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

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Abstract

This report was developed to address the need for comprehensive analysis of U.S. Forest Service (USFS) Region 1 air quality monitoring data. The monitoring data includes Phase 3 (long-term data) lakes, National Atmospheric Deposition Program (NADP), and Interagency Monitoring of Protected Visual Environments (IMPROVE). Annual and seasonal data for the periods of record were evaluated for trends using non-parametric (SAS) protocols. The most significant trends were the consistent decrease in SO_4^{2-} and increase in NH_4^+ at the NADP sites. Standard visual Range increased and extinction decreased at all the IMPROVE sites. Annual visibility was reduced during years of heavy wildland fire. In conclusion, considerations were listed regarding current and future monitoring and National Forest air quality protection including lake sampling protocols, and NADP and IMPROVE site continuation.

Keywords: Northern Rocky Mountain air quality, NADP, IMPROVE, lake chemistry, SAS, air quality trends

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

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Current Monitoring

The U.S. Forest Service (USFS) Region 1 Air Quality program has been actively monitoring air quality related values (AQRVs) and wilderness air quality values (WAQVs) since 1989. Formal AQRV monitoring plans for regional Class I Wilderness areas were developed between 1989 and 1996. For Class II Wilderness areas, formal WAQV plans were developed in 2007 and 2008 in accordance with the Ten Year Wilderness Challenge. Towns and wilderness areas within USFS Region 1 are shown in figure 1. Table 1 summarizes the history of AQRV and WAQV planning for the region's wilderness.

Class 1 plans are available in hard copy from Mark Story, Gallatin NF, Bozeman, Montana. Class II WAQV plans are posted on the USFS Air Quality website, (http://www.fs.fed.us/r1/gallatin/resources/air/aq_plans/). The website also includes the USFS Region 1 AQRV/WAQV Monitoring Plan (Story and others 2008).

Criteria Pollutants

The Clean Air Act designated that criteria pollutants are sulfur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), carbon monoxide (CO), lead (Pb), and particulate matter (PM_{10} and $PM_{2.5}$).

These pollutants are known to adversely affect plant life, water quality, aquatic species, health of humans and wildlife, and visibility. Sources of sulfur dioxide and lead are generally associated with urbanization and industrialization rather than with natural resource management activities or wildland fires. Wildland fires and natural resource management activities (such as timber harvest, road construction, site preparation, and mining) generate NO_x, CO, O_3, PM_{10}, and $PM_{2.5}$. A series of large wildland fires can generate NO_x emissions comparable to the total annual statewide contributions by industry and vehicles. Ozone can be a by-product of fire, although high O_3 exposures are infrequent (Sandberg and Dost 1990).

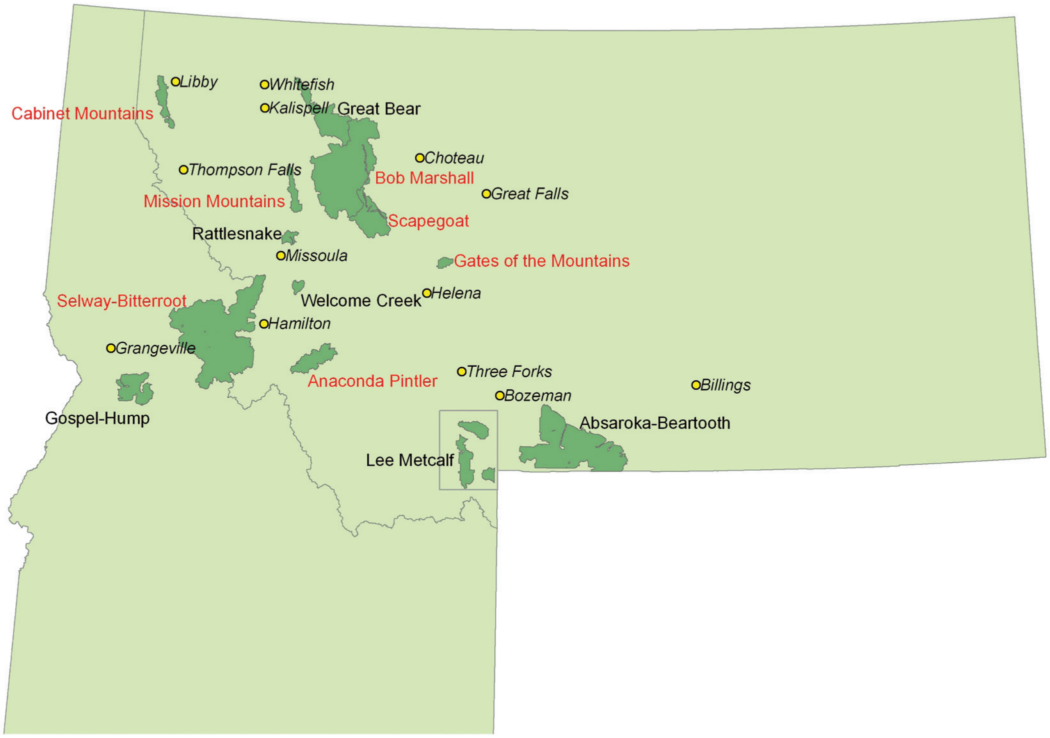

Figure 1—Towns and wilderness areas within USFS Region 1.

Table 1—Information for Class I and II wilderness areas in USFS Region 1 and their corresponding air quality plans.

Wilderness area	Class	Year of wilderness designation	Size acres	AQRV or WAQV plan	Plan date
Bob Marshall (BMW)	1	9/3/1964	1,009,356	Bob Marshall Wilderness Air Quality Related Values Management Plan	6/5/1989
Cabinet Mountains (CMW)	1	9/3/1964	94,272	Air Quality Related Values Management Plan for the Cabinet Mountains Wilderness Area Montana	6/1/1993
Gates of the Mountains (GMW)	1	9/3/1964	28,562	Air Quality Related Values Management Plan for the Gates of the Mountains Wilderness Area	12/31/1994
Selway-Bitterroot (SBW)	1	9/3/1964	1,340,502	Air Quality Related Values Management Plan for the Selway-Bitterroot Wilderness Area Idaho-Montana	7/29/1994
Anaconda-Pintler (APW)	1	9/3/1964	158,615	Air Quality Related Values Management Plan for the Anaconda-Pintler Wilderness	3/1/1995
Scapegoat (SGW)	1	9/3/1964	239,936	Air Quality Related Values Management Plan for Scapegoat Wilderness	12/1995
Mission Mountains (MMW)	1	9/3/1964	73,877	Air Quality Related Values Management Plan for the Mission Mountains Wilderness Area	6/1/1996
Absaroka- Beartooth (ABW)	2	3/27/1978	943,626	Wilderness Air Quality Value WAQV Class II Monitoring Plan Absaroka Beartooth Wilderness Lee Metcalf Wilderness	1/9/2008
Lee Metcalf (LMW)	2	10/21/1983	254,288		
Rattlesnake (RW)	2	10/19/1980	32,976	Wilderness Air Quality Value WAQV Class II Monitoring Plan Rattlesnake and Welcome Creek Wilderness Areas	12/20/2007
Welcome Creek (WCW)	2	2 /24/1978	28,135		
Great Bear (GBW)	2	10//28/1978	286,700	Wilderness Air Quality Value WAQV Class II Monitoring Plan Great Bear Wilderness	4/3/2007
Gospel Hump (GHW)	2	2 /24/1978.	206,053	Wilderness Air Quality Value WAQV Class II Monitoring Plan Gospel Hump Wilderness Area	1/9/2008

The EPA is recommending a secondary O_3 standard that will protect vegetation and animals (http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_sp.html). Carbon monoxide is rapidly diluted at short distances from a burning area, as fires are generally spatially and temporally dispersed, and pose little or no risk to public health (Sandberg and Dost 1990).

The pollutant of most concern to public health and visibility impairment is particulate matter. The National Ambient Air Quality Standard (NAAQS) (http://www.epa.gov/ttn/naaqs/) for PM2.5 is 35 $\mu g/m^3$ (micrograms per cubic meter) averaged over 24 hrs, and an average annual arithmetic $PM_{2.5}$ concentration of 15 $\mu g/m^3$. The Montana air quality State Implementation plan (SIP) for particulates is promulgated through the Montana Clean Air Act and implementing regulations. The regulations provide specific guidance on maintenance of air quality including restrictions on open burning. The Act created the Montana Air Quality Bureau (now the DEQ) and the regulatory authority to implement and enforce the codified regulations.

USFS R1 Air Pollution Sources

Air quality in and around USFS R1 wilderness areas is generally good, impacted primarily by episodes of wildland fire smoke and long range transport. The EPA Aerometric Information Retrieval System (AIRS) data base (http://www.epa.gov/air/data/netemis.html) was queried for all stationary permitted sources of air emissions more than 50 tons/year. This database was last updated in 1999; emissions may now be higher or lower than initially recorded.

Total permitted emissions (>50 ton/year/source) in counties within approximately 60 miles of USFS R1 wildernesses or wilderness complexes are recorded in table 2.

The Absaroka Beartooth (ABW) and Lee Metcalf (LMW) Wildernesses have the highest amount of permitted NO_x, and SO_2, due to the petroleum refineries in Billings and Laurel. Most of these emissions disperse to the east of the ABW. The Bob Marshall wilderness has the highest exposure to CO and PM_{10} emissions due to its proximity to the Columbia Falls aluminum plant. That facility is currently operating on a reduced schedule; therefore, emissions are currently lower than table 2 depicts. More detailed data regarding emissions within 60 miles of R1 wilderness areas or complexes are presented in tables 3 to 8.

Absaroka Beartooth and Lee Metchalf Emission Sources

Existing sources of emissions in the ABW and LMW wilderness areas (table 3) include dust from trails and campsites and smoke emissions from wildland fires and prescribed burns. Adjacent area emissions include occasional construction equipment, vehicles, road dust, residential wood burning, wood fires, and smoke from logging slash disposal, prescribed burns, and wildland fires. The Spanish Peaks unit of the LMW receives vehicle, residential, construction, and ski area emissions from the Big Sky area. Down valley airflow in the ABW and LMW drainages is frequently strong during nighttime and early morning hours.

The Billings and Laurel sources are currently permitted annual emissions of 1,928 tons of PM_{10} and 16,481 tons of $S0_2$. Laurel is in non-attainment for $S0_2$ (http://www.deq.mt.gov/AirQuality/Planning/AirNonattainment.asp). Except for occasional upslope, high velocity, east winds, most of the Billings/Laurel emissions are carried to the east and away from the ABW by the predominant west-to-southwest winds. The major sources of emissions affecting the ABW are the cities of Big Timber, Livingston, and Bozeman with vehicle exhaust, wood burning smoke, and road dust. These communities are in compliance with all NAAQS. Big Timber, Livingston, and Bozeman emissions do not visibly impact the ABW. These emissions are dispersed by predominant southern and southwestern winds that come from robust Yellowstone valley wind gradients that typically carry emissions north of the ABW. Other types of emissions in the Yellowstone valley that could affect the ABW include vehicle and agriculture equipment exhaust, road dust, smoke from residential wood burning, and smoke from pile burning, broadcast burning, and wildland fires.

The city of Bozeman is the major source of emissions from the Gallatin valley, north of the LMW. Smaller amounts of emissions occur from Belgrade and Three Forks/Willow Creek and from vehicles on Interstate 90 and Highways 191, 345, and 287. Bozeman emissions do not visibly impact LMW since these emissions are dispersed by predominant westerly and southwesterly wind direction.

Table 2—Emission sources greater than 50 tons/year within 60 miles of USFS R1 wildernesses.

Wilderness	CO	NO_x	PM_{10}	SO_2
	Tons per year			
Absaroka Beartooth (ABW) & Lee Metcalf (LMW)	2,038	5,442	1,259	13,521
Gates of the Mountains (GMW)	778	1,789	1,093	564
Bob Marshall (BMW), Scapegoat (SGW), Great Bear (GBW), Mission Mountains (MMW)	36,347	753	2,512	1,421
Cabinet Mountains (CMW)	1,191	52	303	6
Rattlesnake (RW), Welcome Creek (WCW), Eastern Selway Bitterroot (SBW) and Anaconda Pintler Wilderness (APW)	4,158	2,935	1,327	166
Gospel Hump (GHW) and Western (SBW)	1,150	392	204	22

Table 3—Emission sources greater than 50 tons/year within 60 miles of the Absaroka Beartooth (ABW) and Lee Metcalf (LMW) Wildernesses.

CO	NO_x	PM_{10}	SO_2	Facility name	Location	Industry type
tons per year						
542	11.9	1.52	1,137	Montana Sulfur & Chemical	Billings	inorganic chemicals
386	905	184	3,197	Centex	Laurel	petroleum refining
293	697	155	1,222	ConocoPhillips	Billings	petroleum refining
205	1,504	127	2,698	Pal, Montana - J.E. Curette Plant	Billings	electric services
191	324	60.3	74.7	Western Sugar	Billings	beet sugar
149	41.5	63.3	2.21	Louisiana-Pacific - Belgrade	Belgrade	sawmill
134	733	291	2,894	Exxon	Billings	petroleum refining
42.5	3.12	40.0	24.4	Jell Group	Belgrade	paving mixtures
31.0	685	213	192	Holcim, Inc.	Three Forks	cement
29.8	448	22.8	2,073	Yellowstone Energy Limited	Billings	electric services
23.9	55.4	46.4	6.03	Stillwater Mining Co - E. Boulder	Mcleod	metal ores
6.62	23.4	22.8	0.48	Barretts Minerals Inc.	Dillon	minerals
4.30	10.5	32.2	0.24	Luzenac America - Three Forks	Three Forks	talc
2,038	5,442	1,259	13,521	Total		

In the evenings, air flows down drainages from the north end of the Gallatin valley, carrying Bozeman emissions north and west. This process is particularly noticeable in the winter when frequent inversions constrain mixing heights over Bozeman and air pollutants drift down the Gallatin valley toward Belgrade.

Regional wildland fire smoke accumulated in the ABW and LMW area during periods of extensive wildland fire activity in 1988, 1994, 2000, 2003, 2006, and 2007. The primary sources of wildland fire emissions are central and southern Idaho and southwest Montana. Smoke from wildland fires in Yellowstone National Park can also impact the ABW and LMW area, as occurred in 1988.

Generally the ABW and LMW areas do not develop temperature inversions that trap smoke and reduce its dispersal. Dispersion of emissions within the ABW and LMW is very high due to the mountainous terrain and high wind activity. The Main Boulder Canyon, Gallatin Canyon, and the West Fork Gallatin (Big Sky) have some potential for inversion and cumulative concentrations of smoke and residential and transportation emissions. Visible inversion conditions occasionally occur in the Big Sky area, which has been designated as the Big Sky Impact Zone by the Montana DEQ (http://www.deq.state.mt.us/AirQuality/Planning/MONTANA_SMOKE_MGNT_impact_zone.htm).

Due to temperature and density differences, winds typically flow up valleys and up mountain slopes during the daytime and reverse direction during the cooler hours of the evening and night. Mountain winds in the ABW and LMW area are usually stronger than valley winds (NASA [n.d.])

