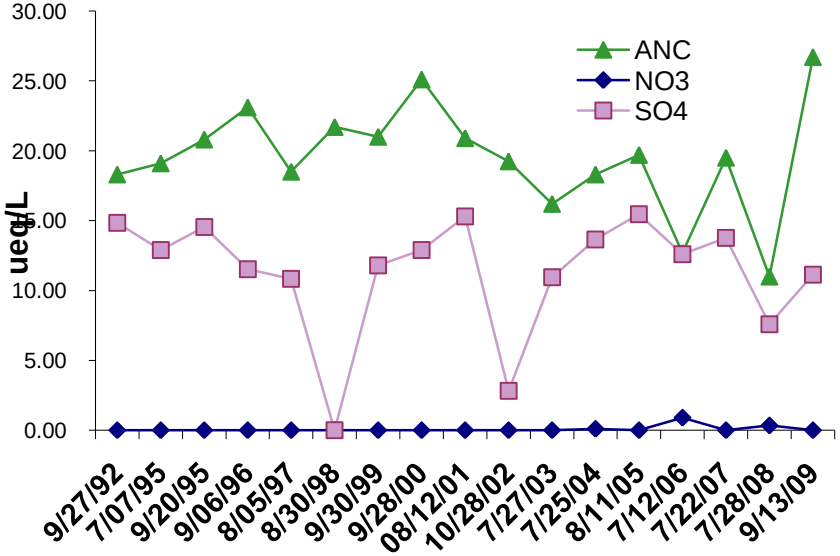
Upper Libby Lake



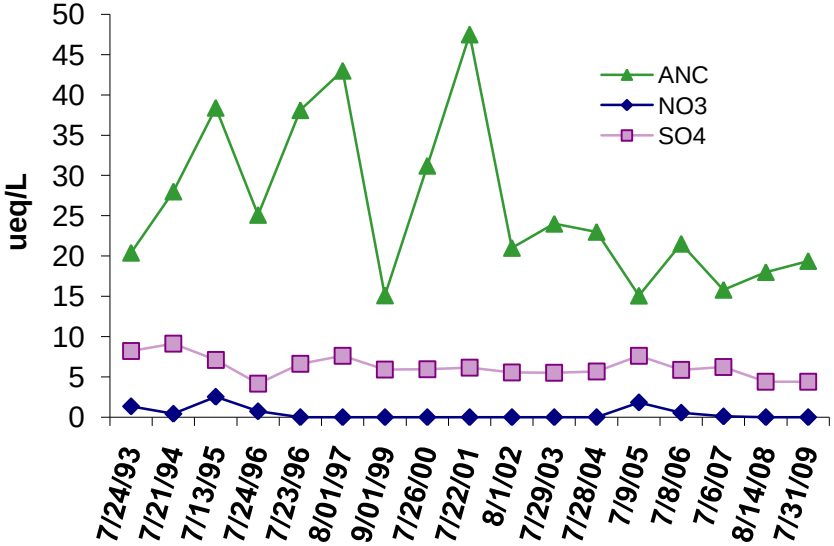
Shasta Lake