Cabinet Mountains Wilderness Emission Sources

Air Quality in the Cabinet Mountains Wilderness (CMW) is generally good (table 4), with few upwind point source emissions and periodic strong wind dispersion. Libby is in non-attainment for the $PM_{2.5}$ annual standard and has some of the most persistent particulate-matter caused human health issues in Montana. These are documented in the Montana DEQ air monitoring network review (http://www.deq.mt.gov/AirMonitoring/networkRev/network2003.pdf). The Libby $PM_{2.5}$ issues are caused by reduced dispersion in Libby's incised valley location. Conditions of reduced dispersion are atypical in CMW, which is located in a higher elevation mountainous area with considerably better air dispersion. CMW is also in the path of long distance transport of air pollutants from Washington and Oregon. Emission sources in CMW include dust from trails during dry conditions and smoke

Table 4—Emission sources near the Cabinet Mountains Wilderness (CMW).

CO	NO_x	PM_{10}	SO_2	Facility name	Location	Industry type
tons per year						
1,052	36.6	69.8	3.70	Stimson Lumber - Libby	Libby	lumber
129	14.3	63.9	1.90	Plum Creek Mfg., Lp-Ksanka	Libby	lumber
10.1	2.20	57.1	0.37	Eureka Pellet Mills	Eureka	lumber
		63.6		Owens & Hurst	Lincoln County	lumber
1,191	52	303	6	Total		

from wildland fires and prescribed burns. Adjacent area sources are primarily occasional construction equipment, vehicles, road dust, residential wood burning, wood fires, and smoke from logging emissions slash disposal, prescribed burns, and wildland fires. CMW also receives some vehicle, residential, and construction emissions from the Libby area and from the Highway 56 and Highway 2 corridors.

Gates of the Mountains Wilderness Emission Sources

The southern edge of the Gates of the Mountains Wilderness (GMW) is about 14 miles from the ASARCO smelter in East Helena, which was the largest source of SO_2 emissions in Montana before shutting down in 2001. Area emissions adjacent to the GMW (table 5) from the Helena valley and I-15 corridor include construction equipment, vehicles, road and agricultural dust, residential wood burning, wood fires, and smoke from logging slash disposal, prescribed burns, and wildland fires.

Bob Marshal, Scapegoat, Great Bear, and Mission Mountains Wildernesses Emission Sources

Air Quality in the Bob Marshall Wilderness (BMW) complex is good (table 6), with limited upwind emissions from large stationary local emission sources and periodic robust wind dispersion. Existing emissions sources in the wilderness complex include dust from trails during dry conditions and smoke emissions from wildland fires and prescribed burns. Adjacent area emissions include occasional construction equipment, vehicles, road dust, residential wood burning, wood fires, and smoke from logging emissions slash disposal, prescribed burns, and wildland fires. The BWM complex receives vehicle, residential, and construction emissions from the upper Flathead valley (Kalispell, Columbia Falls, Whitefish, Hungry Horse, and West Glacier).

The main permitted industrial sources in the Flathead valley include Columbia Falls Aluminum Company (currently only partially in operation) for sulfur dioxides (SO_x) and particulates and two Plum Creek facilities

Table 5—Emission sources near the Gates of the Mountains Wilderness (GMW).

CO	NO_x	PM_{10}	SO_2	Facility name	Location	Industry type
tons per year						
355	367	924	40.4	Golden Sunlight Mine	Whitehall	gold ores
246	336	433	36.7	Montana Tunnels Mine	Jefferson City	gold ores
141	336	95.1	239	Continental Lime	Townsend	lime
23.0	697	199	241	Ash Grove Cement	Clancy	cement
10.8	26.5	29.4	1.91	Basin Creek Mine	Basin	gold ores
778	1,789	1,093	564	Total		

Table 6—Emission sources near the Bob Marshall (BMW), Scapegoat (SGW), Great Bear (GBW), and Mission Mountains (MMW) Wildernesses.

CO	NO_x	PM_{10}	SO_2	Facility name	Location	Industry type
tons per year						
32,523	10.6	1,447	1,386	Columbia Falls Aluminum	Kalispell	aluminum plant
1,365	150	156	9.28	Plum Creek Evergreen	Kalispell	lumber
1,080	480	445	15.5	Plum Creek Manufacturing, L.P.	Columbia Falls	lumber
1,052	36.6	69.8	3.70	Stimson Lumber	Libby	lumber
129	14.3	63.9	1.90	Plue Creek Mfg., Lp-Ksanka	Libby	lumber
94.7	5.45	178	1.07	American Timber Company	Olney	lumber
58.8	23.3	1.54	0.08	MPC Cut Bank Mainline #1	Cut Bank	natural gas
24.0	4.08	64.4	0.90	Stoltze Land and Lumber	Columbia Falls	lumber
10.8	26.5	29.4	1.91	Basin Creek Mine	Lewis & Clark Co	gold ores
10.1	2.20	57.1	0.37	Eureka Pellet Mills	Lincoln Co	lumber
36,347	753	2,512	1,421	Total		

(Kalispell and Columbia Falls) for nitrogen oxides (NO_x) and PM_{10}. Kalispell, Columbia Falls, and Whitefish are designated non-attainment areas by the Montana DEQ for PM_{10} (http://www.deq.mt.gov/AirQuality/Planning/AirNonattainment.asp). East of the Great Bear Wilderness, there are several stationary sources of NO_x emissions from natural gas processing and transportation facilities in Glacier and Teton Counties (primarily in Cut Bank). The very strong dispersion and predominantly west-to-east wind direction transports most of these eastside emissions downwind of the GBW. The Mission Mountain Wilderness (MMW) receives emissions from the lower Flathead valley, including the Highway 93 corridor. The southern part of the MMW is subject to Missoula area emissions described for the RW.

Existing sources of emissions in the Rattlesnake Wilderness (RW), Welcome Creek Wilderness (WCW), and eastern Selway Bitterroot Wilderness (SBW) (table 7) include dust from trails during dry conditions and smoke from wildland fires and prescribed burns. Emissions from adjacent areas include occasional construction equipment, vehicles, road dust, residential wood burning, wood fires, and smoke from logging slash disposal, prescribed burns, and wildland fires. The RW receives vehicle, residential, and construction from the Missoula area. The WCW has very limited local sources. Down valley airflow in the RW and the WCW drainages is frequently strong during nighttime and early morning hours. The entire RW and WCW area is considered to be in attainment by the Montana DEQ. The eastern SBW receives valley emissions from Stevensville, Hamilton, and Darby and some agriculture burning emissions. The primary air pollution source for the eastern SBW is wildland fire smoke from Idaho.

The main source of air pollutants to RW and, to a lesser degree, WCW is the city of Missoula and surrounding

Table 7—Emission sources near the Rattlesnake (RW), Welcome Creek (WCW), eastern Selway Bitterroot (SBW), and Anaconda Pintler (APW) Wildernesses.

CO	NO_x	PM_{10}	SO_2	Facility name	Location	Industry type
tons per acre						
3,804	2,253	697	149	Stone Container	Missoula	paper mill
265	186	141	9.94	Stimson Lumber	East Bonner	sawmill
54.0	435	348	6.49	Louisiana-Pacific	Missoula	wood products
23.6	56.3	141	0.87	Pyramid Mtn Lumber	Seeley Lake	sawmill
11.1	4.42			Conoco, Inc. Bulk Terminal	Missoula	petroleum
4,158	2,935	1,327	166	Total		

area (table 7). A chronological history of Missoula air quality issues and trends is available at Missoula County, 2006 (http://www.co.missoula.mt.us/airquality/). The major source of emissions in the Missoula valley includes vehicle exhaust, wood burning smoke, and road dust, and industrial emissions. The main permitted industrial sources in the Missoula valley include Stone Container for NO_x and PM_{10}.

Air quality in the Gospel Hump Wilderness (GHW) and western Selway Bitterroot Wilderness (SBW) is generally good (table 8) with limited emissions from upwind large stationary sources and periodic strong wind dispersion. The GHW in particular is subject to long distance transport from Washington and Oregon (Graw personal communication). Existing emission sources in the GHW include dust from trails during dry conditions and smoke from wildland fires and prescribed burns. Area emission sources adjacent to the GHW and western SBW include construction equipment, vehicles, road dust, logging emissions, residential wood burning, wood fires, and smoke from slash disposal, prescribed burns, and wildland fires. The GHW receives some vehicle, residential, and construction emissions from the Grangeville to McCall corridor along Highway 95, adjacent logging, jet boat emissions on the Salmon river, and snowmobile emissions along the Buffalo Hump corridor. Local emission levels are low due to the sparsely populated area and vast areas for dispersion. Down valley airflow in the GHW drainages (Johns Creek and Crooked Creek on the north and Salmon River tributaries on the south—Wind River, Sheep Creek, and Crooked Creek) is frequently strong during nighttime and early morning hours. The entire GHW is considered to be in attainment by the Idaho DEQ.

Analysis Methods

Methods for analysis followed the Data Analysis Protocol for Long-Term Lake Monitoring (DAP) (Gurrieri 2006), which was derived from the statistical, graphical, and protocol development methods of Gilbert (1987), Helsel and Hirsch (1992), and Ward and others (1990). Trends were tested using the Kruskall-Wallis Test for seasonality, the Mann-Kendall, and the Seasonal Mann-Kendall tests. These nonparametric tests work well with monotonic trends. They do not require normally distributed data and are much more resistant to outliers and missing data than parametric tests (Gurrieri 2006).

The null hypothesis (H_o) is that there is no significant trend (in lake, NADP, and IMPROVE parameters) over time. The alternative hypothesis (H_1) means a significant increasing or decreasing trend (in the lake, NADP, or IMPROVE parameters) was found over time.

Figure 2 is used by the Data Analysis Protocol to analyze trends in long-term lake monitoring data and was used to guide the data analysis.

The data analysis for this paper was generated using SAS software, Version 9.1.3 of the SAS System for Windows. Copyright © 2008 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

After the data was imported into SAS, the Kruskal-Wallis test was run for each parameter to see if there was a difference among seasons. If seasonality existed statistically at an $\alpha < 0.05$ level then the Seasonal Mann-Kendall test was run. If seasons were not statistically different, then the Mann-Kendall test was run on the annual data. The Mann-Kendall and Seasonal Mann-Kendall tests report whether or not a trend exists, they do not

Table 8—Emission sources near the Gospel Hump Wilderness (GHW) and the western Selway Bitterroot SBW Wildernesses.

CO	NO_x	PM_{10}	SO_2	Facility name	Location	Industry type
tons per acre						
807	275	24.1	8.88	Potlatch Corporation Wood Products	Pierce	lumber
246	110	59.2	10.5	Evergreen Forests & Tamarack Energy	New Meadows	sawmill
96.7	6.46	121	2.55	Shearer Lumber Products	Elk City	sawmill
1,150	392	204	22	Total		

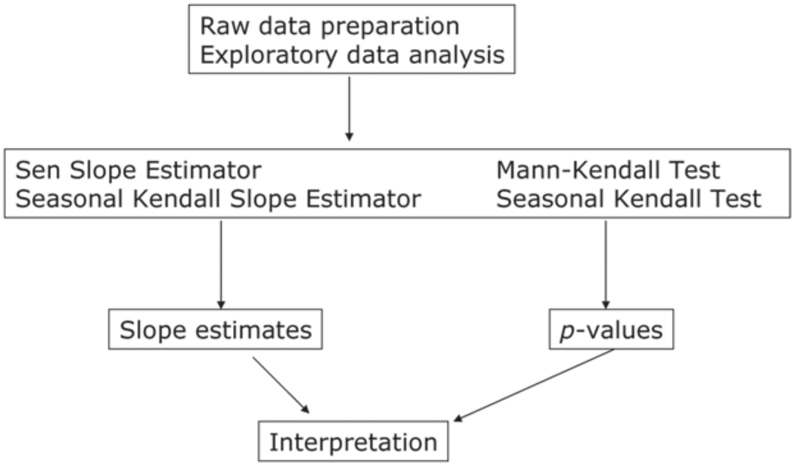

Figure 2—Flow diagram depicting temporal trend analysis protocol (Gurrieri 2006).

evaluate the magnitude of the trend. The Mann-Kendall test was also run to look for trends among each season.

The Mann-Kendall and Seasonal Mann-Kendall use alpha (α) to quantify the probability that a trend exists. For this report the alpha level for statistical significance was set at $\alpha < 0.1$. A value of $\alpha = 0.001$ means there is a 0.1% chance of making a mistake when rejecting the null hypothesis that no trend exists (Salmi and others 2002).

Lake data were downloaded from the National USDA Forest Service website for chemistry of lakes, streams, and bulk deposition on and near the National Forests, (USFS NRIS-Air database http://www.fs.fed.us/waterdata/). Protocols for lake sampling often call for three samples to be taken during three specific times of year so that differences due to seasonality can be detected. Lake sampling in the USFS Region 1 usually occurred only once or twice a year so any changes over and between seasons could not be compared. In the case when two or more samples did occur, only data from the samples that used the most common deep sampling method (Story 2008) was used. Data from samples closest to the most common date were selected to minimize seasonality differences in data. Samples with close dates were averaged. Only data that was contaminated (lab suggested contamination) were deleted. The revised data sets were used for the SAS analysis.

Six lakes in R1 undergo long-term Phase 3 monitoring: Lower Libby Lake and Upper Libby Lake, in the CMW, North Kootenai Lake and Shasta Lake, in the SBW, and Stepping Stone Lake and Twin Island Lake, in the ABW (Story 1999). Each lake was analyzed for trends in specific conductance (μS/cm), pH, ANC (mg/L), NH_4^+, NO_3^-, SO_4^{2-}, Ca^{2+}, and Cl^-.

The National Atmospheric Deposition Program (NADP) data were downloaded from the NADP website (http://nadp.sws.uiuc.edu). The following six sites were analyzed for trends in annual and seasonal concentrations (mg/L): Lost Trail Pass (MT97), Clancy (MT07), Glacier (MT05), Tower Junction (WY08), Craters of the Moon (ID03), and Little Bighorn Battlefield National Monument (MT00). Lost Trail Pass (MT97), Clancy (MT07), and Glacier (MT05) were also analyzed for trends in annual and seasonal deposition (kg/ha). Each site was analyzed for trends in specific conductance, pH, NO_3^-, NH_4^+, SO_4^{2-}, Ca^{2+}, Cl^-, Na^+, K^+, and Mg^{2+}.

The IMPROVE (Interagency Monitoring or Protected Visual Environments) data were received from the Atmospheric Data Analyst for CIRA (Cooperative Institute for Research in the Atmosphere) because the 2006 data were not yet available on the public website (http://vista.cira.colostate.edu/improve/). Data were analyzed for seven IMPROVE sites: CABI1, GAM01, GLAC1, HECA1, MONT1, SULA1, and YELL2. Each site was analyzed for trends in the extinction coefficient (E) for the following parameters: ESO4, ENO3, EOMC (organic mass from carbon), Esoil (fine soil), ECM (coarse mass), ELAC (Light Absorbing Carbon), Esea_salt (sea salt), Rb_{ext} (sum aerosol extinctions), SVR (standard visibility range), dv (deciview), MF ($PM_{2.5}$), and MT (PM_{10}).

Lake Chemistry and Trends

The U.S. Forest Service Region 1 Air Resource Monitoring Program, encompassing approximately 1,750 wilderness lakes, has emphasized the monitoring of lake chemistry, which provides diagnostic indicators of atmospheric deposition since 1989. The lakes are a main attraction for wilderness recreation users but also provide a chemical record of air pollution impacts. Many alpine lakes are vulnerable to acid deposition because they are very dilute and have little acid buffering capacity. Dilute, poorly buffered lake water results from limited weathering, thin soils, sparse vegetation, and short groundwater flow paths (Campbell and others 1995). Lake chemistry also affects community composition of microorganisms, invertebrates, and other aquatic fauna and flora, which ultimately affects the health and productivity of fish. Since 1989, USFS R1 personnel—primarily wilderness rangers and volunteers from Yellowstone Ecosystem Studies—have sampled 176 lakes in R1 wildernesses. The sampling has consisted of a three-phase program (Story and Grenon 2008).

Six lakes were selected for long term Phase 3 monitoring: Lower Libby Lake and Upper Libby Lake, in the CMW, North Kootenai Lake and Shasta Lake, in the SBW, and Stepping Stone Lake and Twin Island Lake, in the ABW (Story 1999). Figure 3 indicates the location of Phase 3 lakes. The lakes were selected due to their high sensitivity to acid precipitation and are considered representative of the R1 wilderness lakes. Figure 4 shows a sensitive high alpine Phase 3 lake. The SBW, ABW, and parts of the CMW consist of granite, gneiss, or quartzite bedrock, which are chemically resistant and result in low alkalinity surface waters.

Phase 3 sample methods are described in detail in Story and Grenon (2008) and Story (2008). For each lake, duplicate samples were collected at 0.5 meters below the surface in the deepest part the lake. Samples were kept cool in field coolers with frozen gel packs and shipped to the Air Resource Management Laboratory (http://www.fs.fed.us/waterlab/) as soon as possible. Filtering was done in the lab within 24 hours of samples arriving at the lab.

All analyses used QA/QC guidelines and EPA reference standards established in the Handbook of Methods for Acid Deposition Studies (EPA 1987) and Standard Methods (APHA 1989). The data were reviewed for conformance with quality assurance standards prior to use. All of the lake data is available from the USFS NRIS-Air database (http://www.fs.fed.us/waterdata/).

Sampling in the six lakes chosen for analysis started between 1991 and 1993, and were typically sampled at least once each year. Due to infrequent sampling, trends were run using one sample per year with the Mann-Kendall test and Sen's Slope estimator. Trends were run for

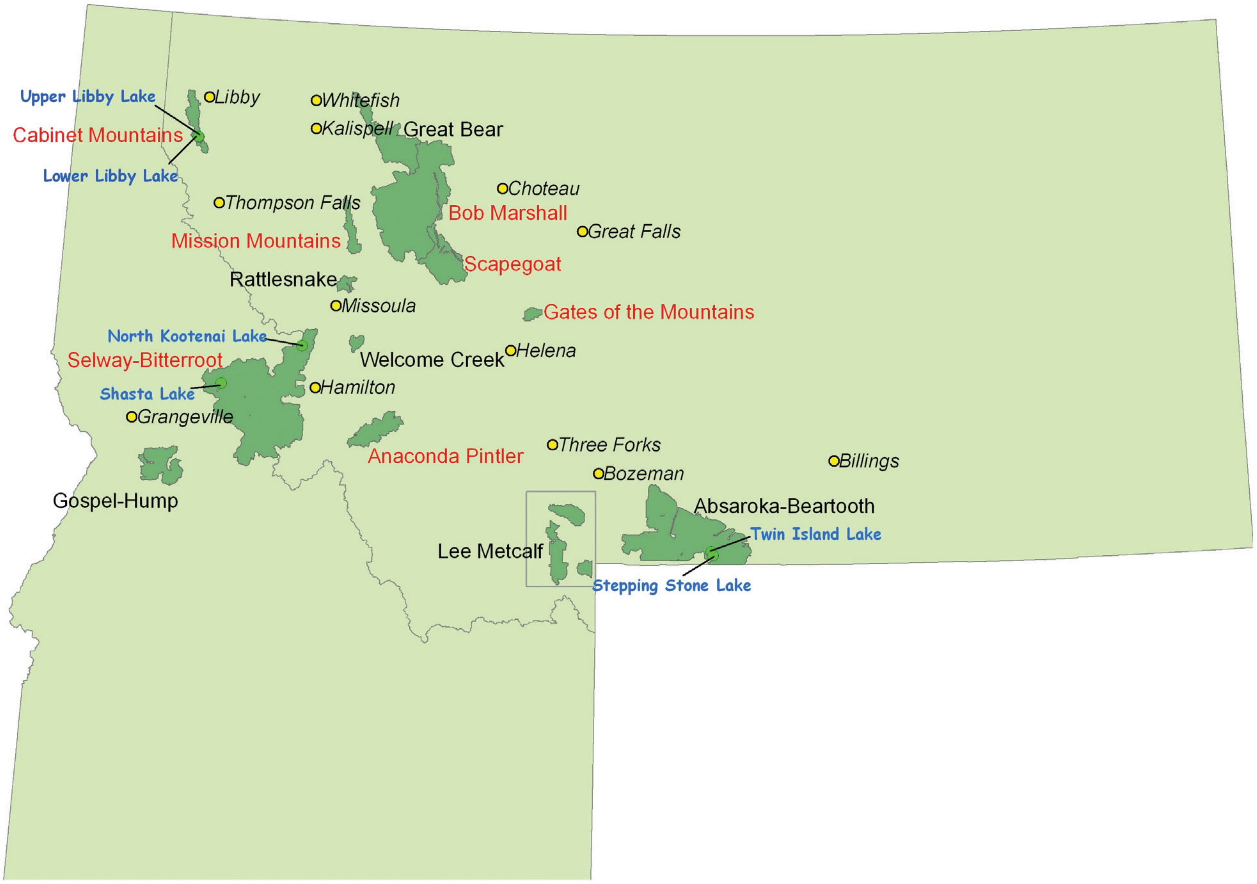

Figure 3—USFS R1 Phase 3 lake locations.

Figure 4—Stepping Stone Lake in the Absaroka-Beartooth Wilderness.

concentrations (mg/L) of ANC (mg/L), NH_4^+, NO_3^-, pH, SO_4^{2-}, Ca^{2+}, and Cl^-, and conductivity (µS/cm) over time.

Significant trends in R1 Wilderness lake chemistry are presented in table 9 (p-values and trend direction). The direction of the Trend and Sen's Slope estimator is indicated either by an upward/increase ↑ or downward/decrease ↓ in the trend of the parameter analyzed. The closer the p-value to 0, the stronger the evidence of a trend.

Concentrations of SO_4^{2-} decreased in Lower Libby Lake, CMW. No significant trends were observed in Upper Libby Lake for any of the measured parameters.

In the SBW, Cl^- decreased in North Kootenai Lake. Specific conductance decreased and NO_3^- concentrations increased in Shasta Lake.

In the ABW, ANC, specific conductance, and Cl^- decreased in Stepping Stone Lake. The pH increased in both Stepping Stone Lake and Twin Island Lake.

Figures 5 to 10 illustrate lake chemistry trends in the six Phase 3 lakes. Data gaps occurred where sample contamination was suspected (lab suggested) or no samples were collected using the deep sampling method described in Story and Grenon (2008).

Table 9—Mann-Kendall p-values for annual lake data and trend direction. Highlighted cells indicate statistically significant trends when $p < 0.1$.

Parameter (mg/L)	Lower Libby	Upper Libby	N. Kootenai	Shasta	Stepping Stone	Twin Island
ANC	0.138	0.428	0.767	0.246	**0.002 ↓**	0.381
ConductivityµS/cm	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^{2+}	0.552	1	0.692	0.246	0.656	0.274
Cl^-	0.276	1	**0.048 ↓**	0.583	**0.003 ↓**	0.827

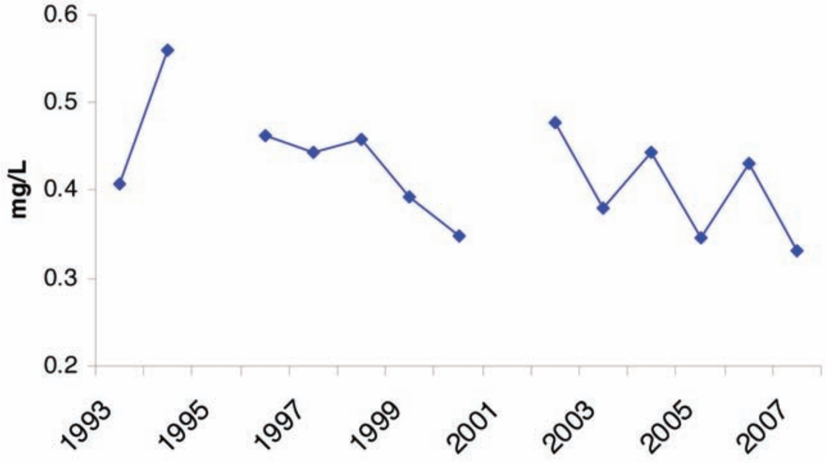

Figure 5—Long-term trends in lake water ANC concentrations for Stepping Stone Lake.

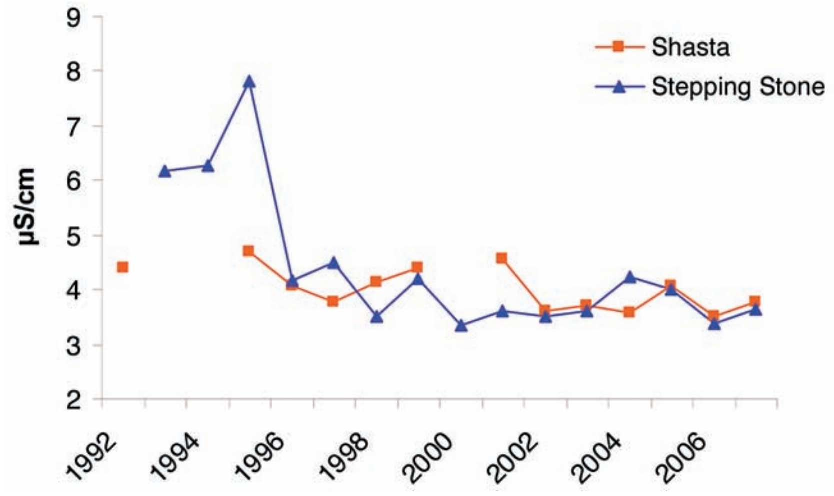

Figure 6—Long-term trends in lake-water specific conductance.

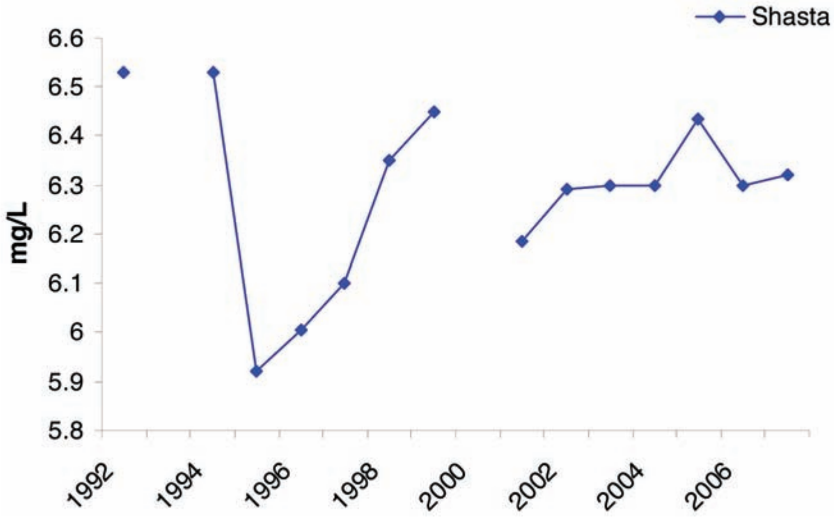

Figure 7—Long-term trends in lake-water NO_3^- concentrations.

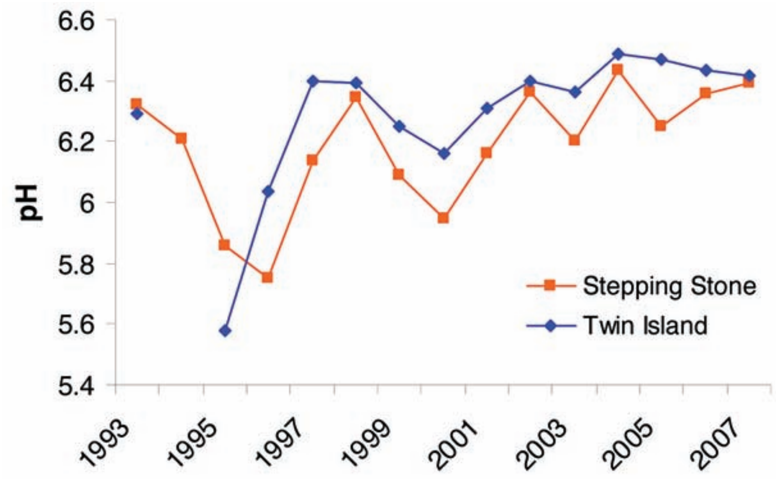

Figure 8—Long-term trends in lake-water pH.

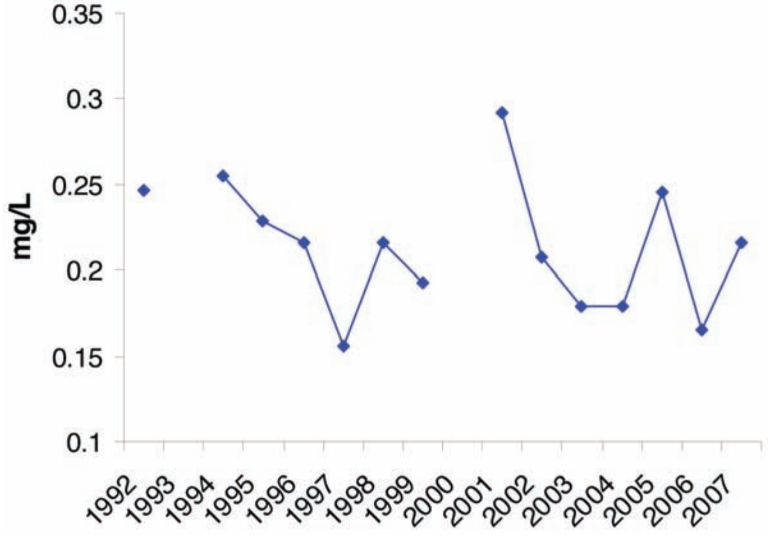

Figure 9—Long-term trends in lake-water SO4^{2-} concentrations at Lower Libby Lake.

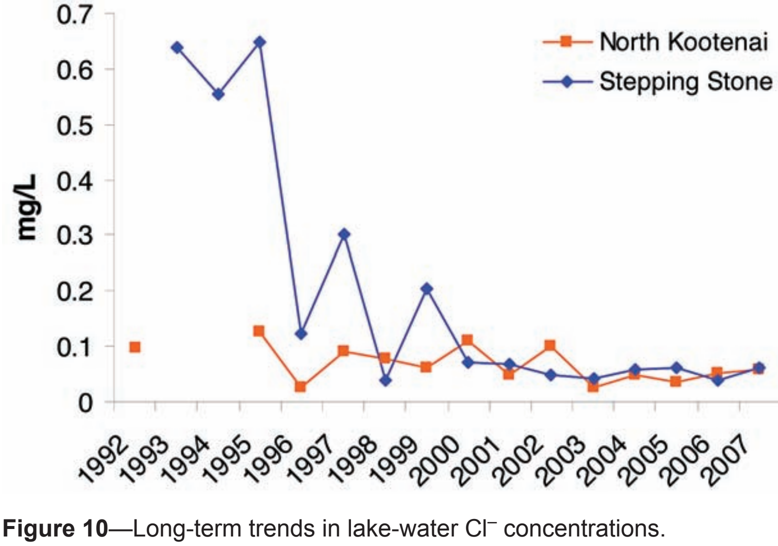

Figure 10—Long-term trends in lake-water Cl^{-} concentrations.