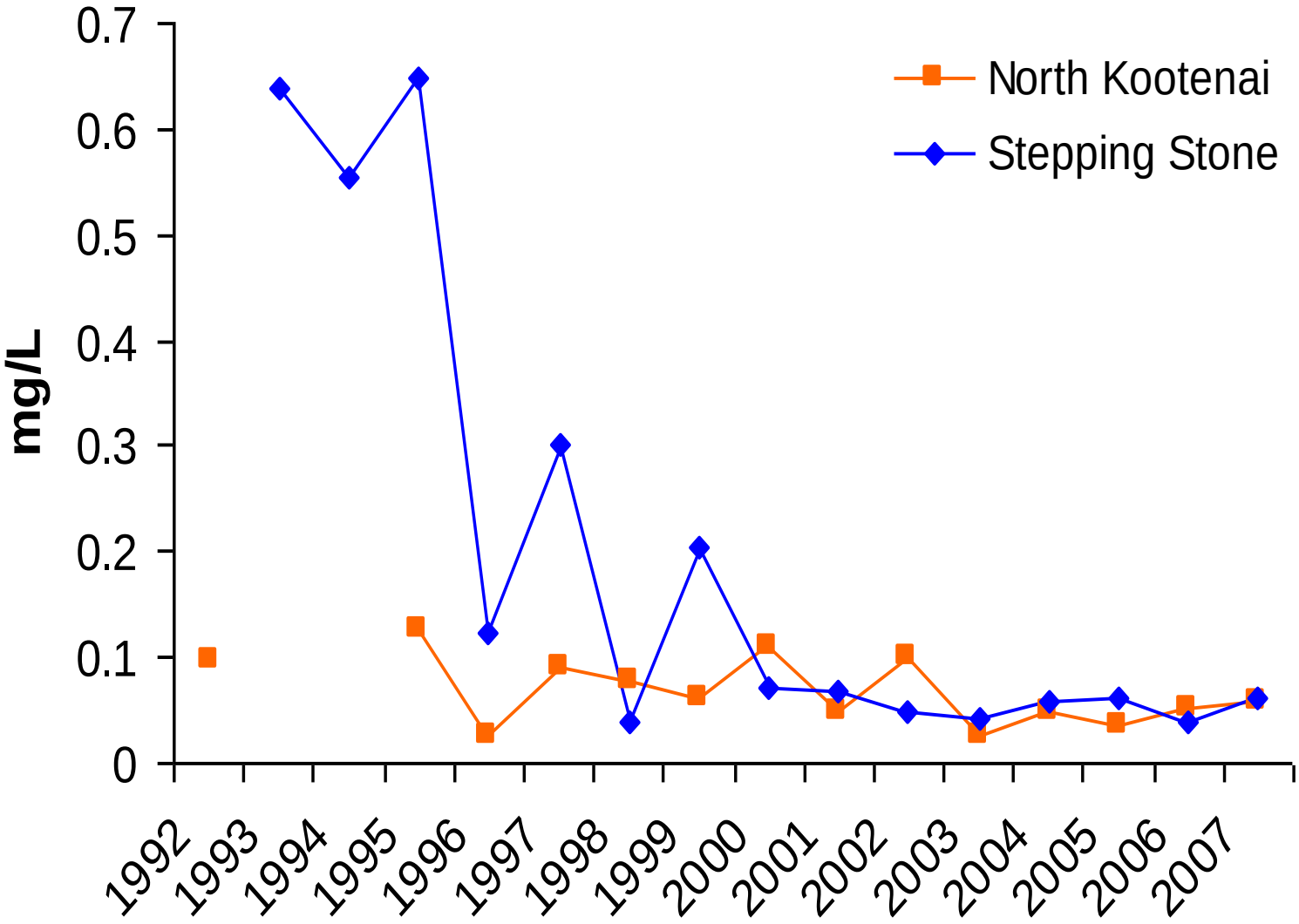


North Kootenai Lake

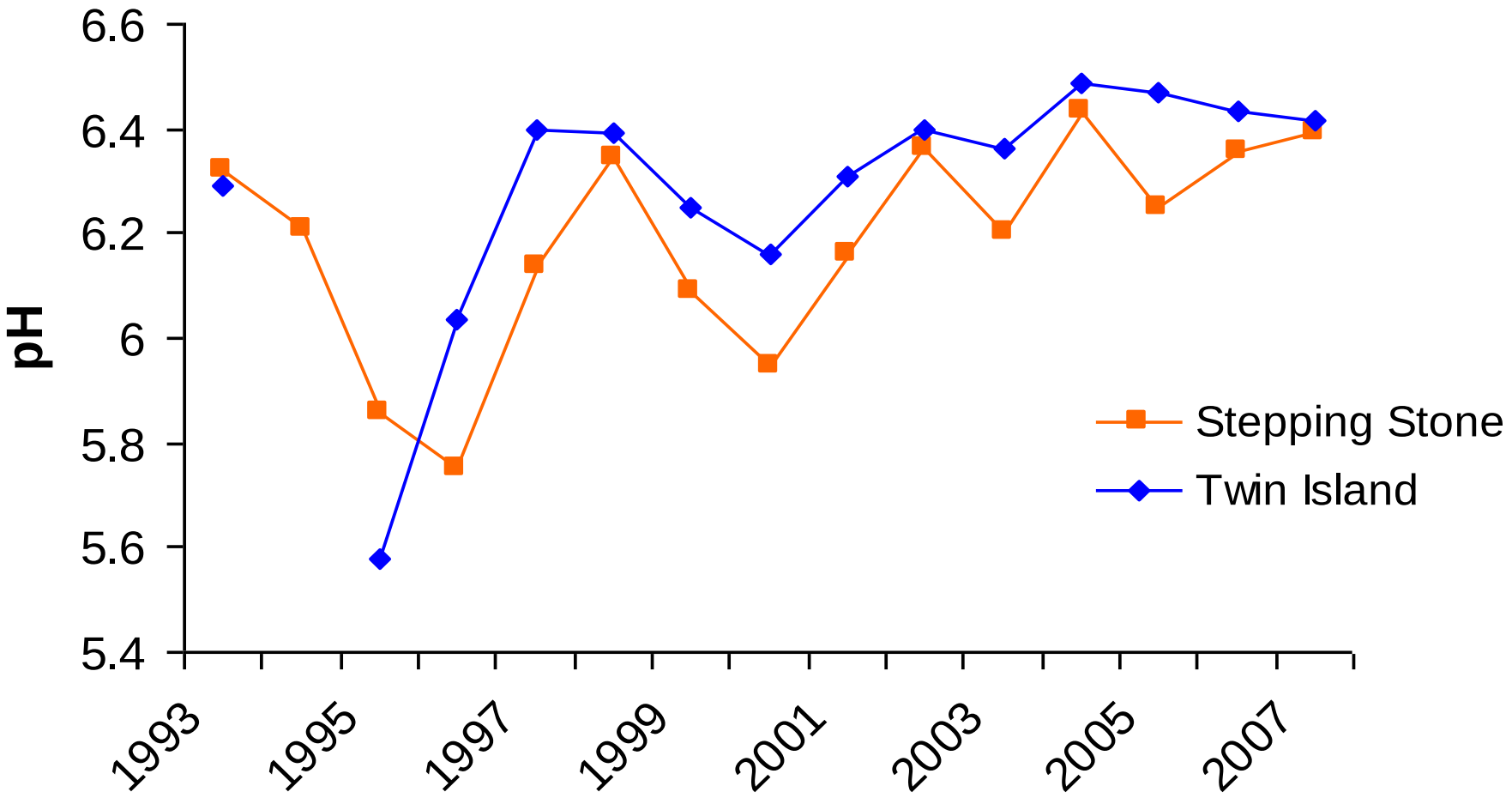