Lake Sampling Discussion

Nitrate trends in the R1 Phase 3 lakes are less evident than trends in the Bridger-Teton and Shoshone National Forest in the Wind River Range, Wyoming, where increasing lake water NO_3^- concentrations were detected in several lakes (Bevenger 2008; Svalberg and Mebane 2006). In the Rocky Mountains, the largest trends have occurred in the Colorado Front Range (Williams and others 1996) where several lake NO_3^- levels have increased from below detection limits to around 10 µeq/L (0.62 mg/L) and are considered at or near nitrogen saturation levels.

Of the R1 lakes sampled, only Shasta Lake shows a significant increasing trend in NO_3^-. The low nitrate concentrations in the Phase 3 lakes, which were below detection limits for most sampling events, are likely due to rapid assimilation of atmospherically deposited nitrogen by aquatic and terrestrial biota. The exception is Upper Libby Lake, which has very sparse soil development, is very oligotrophic, and has limited algae, which may limit nitrate assimilation rates (Story and Grenon 2008). Fenn and others (2003) and other findings indicate that many places in the Rocky Mountains may be at or near nitrogen saturation. Future sampling may provide better indications/continuation of trends in USFS R1.

Despite overall trends in the West of decreasing SO_4^{2-} atmospheric deposition, only one of the lakes (Lower Libby) in this report showed a decreasing SO_4^{2-} trend. The lack of lake water response may be masked by inputs of sulfate from internal weathering sources or the lakes may be too far from SO_4^{2-}emission sources to be significantly affected by an emission decrease. The lack of a decreasing SO_4^{2-} trend in the R1 lakes (except for Lower Libby Lake) contrasts with the Wind River lakes (Svalberg and Mebane 2006) and the Shoshone lakes (Bevenger 2008) where sulfate concentrations in Deep Lake and Hobbs Lake (Wind River), and Ross Lake (Shoshone) have decreased. The Wind River and Shoshone lakes have a longer and more frequent sampling record, which may increase the statistical power to detect trends. Sulfate concentrations in North Kootenai Lake were higher than the other Phase 3 lakes, which Eilers (2003) speculates may be due to the presence of sulfur-bearing minerals (such as FeS_2) in the bedrock.

The smaller the ANC the more sensitive the lake is to acid deposition from the atmosphere. The decrease in ANC and specific conductance in Stepping Stone Lake is not clearly related to an increase in acid deposition because no trends in lake water concentrations of NO_3^- and SO_4^{2-} were detected. There is suggestive evidence that ANC increased in Twin Island Lake from 1999 to 2007 but decreased in Lower Libby, Upper Libby, North Kootenai, and Stepping Stone Lakes (Story and Grenon 2008). The Mann-Kendall test statistically validated an ANC decrease only at Stepping Stone Lake. Generally, a decrease in ANC coincides with a decrease in pH. Both Twin Island and Stepping Stone Lakes showed a significant increase in pH despite the decreasing trends in ANC at Stepping Stone Lake. In the Shoshone National Forest, Saddlebag and Ross Lakes (Fitzpatrick Wilderness) have also demonstrated decreased trends in ANC, which may be from a coinciding increase in NO_3^- (Bevenger 2008).

The reduction in Cl^- in both North Kootenai and Stepping Stone Lakes is not readily explainable, but it may be related to contamination in 1993 to 1995. Seasonality often plays an important role in data variation. Since there was only one lake sample per year analyzed and the samples were not always taken during the same season, potential seasonality in the above data could be a factor. Variation in lake chemistry can also be influenced by weather patterns (rain events and predominant wind patterns during the several days preceding the sampling period) and the date and time of sampling.

NADP Data and Trends

The National Atmospheric Deposition Program (NADP) was initiated in 1978 to monitor geographical and temporal trends in the chemical composition of rain and snow (wet deposition) with the primary purpose of acid rain benchmark monitoring. The program was prompted by scientific evidence and public concern in the 1970s that acid rain could be damaging aquatic ecosystems throughout the United States. The program grew steadily though the early 1980s and has stabilized at about 200 sites. The NADP network data is used by a wide variety of government administrators, resource specialists, and university scientists in monitoring the amounts of wet deposition and effects on agriculture, forests, rangelands, freshwater streams, lakes, and cultural resources. Atmospheric deposition is commonly referred as "acid rain" but can occur as acid snow, fog, or dry deposition. The NADP data from all sites is readily retrievable at the NADP web site at http://nadp.sws.uiuc.edu. Figure 11 shows NADP site locations in Region 1.

The NADP site at Lost Trail Pass (MT97) on the Sula District of the Bitterroot National Forest is the only NADP site in Montana operated by the U.S. Forest Service and is the only high elevation NADP site in Montana and Idaho. Data for the MT97 site from 1990 to 2006 is summarized in Story and Grenon (2008). Other NADP sites are very

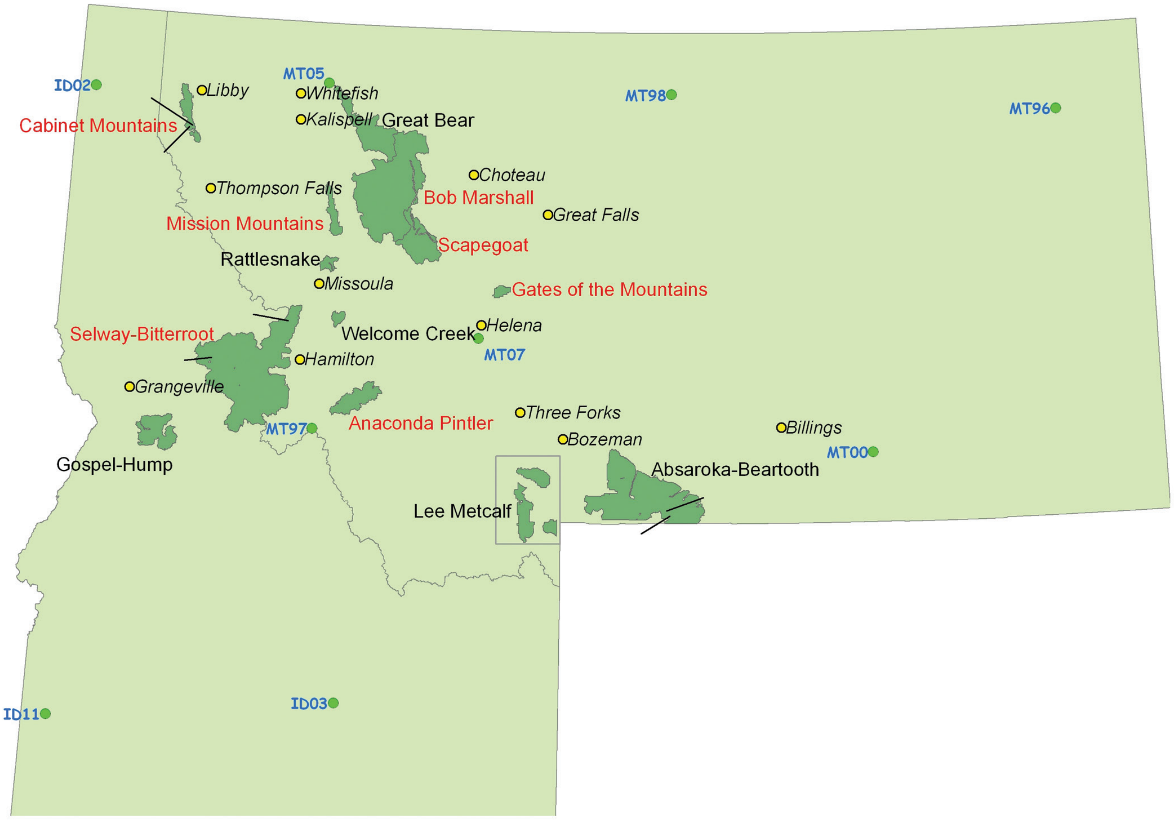

Figure 11—Active NADP site locations in and around MT.

useful for USFS R1 wilderness monitoring as shown in figure 11. Figure 12 shows a typical NADP site setup.

All of the NADP sites are operated according to NADP protocols (http://nadp.sws.uiuc.edu/documentation/completeness.asp). Sample buckets (3.5 gallons) are exchanged each Tuesday. Sample weights are measured, daily precipitation is recorded on the site from the rain gage strip charts, and the samples are shipped to the Central Analytical Lab (CAL) at the University of Illinois in Champaign (Illinois State Water Survey). The CAL analyzes samples for pH, specific conductance, Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+, NO_3^-, Cl^-, and SO_4^{2-}. The data is carefully evaluated at the NADP Coordination Office for quality control and consistency. Quality control throughout the CAL and NADP offices is very rigid and consistent. Data is available about 6 months after the samples are analyzed and quality control checked by the CAL. For deposition (or loading) in kg/ha, total inorganic N was analyzed but pH and specific conductance were not. The NADP concentration (mg/L) data are precipitation-weighted and the loading NADP data (kg/ha) are total wet deposition.

Data from the following six sites were analyzed for annual and seasonal trends: Lost Trail Pass (MT97), Clancy (MT07), Glacier (MT05), Tower Junction (WY08), Craters of the Moon (ID03), and Little Bighorn Battlefield National Monument (MT00). Lost Trail Pass (MT97), Clancy (MT07), and Glacier (MT05) were also analyzed for trends in annual and seasonal deposition. Each site was analyzed for trends in NO_3^-, NH_4^+, specific conductance, pH, SO_4^{2-}, Ca^{2+}, Cl^-, Na^+, K^+, and Mg^+.

Annual NADP Concentration Trends

Statistically significant increase in annual NH_4^+ concentration (mg/L) were present at Glacier, Craters of the Moon, Little Bighorn, and Tower Junction. For NO_3^-, only Tower Junction showed an increase. Specific conductance appears to be decreasing at Glacier, Craters of the Moon, Little Bighorn and Tower Junction. The only significant trend in lab pH was a decrease at Clancy. Downard trends in SO_4^{2-} were statistically significant at all sites except Lost Trail Pass. Decreasing trends in Ca^{2+}, Na^+, and Mg^+ were detected at all sites except for Lost Trail Pass. Cl^- and K^+ exhibited decreasing trends at all sites. Table 10 and figures 13 to 15 should help visualize annual trends in concentration during the period of record evaluated.

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Figure 12—Lost Trail pass (MT97) NADP Site.

Table 10—Statistically significant annual NADP concentration trends found with the Mann-Kendall (light blue cells) and with Seasonal Mann-Kendall tests (yellow cells) are bolded. Highlighted cells indicate statistically significant trends using $p < 0.1$.

Parameter (mg/L)	Clancy	Glacier	Lost Trail Pass	Craters of the Moon	Little Bighorn	Tower
NO_3^-	0.259	0.23	0.436	0.806	0.858	0.041 ↑
NH_4^+	0.291	<0.001 ↑	0.146	<0.001 ↑	<0.001 ↑	<0.001 ↑
cond	0.689	0.002 ↓	0.436	0.001 ↓	0.054 ↓	0.017 ↓
pH	0.029 ↓	0.513	0.932	0.227	0.98	0.646
SO_4^{2-}	0.022 ↓	<0.001 ↓	0.488	<0.001 ↓	<0.001 ↓	<0.001 ↓
Ca^{2+}	0.015 ↓	<0.001 ↓	0.23	0.001 ↓	0.026 ↓	0.033 ↓
Cl^-	0.003 ↓	<0.001 ↓	0.033 ↓	<0.001 ↓	<0.001 ↓	<0.001 ↓
Na^+	0.007 ↓	<0.001 ↓	0.173	0.003 ↓	<0.001 ↓	<0.001 ↓
K^+	0.005 ↓	<0.001 ↓	0.017 ↑	0.001 ↓	0.004 ↓	0.013 ↓
Mg^+	0.043 ↓	<0.001 ↓	0.401	<0.001 ↓	0.001 ↓	<0.001 ↓

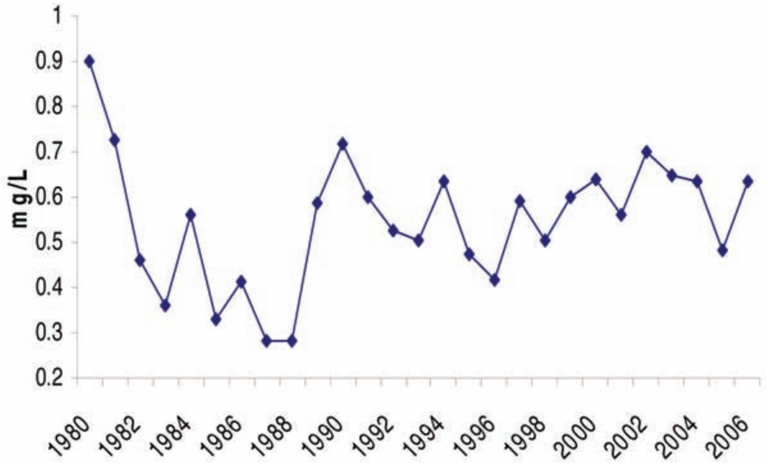

Figure 13—Trends in annual volume-weighted mean (VWM) NO3^{-} concentrations at Tower Junction NADP site

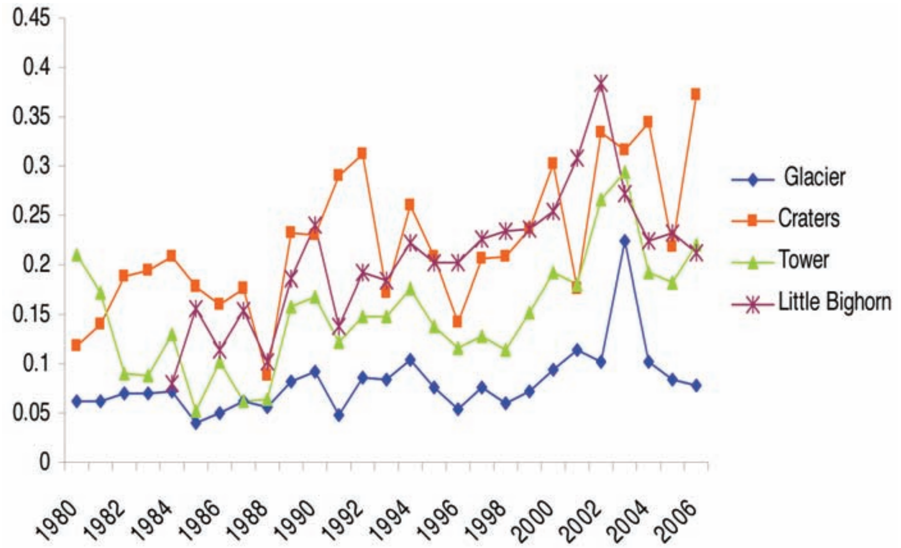

Figure 14—Trends in annual VWM NH_4^+ concentrations at NADP sites.

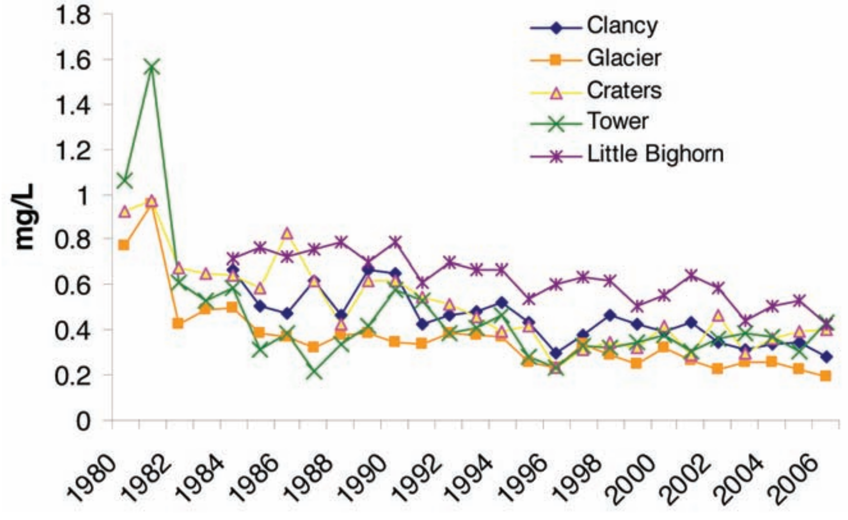

Figure 15—Trends in annual VWM SO4^{2-} concentrations at NADP sites.

Annual NADP Deposition (Loading) Trends

Trends in annual wet deposition (or loading) are shown in table 11 and figures 16 to 20. Trends indicated increasing amounts of nitrogen. NO_3^- shows an increasing loading trend only at Clancy. NH_4^+, Inorganic Nitrogen, SO_4^{2-}, Cl^-, Na^+, and Mg^+ exhibited increasing trends at Clancy and Glacier. Glacier also shows a decreasing trend in Ca^{2+} and K^+.

Seasonal Trends at NADP Sites

USFS R1 NADP sites were also analyzed for statistically significant trends in concentration for each parameter through each season (winter, spring, summer, and fall) to evaluate individual seasonal differences. The NADP sites closest to USFS R1 wilderness areas were analyzed for trends in deposition among each season. Results are presented in tables 12 to 17 and figures 21 to 35.

Table 11—Statistically significant annual NADP deposition trends found with the Mann-Kendall (light blue cells) and with Seasonal Mann-Kendall tests (yellow cells) are bolded. Highlighted cells indicate statistically significant trends using p < 0.1.

Parameter kg/ha	Clancy	Glacier	Lost Trail
NO_3^-	**0.036 ↑**	0.739	0.24
NH_4^+	**<0.001 ↑**	**0.002 ↑**	0.533
SO_4^{2-}	**<0.001 ↓**	**<0.001 ↓**	0.16
Ca^{2+}	0.929	**<0.001 ↓**	0.48
Cl^-	**<0.001 ↓**	**<0.001 ↓**	0.71
Mg^{2+}	**<0.001 ↓**	**<0.001 ↓**	0.1509
K^+	0.732	**<0.001 ↓**	0.112
Na^+	**<0.001 ↓**	**<0.001 ↓**	0.967
Inorganic N	**0.001 ↑**	**0.076 ↑**	0.59

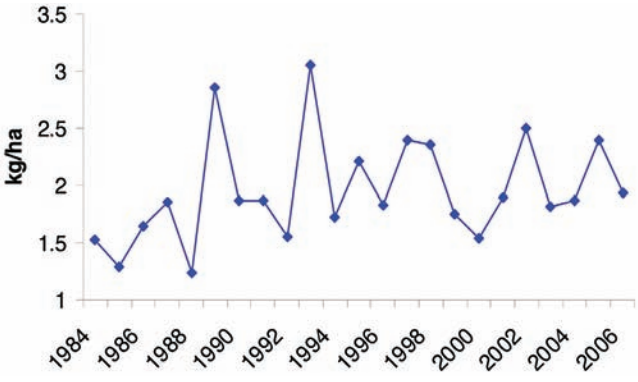

Figure 16—Trend in annual nitrate deposition at Clancy NADP site.

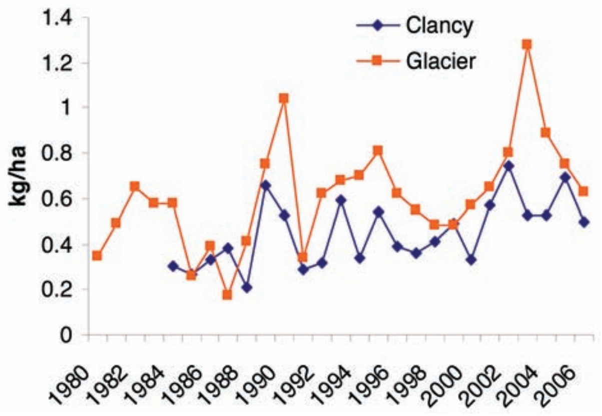

Figure 17—Trend in annual NH_4^+ deposition at NADP sites.

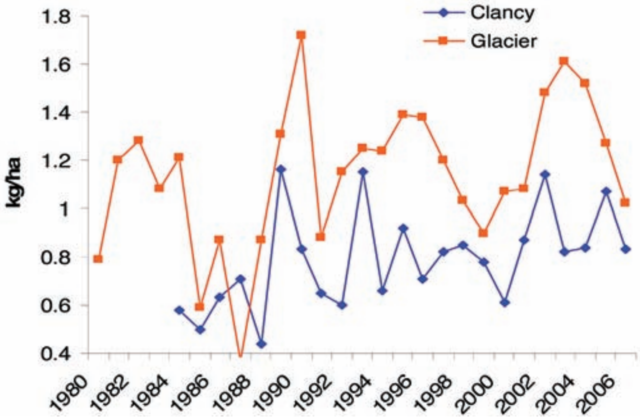

Figure 18—Trend in annual inorganic N deposition at NADP sites.

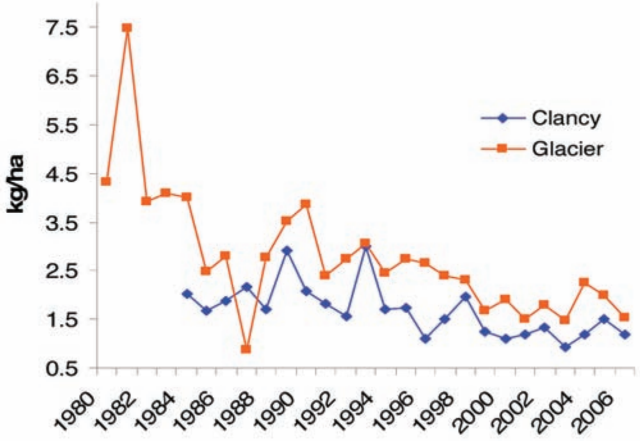

Figure 19—Trend in annual sulfate deposition at NADP sites.

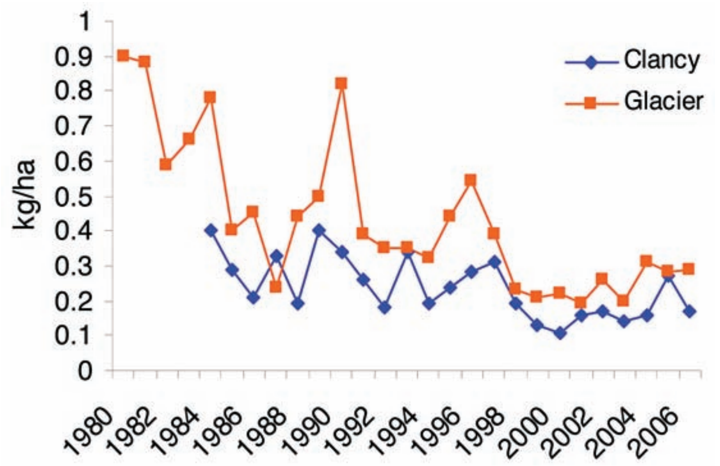

Figure 20—Trends in annual Cl^- deposition at NADP sites.

Table 12—Clancy NADP site Mann-Kendall p-values for seasonal trends. Highlighted cells indicate statistically significant trends using $p < 0.1$. The grey cells indicate parameters that were not available.

Parameter	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
	mg/L				*kg/ha*			
NO_3^-	1	0.193	0.756	0.640	0.106	0.233	0.901	0.245
NH_4^+	0.732	0.115	0.876	0.876	0.146	**<0.001 ↑**	0.534	**0.028 ↑**
cond	0.451	0.373	0.755	0.756				
pH	0.034 ↓	0.304	0.696	0.161				
SO_4^{2-}	**0.034 ↓**	0.451	0.436	0.533	**0.003 ↓**	**0.039 ↓**	**0.053 ↓**	**0.047 ↓**
Ca^{2+}	**0.039 ↓**	0.582	1	**0.043 ↓**	**0.046 ↓**	0.901	0.104	0.790
Cl^-	**0.016 ↓**	0.169	0.533	**0.087 ↓**	**<0.001 ↓**	**0.024 ↓**	0.154	**0.097 ↓**
Na^+	**0.024 ↓**	**0.028 ↓**	0.696	0.161	**<0.001 ↓**	**0.066 ↓**	0.442	**0.053 ↓**
K^+	**0.032 ↓**	0.241	0.756	**0.085 ↓**	0.122	0.901	0.862	0.613
Mg^{2+}	**<0.001 ↓**	**0.071 ↓**	**0.060 ↓**	**0.004 ↓**	**<0.001 ↓**	**0.072 ↓**	0.551	0.381
Inorganic N					**0.018 ↑**	**0.025 ↑**	0.534	**0.067 ↑**

Table 13—Glacier NADP site Mann-Kendall p-values for seasonal trends. Highlighted cells indicate statistically significant trends using $p < 0.1$. The grey cells indicate parameters that were not available.

Parameter	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
	mg/L				*kg/ha*			
NO_3^-	0.588	**0.008 ↑**	0.700	0.677	0.851	0.381	0.182	0.874
NH_4^+	0.428	**<0.001 ↑**	0.123	0.196	0.883	**0.003 ↑**	0.210	**0.081 ↑**
cond	0.632	0.708	**0.003 ↑**	0.017 ↑				
pH	0.162	0.843	0.103	0.182				
SO_4^{2-}	<0.001 ↓	<0.001 ↓	<0.001 ↓	<0.001 ↓	<0.001 ↓	0.004 ↓	<0.001 ↓	<0.001 ↓
Ca^{2+}	0.066 ↓	0.098 ↓	0.061 ↓	0.020 ↓	0.010 ↓	0.017 ↓	0.001 ↓	0.034 ↓
Cl^-	0.002 ↓	<0.001 ↓	<0.001 ↓	<0.001 ↓	0.710 ↓	0.008 ↓	<0.001 ↓	<0.001 ↓
Na^+	0.002 ↓	0.047 ↓	<0.001 ↓	<0.001 ↓	0.002 ↓	0.083 ↓	<0.001 ↓	<0.001 ↓
K^+	**0.024 ↓**	0.691	**0.077 ↓**	**0.009 ↓**	**0.001 ↓**	0.404	**0.014 ↓**	**0.038 ↓**
Mg^{2+}	<0.001 ↓	0.002 ↓	0.003 ↓	<0.001 ↓	<0.001 ↓	<0.001 ↓	<0.001 ↓	<0.001 ↓
Inorganic N					0.786	**0.037 ↑**	0.933	0.312

Table 14—Lost Trail Pass NADP site Mann-Kendall p-values for seasonal trends. Highlighted cells indicate statistically significant trends using $p < 0.1$. The grey cells indicate parameters that were not available.

Parameter	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
	mg/L				*kg/ha*			
NO_3^-	0.652	0.458	0.232	1	**0.090 ↑**	0.364	**0.009 ↓**	0.621
NH_4^+	**0.031 ↑**	0.742	0.869	0.322	0.197	0.836	0.901	0.738
cond	0.500	0.387	**0.091 ↓**	**0.091 ↑**				
pH	0.718	0.432	**0.083 ↑**	0.284				
SO_4^{2-}	0.500	0.902	**0.077 ↓**	0.232	0.869	1	**0.007 ↓**	0.967
Ca^{2+}	0.471	0.509	0.620	0.138	0.320	0.408	**0.095 ↓**	0.227
Cl^-	0.299	0.341	0.216	0.364	0.321	0.252	**0.073 ↓**	0.181
Na^+	0.299	0.283	**0.069 ↓**	0.216	0.230	0.187	**0.026 ↓**	0.202
K^+	0.185	**0.098 ↑**	0.901	**0.055 ↑**	0.509	0.173	0.650	0.116
Mg^{2+}	0.534	0.835	**0.096 ↓**	0.402	0.967	0.648	**0.016 ↓**	0.933
Inorganic N					0.136	0.741	**0.089 ↓**	0.618

Table 15—Craters of the Moon NADP site Mann-Kendall p-values for seasonal trends. Highlighted cells indicate statistically significant trends using $p < 0.1$. The grey cells indicate parameters that were not available.

Parameter (mg/L)	Winter	Spring	Summer	Fall
NO_3^-	0.518	0.491	1	0.843
NH_4^+	0.381	0.453	**0.053 ↑**	**0.016 ↑**
cond	**0.009 ↓**	**0.026 ↓**	0.128	**0.053 ↓**
pH	0.127	0.738	0.277	0.363
SO_4^{2-}	<0.001 ↓	0.005 ↓	0.002 ↓	<0.001 ↓
Ca^{2+}	**<0.001 ↓**	0.217	**0.040 ↓**	**0.060 ↓**
Cl^-	<0.001 ↓	0.002 ↓	<0.001 ↓	<0.001 ↓
Na^+	<0.001 ↓	0.061 ↓	0.002 ↓	<0.001 ↓
K^+	**<0.001 ↓**	0.103	0.285	**0.034 ↓**
Mg^{2+}	<0.001 ↓	0.002 ↓	0.004 ↓	0.002 ↓

Table 16—Little Bighorn NADP site Mann-Kendall p-values for seasonal trends. Highlighted cells indicate statistically significant trends using $p < 0.1$. The grey cells indicate parameters that were not available.

Parameter (mg/L)	Winter	Spring	Summer	Fall
NO_3^-	0.460	0.833	0.233	0.286
NH_4^+	**0.009 ↑**	0.119	0.107	**0.003 ↑**
cond	1	0.187	**0.040 ↓**	0.707
pH	0.153	0.597	0.519	0.941
SO_4^{2-}	0.013 ↓	0.009 ↓	0.004 ↓	0.027 ↓
Ca^{2+}	0.509	0.119	0.150	0.472
Cl^-	0.012 ↓	<0.001 ↓	<0.001 ↓	<0.001 ↓
Na^+	0.010 ↓	0.001 ↓	<0.001 ↓	0.002 ↓
K^+	0.111	**0.071 ↓**	0.345	0.188
Mg^{2+}	0.015 ↓	0.011 ↓	0.027 ↓	0.041 ↓

Table 17—Tower Falls NADP site Mann-Kendall p-values for seasonal trends. Highlighted cells indicate statistically significant trends using $p < 0.1$. The Grey cells indicate parameters that were not available.