Stepping Stone Lake Absaroka-Beartooth Wilderness



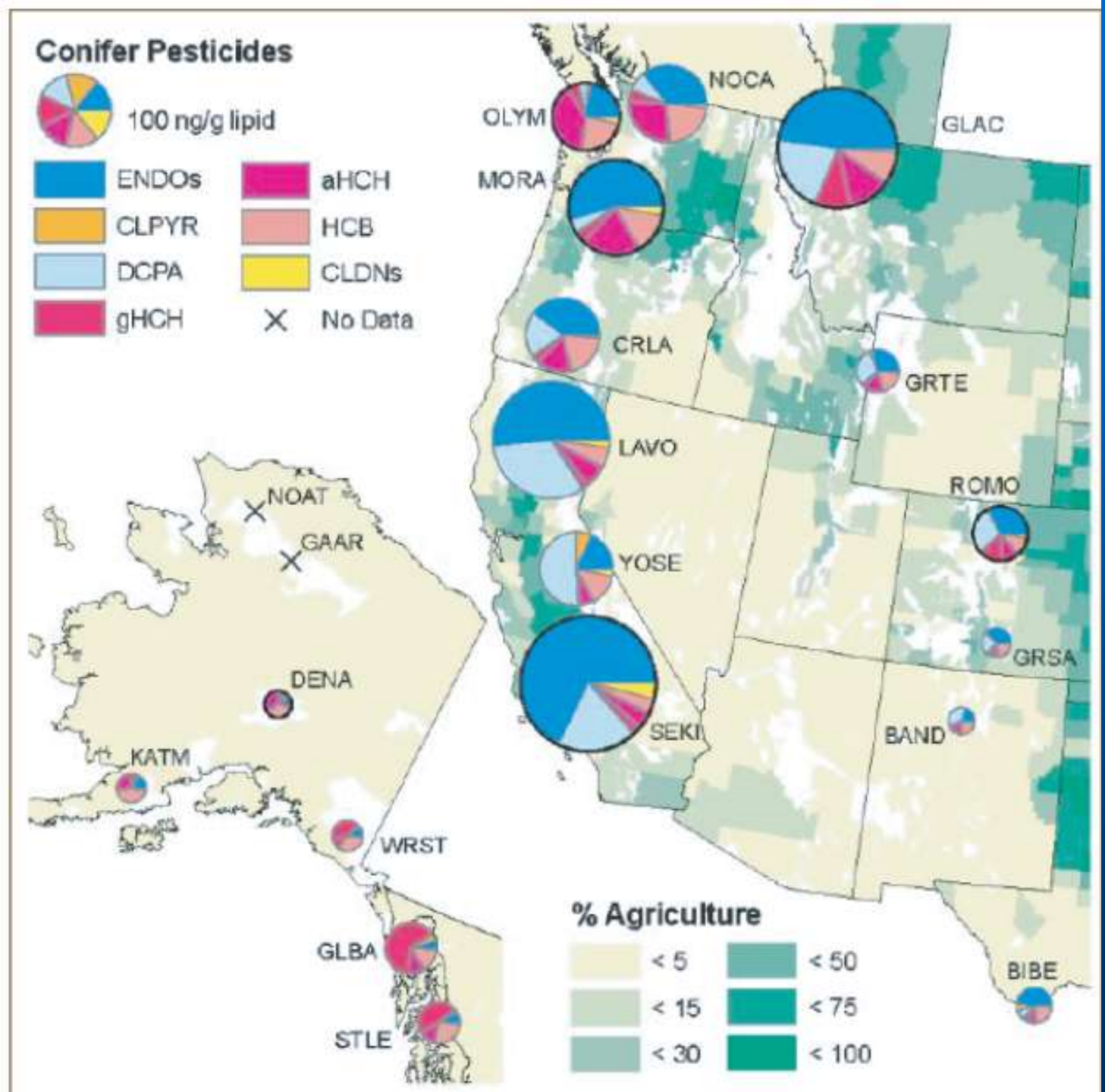


Trends in lake Chloride concentrations.


6.6
6.4
6.2
6
5.8
5.6
5.4
pH
1993
1995
1997
1999
2001
2003
2005
2007
Stepping Stone
Twin Island