Parameter (mg/L)	Winter	Spring	Summer	Fall
NO_3^-	0.851	**0.021 ↑**	0.287	0.374
NH_4^+	0.035 ↑	<0.001 ↑	0.004 ↑	0.018 ↑
cond	**0.070 ↓**	1	**0.039 ↓**	0.385
pH	**0.008 ↓**	0.348	0.234	0.285
SO_4^{2-}	<0.001 ↓	0.087 ↓	0.013 ↓	0.038 ↓
Ca^{2+}	**0.001 ↓**	1	0.661	0.594
Cl^-	<0.001 ↓	0.009 ↓	<0.001 ↓	0.002 ↓
Na^+	<0.001 ↓	0.039 ↓	<0.001 ↓	0.072 ↓
K^+	**0.004 ↓**	0.917	0.491	0.213
Mg^{2+}	<0.001 ↓	0.478 ↓	0.055 ↓	0.005 ↓

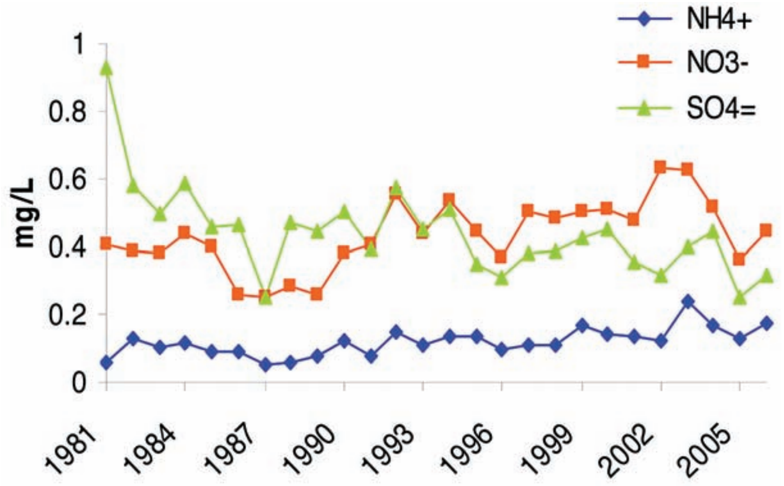

Figure 21—Trends in VWM concentrations during spring at Glacier NADP site.

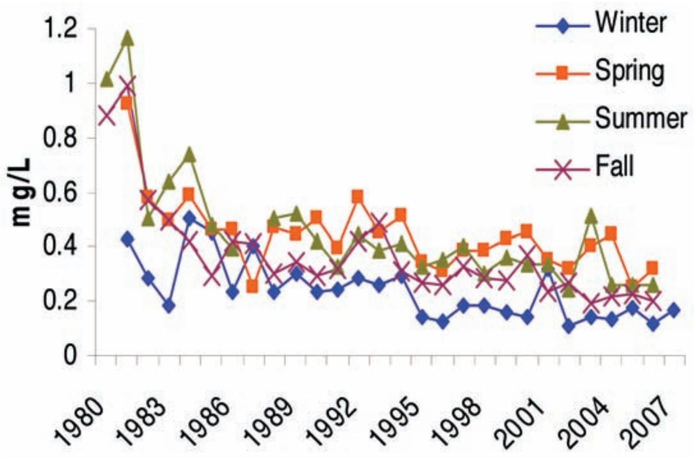

Figure 22—Trends in seasonal sulfate deposition at Glacier NADP site.

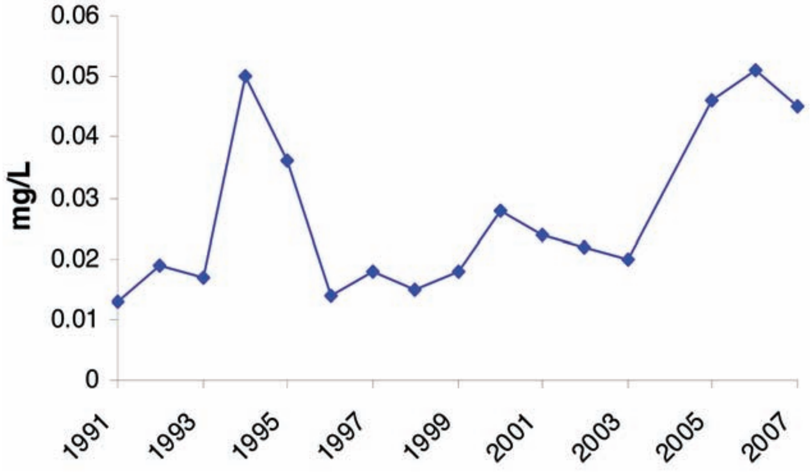

Figure 23—Trends in winter VWM NH_4^+ concentrations at Lost Trail Pass NADP site.

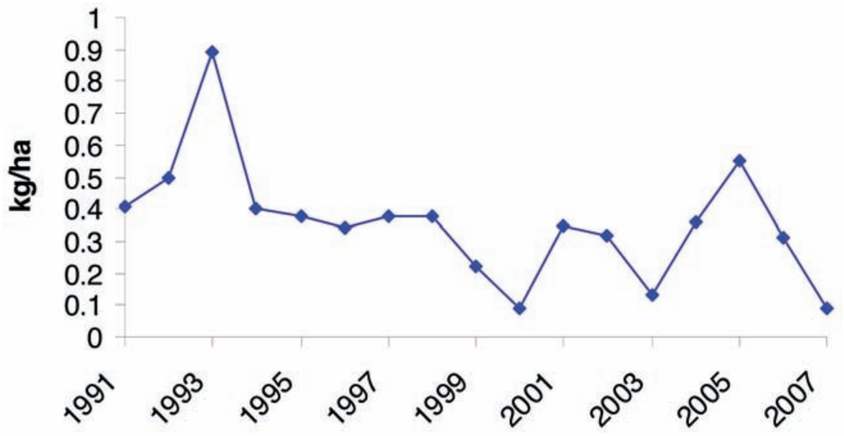

Figure 24—Trends in sulfate deposition during summer at Lost Trail Pass NADP site.

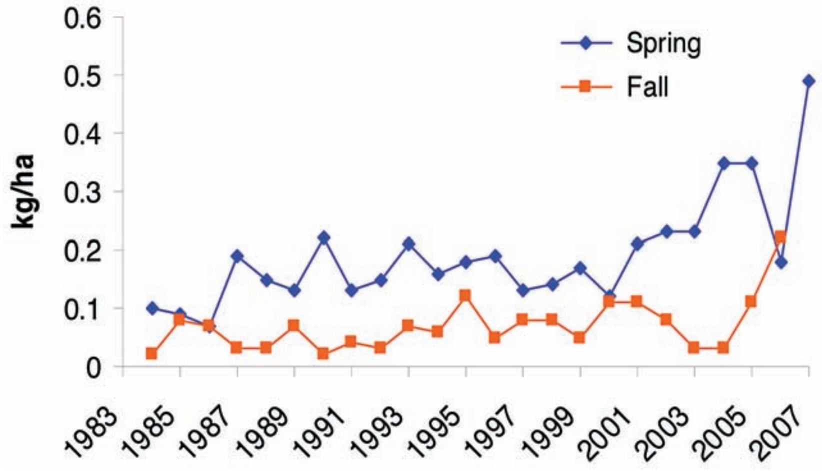

Figure 25—Seasonal trends in NH_4^+ loading at Clancy NADP site.

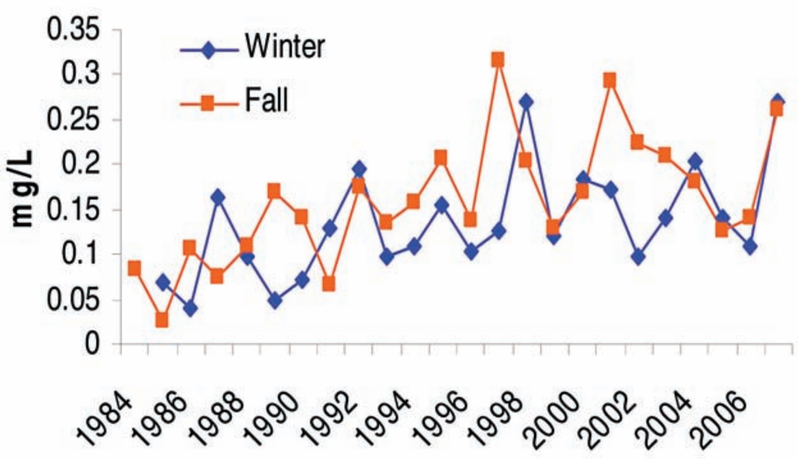

Figure 26—Seasonal trends in NH_4^+ at Little Bighorn NADP site.

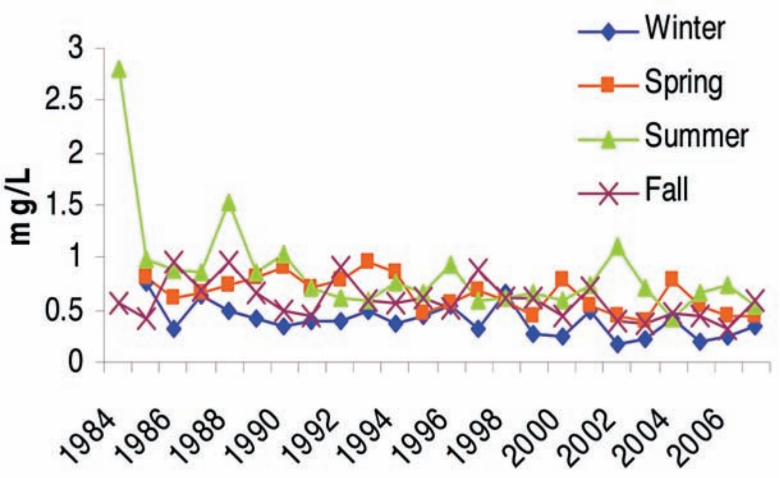

Figure 27—Seasonal trends in sulfate at Little Bighorn NADP site.

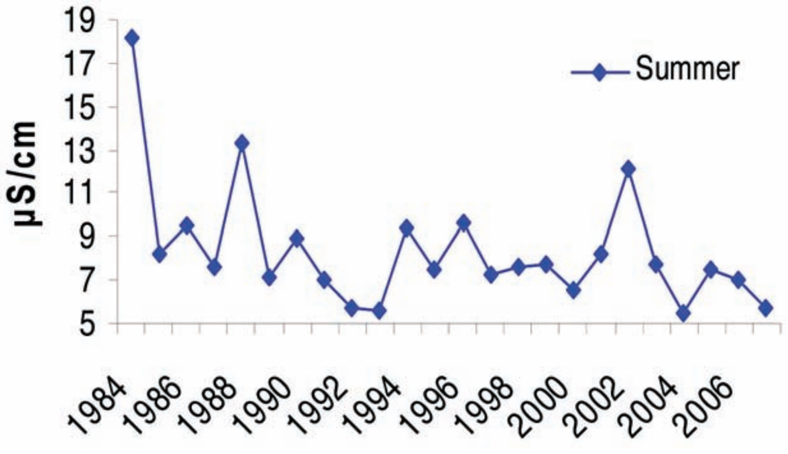

Figure 28—Seasonal summer trend in conductivity at Little Bighorn NADP site.

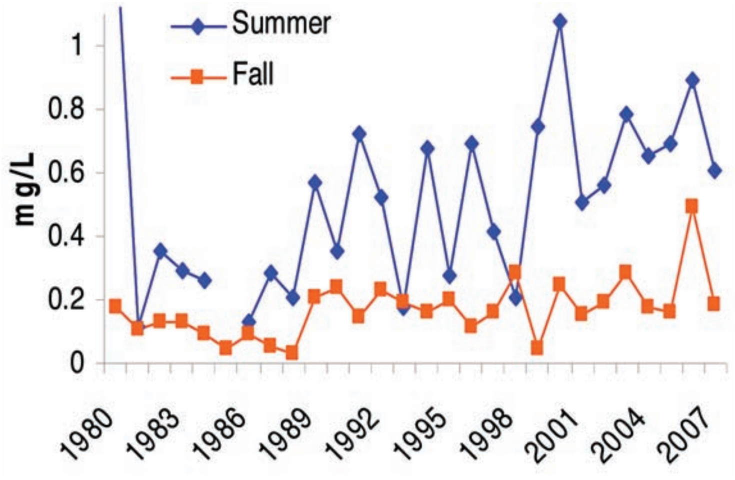

Figure 29—Seasonal trends in NH_4^+ at Craters of the Moon NADP site.

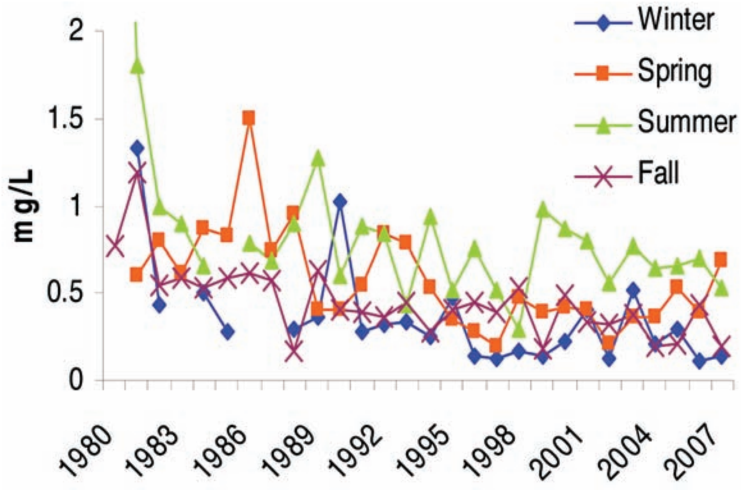

Figure 30—Seasonal trends in sulfate at Craters of the Moon NADP site.

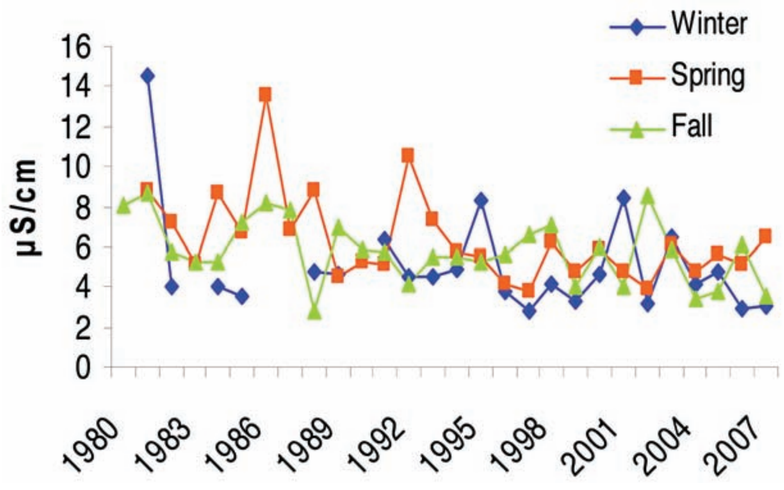

Figure 31—Seasonal trends in conductivity at Craters of the Moon NADP site.