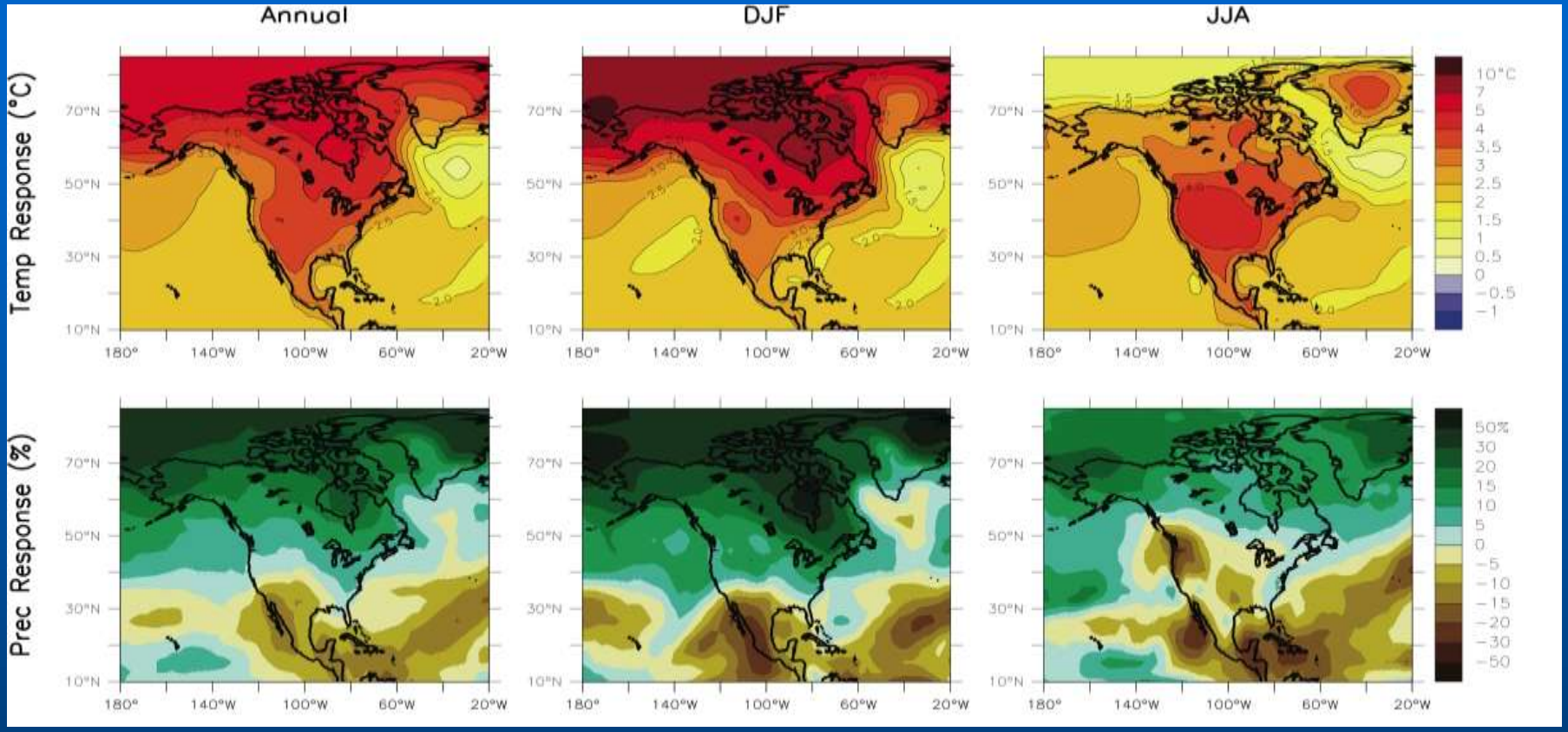
Conclusions

- Trend interpretation, particularly cause/effect, is difficult and complex
- Lake ANC decrease not statistically validated except at Stepping Stone Lake. The pH increasing trend and decrease in lake cation trends are not readily explainable.
- Consistent NH4 increase trend at all of the NADP sites. This may be partially due to increased agriculture emissions such as feedlots in E. Oregon and E. Washington
- Non-detect to low NO3 levels
- Consistent decrease SO4 at NADP sites is consistent with US trends the last 2 decades with reduced industrial sulfate emissions
- Consistent improvement in visibility at all of the IMPROVE sites as expressed in increased SVR, decreased deciviews, and reduced extinction. Lower visibility years coorelate with high wildfire activity.



Western Airborn Contaminants Project
NPS - 2009

Climate Projections for North America



Northern Rockies: Roughly 3-4 F average annual warming by 2050 and 6° F by 2100; no change to ~ 5% increase in annual precipitation; Drier summers and slightly wetter winters (DJF); Potential for more dramatic extremes.

Management Differences

Stillwater Mining Company smelter improved S02 controls and smelter relocation to Columbus 1993

MAGIC model defense of Rock Creek Mine/Montana DEQ vs. Cabinet Resources Group litigation 2000

multiple PSD use of MAGIC model & R2 ΔANC (Montana DEQ and PSD consultants)

BLM cumulative effects air quality analysis contracts – MAGIC model evaluations of ABW lakes

support for AQRV monitoring – Wilderness Stewardship Challenge

Unknowns and Questions?

nitrogen saturation?

yearly variability?

seasonality?

NADP/ USGS snow chemistry ammonia, sulfate, mercury elevated levels in west-central Montana?

trace airborn contaminants?

Reduction in Ca, Na, K, Mg, Cl at NADP sites?

Biological parameters? (plankton, periphyton, macro-invertebratres)

organic nitrogen and organic carbon?

climate change effects?