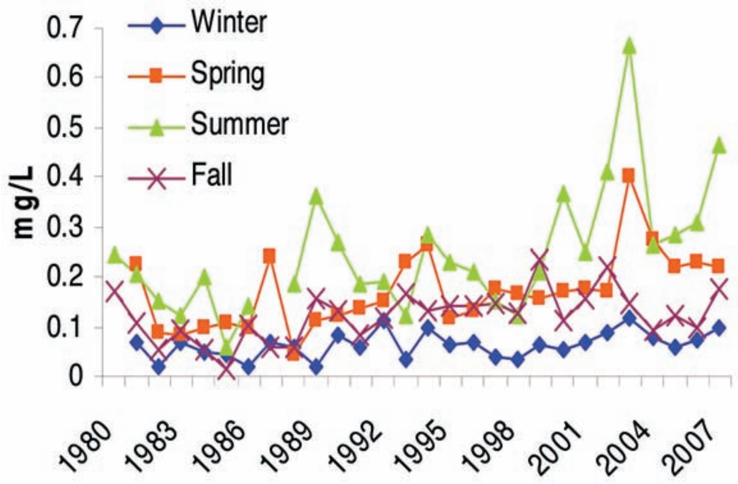

Figure 32—Seasonal trends in NH_4^+ at Tower Falls NADP site.

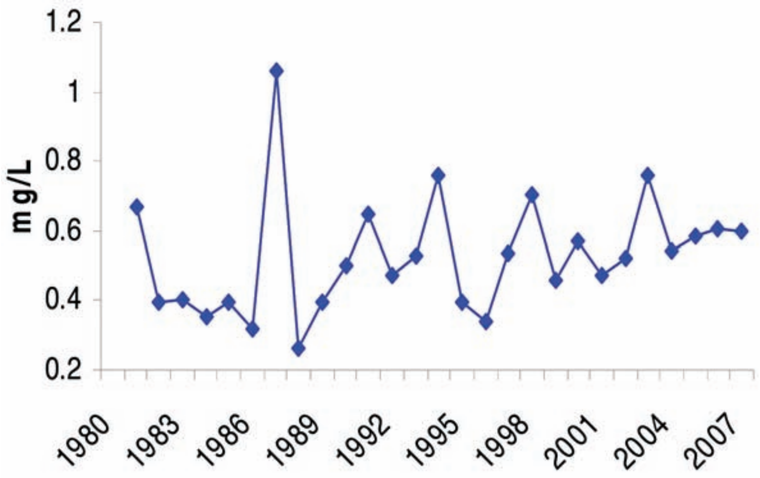

Figure 33—Spring nitrate trend at Tower Falls NADP site.

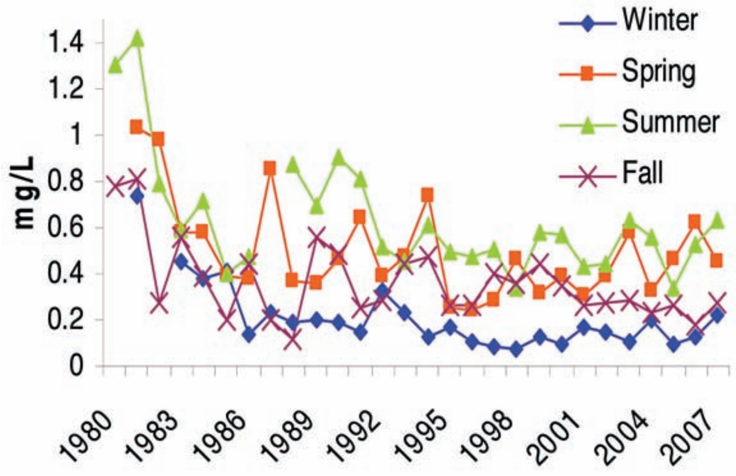

Figure 34—Seasonal trends in sulfate concentration at Tower Falls NADP site.

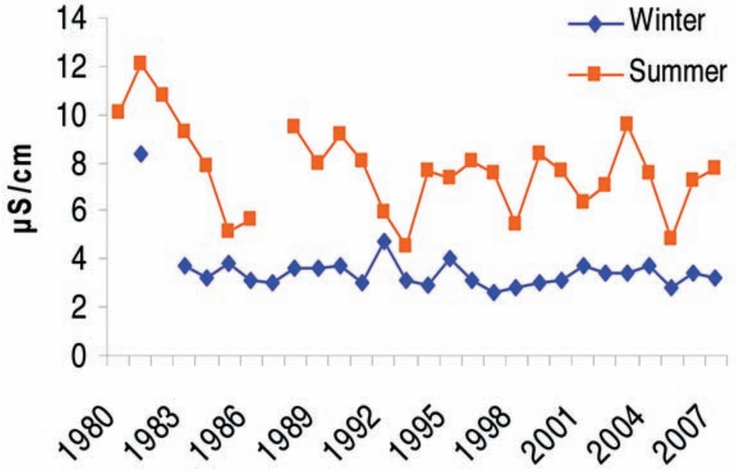

Figure 35—Seasonal trends in conductivity at Tower Falls NADP site.

NADP Data Discussion

The NADP data evaluated only accounts for wet deposition (total deposition also includes dry and fog deposition). In the Northern Rocky Mountains, dry deposition can be a substantial component of total deposition. Data from CASTNet samplers estimate total nitrogen dry deposition in this area to be about 25 to 33 percent of total deposition (Ingersoll and others 2008).

The NADP samplers (Airochem Metrics) were designed to collect rainfall in relatively calm environments; harsher environments (commonly found in mountains) often pose difficulties for data collection. The NADP equipment limitation in winter environments (Goodison and others 1998; Yang and others 2000), and the inefficient NADP sample buckets and rain gage can compromise data collection from high elevation sites, particularly at the MT97 Lost Trail Pass.

The most significant result of the NADP data analysis is the increase trend in ammonia (either concentration or deposition) present within at least one season of the year for all sites. Fenn and others (2003) and the NADP data report (NADP 2007) document consistent increases in ammonia deposition and concentration over much of the western United States. Ingersoll and others (2008) and Bevenger (2008) also documented a moderately significant upward trend in ammonium concentration at NADP sites in the Northern Rockies subregion. In an intensive analysis of NADP trends from 1985 to 2002, Lehman (2004) documents a nationwide NH_4^+ increase, particularly in agriculture areas of the Midwest. The percent increase in NH_4^+ concentration during the 1985 to 2002 period was 30 percent at the Glacier NP NADP site, 57 percent at Clancy, and 46 percent at Yellowstone NP. Lehmann and others (2007) found increases in ammonium concentrations at NADP stations over most of the United States with trends in ammonium to sulfate ratios exceeding 1.0, creating an ammonia rich environment for more than one half of the United States from 2002 to 2004. Fenn and others (2003) found that concentrations of $N0_3^-$ and NH_4^+ at NADP sites in Oregon and Washington have been increasing since monitoring began in 1980. The NH_4^+ increase is attributable to increasing fertilizer and animal feedlot operations. Campbell (2004) indicates that for the Intermountain West, ammonia makes up about one third of the total nitrogen deposition at many sites. Concentrated animal feedlot operations are a large source of NH_4^+ through volatilization from feedlots, waste lagoons, and land-based waste application. Fertilizer production is another large source of atmospheric nitrogen. Galloway (1995) suggests that $N0_3^-$ fertilizer production has resulted in NH_3 emissions and in time can cause delayed ecosystem acidification.

The less pronounced nitrate trend (mg/L) found at Tower Junction and Glacier during spring is consistent with Lehmann and others (2005). They found that in the northeast United States, $N0_3^-$ concentration trends have decreased by 25 percent due to the 1990 Clean Air Act amendments that mandated emission reductions for stationary sources. Lehmann and others (2005), however, have also found that $N0_3^-$ concentrations in the Rocky Mountains have generally increased, particularly around urban areas with large transportation sources. In the western United States, nitrate increases are most closely associated with proximity to urban areas (Fenn and others 2003). Particularly notable is the Colorado Front Range (Nanus and others 2008), where $N0_3^-$ in wet deposition and lakes are elevated. Nanus and others (2008) also reported a statistical correlation in $N0_3^-$ ($p < 0.05$) from lakes and $N0_x$ emissions within 300 km from Rocky Mountain NP, Grand Teton NP, Great Sand Dunes NP, and Yellowstone NP with the strongest correlations in the central and southern Rockies in Colorado.

This NADP analysis has documented consistent decreasing trends in SO_4^{2-} deposition SO_2 emissions dissolve in atmospheric water vapor forming sulfurous acid (H_2SO_3), which is rapidly oxidized by dissolved O_2 to H_2SO_4 allowing SO_4^{2-} deposition (Kellogg and others 1972). This trend is consistent with a 43 percent decrease in national SO_2 emissions from 1990 to 2007 and a 24 percent decrease from 2001 to 2007 (EPA 2008). The EPA (2008) also documented statistically significant decreases in net SO_2 emissions found in Glacier NP and Yellowstone NP from 1990 to 1999 with at 27 percent decrease at both sites. This widespread decrease in SO_4^{2-} deposition is also a result of the Clean Air Act 1990 amendment provisions as well as closure and/or emission reductions of several smelters and coal burning power plants in the western United States. Lehmann and others (2005) documented sulfate reduction in the 1985 to 2002 period at all of the western U.S. NADP sites including Glacier NP (47 percent reduction), Clancy (49 percent reduction), Yellowstone NP (39 percent reduction), Priest Lake (45 percent reduction), and Craters of the Moon (66 percent reduction).

Several of the NADP sites showed statistically significant decreasing trends in Ca^{2+}, Cl^-, Na^+, K^+, and Mg^{2+} deposition ($p \leq 0.1$). Recent trends in Colorado report 9 of 10 high elevation NADP sites had statistically significant decreasing Na^+ and Cl^- ($p \leq 0.01$) (Mast, personal communication). These findings are also consistent with reported declines in base cations for the eastern United States and parts of Europe (Hedin and others 1994). In 1990 the Clean Air Act Amendments put stronger restrictions on emissions. In 1994 a change was made in the type of filter used for NADP protocol/procedures at the CAL (Lynch and others 1996). Both of these changes may account for a portion of the cation and anion decreases observed, but not all. Other environmental factors contributing to cation and anion decreases may be due to overall emission decreases but are not readily explained.

IMPROVE Visibility Analysis and Trends

Air pollution has significantly impacted visibility throughout many National Parks and Wilderness areas. Visibility in USFS R1 has been monitored in coordination with the Interagency Monitoring of Protected Visual Environments (IMPROVE) program (http://vista.cira.colostate.edu/improve/) since 1988. Many IMPROVE monitors were established in MT during 2000, figure 36 shows locations of IMPROVE sites in R1 and figure 37 shows an example of an IMPROVE station. Trend data can be graphed using this website but the data was only available through 2004 at the time of this report.

The USFS currently operates four IMPROVE sites in Region 1: CABI1 (which monitors visibility for the CMW), GAMO1 (GMW), MONT1 (Wilderness Class I areas: BMW, MMW, and SGW, and Wilderness Class II areas: RW and WCW), and SULA1 (APW and SBW). Three additional IMPROVE sites are in close proximity and can also be used for wilderness airshed analysis: GLAC1 (located at Glacier National Park and closest to the GBW), YELL2 (located at Yellowstone National Park and closest to the ABW and LMW), and HECA1 (located in the Hells Canyon National Recreation Area and closest to the GHW). Data was analyzed for the following seven IMPROVE sites mentioned above: CABI1, GAM01, GLAC1, HECA1, MONT1, SULA1, and YELL2. All of these sites are valley bottom to lower slopes except for GAM01 and SULA1, which are on the summit of small peaks.

Fine particulate matter is a major contributor to reduced visibility (haze). Particulates can occur from natural sources such as volcanoes, dust, and wildland fires or from anthropogenic sources including industrial, agricultural, vehicles, municipalities, prescribed fire and agricultural burning. Fine particles both absorb and reflect light. Absorption and scattering of light affects haze color and visibility reduction. The type (sulfates, nitrates, etc.) and the condition (humid, dry, etc.) of the pollution particle affect how much light is scattered.

The deciview unit (dv) is a haze index that is a measure of visibility derived from calculated light extinction measurements. Uniform changes in the haze index correspond to uniform incremental changes in visual perception across the entire range of conditions from pristine to highly impaired. The haze index (dv) is calculated directly from the total light extinction (best expressed in inverse megameters, Mm-1): $HI = 10 \ln(b_{ext}/10)$. Deciview decreases as standard visual range (SVR) increases. Examples of high and low visibility days and corresponding dv and SVR for Yellowstone NP (YELL2) are shown in figure 38.

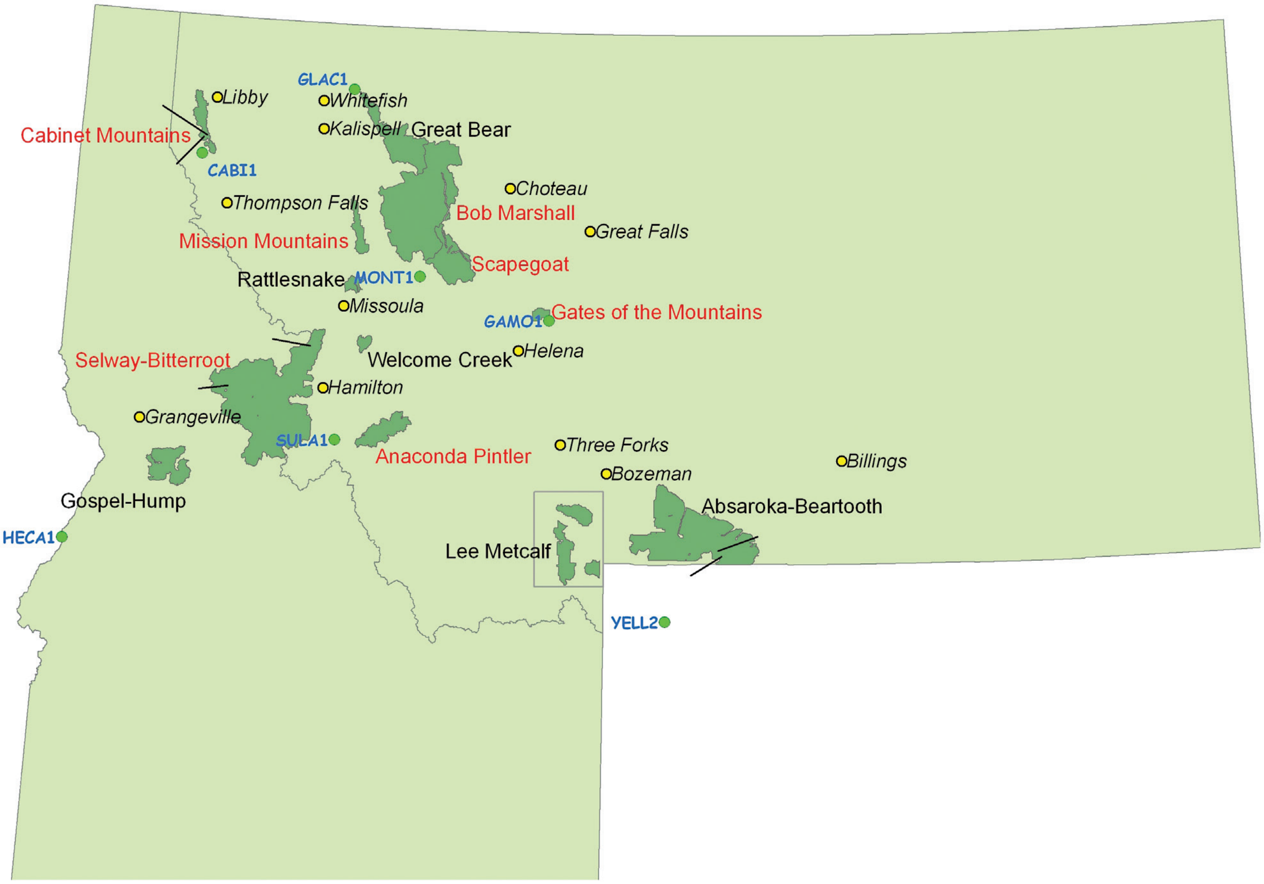

Figure 36—IMPROVE monitoring site locations relative to wilderness areas in USFS R1.

Figure 37—Monture Guard Station IMPROVE site (MONT1), Lolo National Forest. This site is slightly influenced by emission sources in the Bitterroot valley, particularly Missoula. This site houses four modules that pump air in 24 hour periods on Wednesdays and Saturdays. Filters are changed each Tuesday then sampled for a wide variety of chemical air quality constituents. A visibility camera associated with the site is located at Ovando, Montana.

GLAC1 (all parameters), YELL2 (all parameters), and SULA1 (SO_4^{2-} , Esoil, Salt, and MF only) are the only IMPROVE sites with >8 years of data. Data collection at CAB1, GAMO1, HECA1, and MONT1 began in 2000. Eight observations are the minimal number suggested in the Data Analysis Protocol to run the Mann-Kendall and Seasonal Mann-Kendall tests, though more observations increase the confidence of the test. Trends in ESO4, ENO3, EOMC (organic mass from carbon), Esoil (fine soil), ECM (coarse mass), ELAC (light absorbing carbon), Esea_salt (documented as salt in tables), Rb_{ext} (sum aerosol extinctions), SVR, dv, MF ($PM_{2.5}$), MT (PM_{10}) were tested (table 18).

Figure 38—Yell2 IMPROVE Spectrum Series photos in Yellowstone National Park on a clear day (top photo) and on a hazy day (bottom photo). The clear day photo has a dv = 0, B_{ext} = 10, SVR = 390, and the hazy day has a dv = 17, B_{ext} = 52, SVR = 75.

Table 18—IMPROVE parameter symbols and definitions.

Parameter	Definition
ESO_4	Sulfate extinction Mm-1
ENO_3	Nitrate extinction Mm-1
EOMC	Organic Mass from Carbon Mm-1
Esoil	Fine Soil Mm-1
ECM	Coarse Mass Mm-1
ELAC	Light Absorbing Carbon Mm-1
Esea_salt	Sea salt Mm-1
Rb_{ext}	Sum aerosol extinctions Mm-1
SVR	Standard Visibility Range km
dv	Deciview dv
MF	$PM_{2.5}$ µg/m^3
MT	PM_{10} µg/m^3
E prefix	Extinction coefficient Mm-1

*Esoil is referred to as SOIL in graphs, tables and text.
*Esea_salt is referred to as salt in graphs, tables, and text.

Annual IMPROVE Site Trends

SVR increased significantly at GLAC1 and YELL2. Significant decreases in sulfate and nitrate were present at GLAC1. EOMC, ECM, salt Rb_{ext}, dv, MF, MT, and ELAC had decreased trends at GLAC1. YELL2 had decreased trends in EOMC, Esoil, ECM, MF and MT. MF decreased at SULA1. Trend direction and p-values are recorded in table 19. The values based on less than eight observations are displayed in pink cells to qualify the values as provisional until the database receives sufficient additional monitoring data to achieve eight observations. Selected graphs are illustrated in figures 39 to 42.

Seasonal Trends at IMPROVE Sites With at Least 8 Years of Data

GLAC1, YELL2, and SULA1 were analyzed with the Mann-Kendall test to evaluate statistically significant trends for each parameter through each season (winter, spring, summer, and fall). Results are presented in tables 20 to 22 and figures 43 to 56. Figures 57 to 62 show the 25 percent best and worst SVR and dv days at GLAC1, YELL2, and SULA1.

Table 19—Statistically significant annual IMPROVE trends found with the Mann-Kendall light blue cells and with Seasonal Mann-Kendall tests yellow cells are bolded. The grey cells indicate parameters that were not available. Pink cells are possible trends run with the Mann-Kendall test that are not validated/statistically sound because there are less then eight observations. P values < 0.1 signify a trend, ↑ and ↓ signifies increasing and decreasing trends/Sen's Slope direction. IMPROVE parameter units are listed in table 18.

Parameter	CABI1	GAMO1	GLAC1	MONT1	SULA1	YELL2	HECA1
ESO_4	0.23	1	**0.035 ↓**	0.764	0.2	0.798	0.368
ENO_3^-	0.036 ↓	0.016 ↓	**0.044 ↓**	0.016 ↓	<0.001 ↓	0.199	0.23
EOMC	0.548	1	**0.018 ↓**	0.764	<0.001 ↓	**0.033 ↓**	0.764
Esoil	1	1	0.766	0.548	0.629	**0.073 ↓**	0.548
ECM	0.368	0.548	**0.006 ↓**	0.23	0.002 ↓	**0.087 ↓**	0.764
Salt	0.133	1	**0.041 ↓**	0.23	0.428	0.756	0.072 ↓
R_{bext}	0.368	0.764	**0.012 ↓**	0.133	<0.001 ↓	0.124	0.764
SVR	0.133	0.072 ↑	**0.022 ↑**	0.036 ↑	0.003 ↑	**0.040 ↑**	0.133
dv	0.133	0.23	**0.004 ↓**	0.133	<0.001 ↓	0.123	0.23
MF	0.23	0.23	**<0.001 ↓**	0.133	**0.0572 ↓**	**0.003 ↓**	0.764
MT	▨	▨	**<0.001 ↓**	0.133	<0.001 ↓	**0.016 ↓**	0.548
ELAC	1	1	**0.011 ↓**	0.548	<0.001 ↓	0.392	0.764

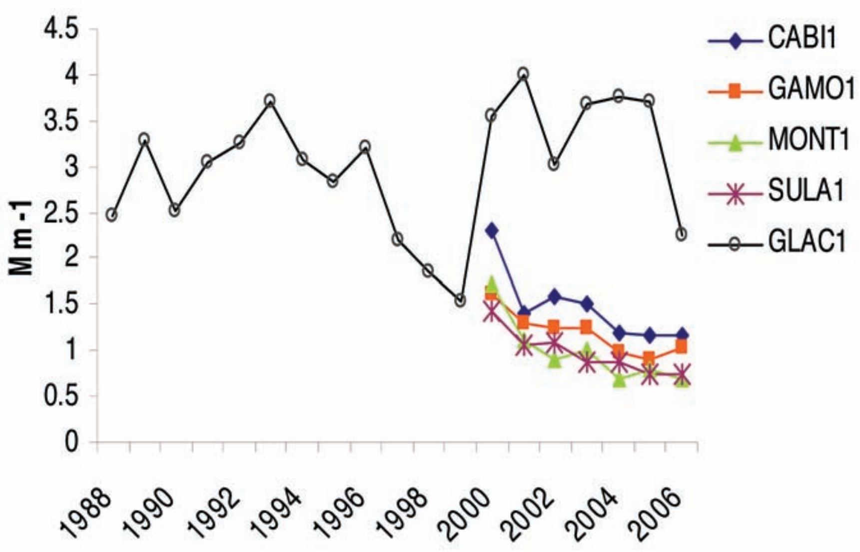

Figure 39—Trends in annual NO_3^- at IMPROVE sites. *Only GLAC1 site is statistically validated with at least 8 observations.

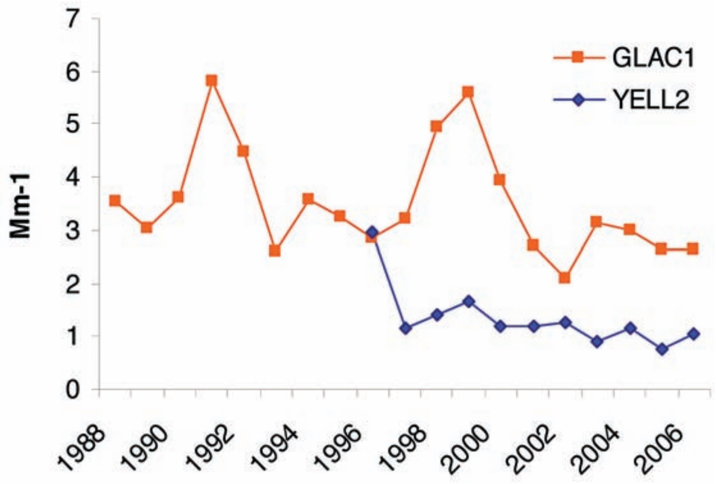

Figure 40—Trends in annual ECM at IMPROVE sites.

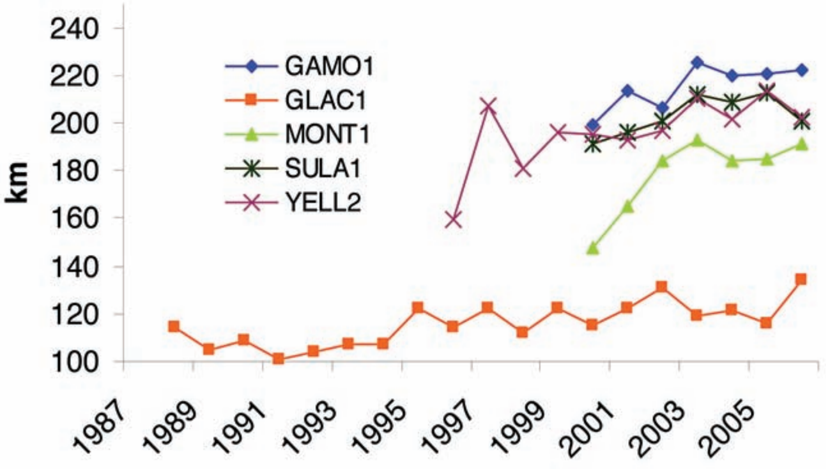

Figure 41—Trends in annual SVR at IMPROVE sites.

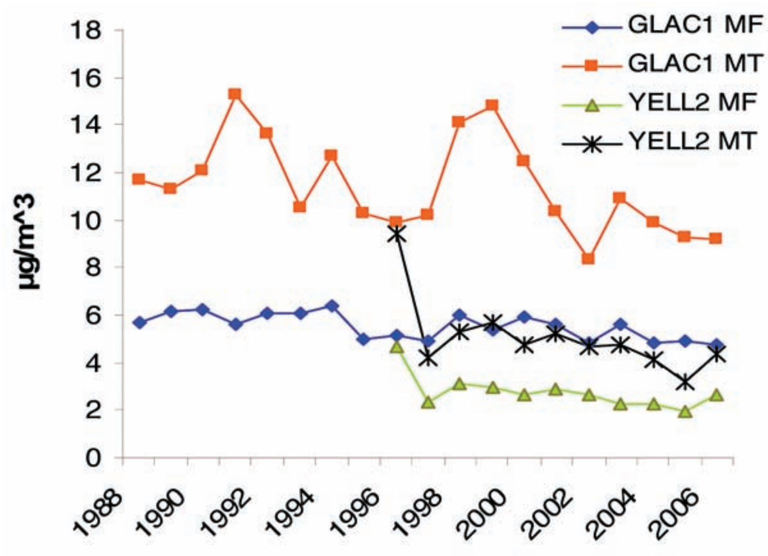

Figure 42—Trends in annual MT and MF at IMPROVE sites.

Table 20—GLAC1 IMPROVE site Mann-Kendall p-values for each season. Highlighted cells indicate statistically significant trends using $p < 0.1$.

Parameter	Winter	Spring	Summer	Fall
ESO_4	0.363	1	**0.003 ↓**	**0.050 ↓**
ENO_3	0.442	**0.002 ↓**	**0.093 ↓**	0.944
EOMC	**0.006 ↓**	0.142	0.401	0.184
Esoil	**0.025 ↓**	1	**0.093 ↑**	0.944
ECM	**0.003 ↓**	0.401	0.726	**0.050 ↓**
ELAC	**0.030 ↓**	0.401	0.442	**0.005 ↓**
salt	0.142	0.294	0.889	0.184
Rb_{ext}	**0.025 ↓**	0.142	0.675	**0.093 ↓**
SVR	0.624	**0.069 ↑**	0.944	**0.021 ↑**
dv	**0.042 ↓**	**0.059 ↓**	0.889	**0.050 ↓**
MF	**0.003 ↓**	**0.036 ↓**	1	**0.080 ↓**
MT	**0.030 ↓**	0.401	0.442	**0.005 ↓**

Table 21—YELL2 IMPROVE site Mann-Kendall p-values for each season. Highlighted cells indicate statistically significant trends using $p < 0.1$.

Parameter	Winter	Spring	Summer	Fall
ESO_4	1	0.152	0.161	0.756
ENO_3	0.466	0.283	0.756	0.276
EOMC	**0.076 ↓**	0.210	1	0.160
Esoil	1	1	0.120	0.120
ECM	1	1	0.213	**0.062 ↓**
ELAC	0.917	0.721	0.756	0.161
salt	0.754	0.858	0.276	0.436
Rb_{ext}	0.917	0.721	0.436	**0.013 ↓**
SVR	0.917	1	0.161	**0.013 ↑**
dv	0.754	0.721	0.276	**0.020 ↓**
MF	**0.048 ↓**	0.474	0.350	**0.029 ↓**
MT	0.118	0.721	0.436	**0.062 ↓**

Table 22—SULA1 IMPROVE site Mann-Kendall p-values for each season. Highlighted cells indicate statistically significant trends using $p < 0.1$.

Parameter	Winter	Spring	Summer	Fall
ESO_4	0.115	0.304	**0.077 ↓**	0.200
Esoil	0.537	1	0.760	1
salt	0.837	**0.016 ↓**	0.855	0.300
MF	**0.064 ↓**	0.115	0.855	0.502

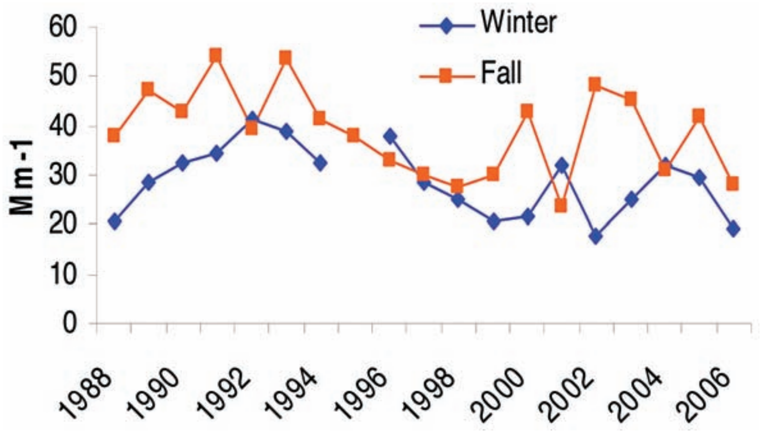

Figure 43—Seasonal trends in Rb_{ext} at GLAC1 IMPROVE site.

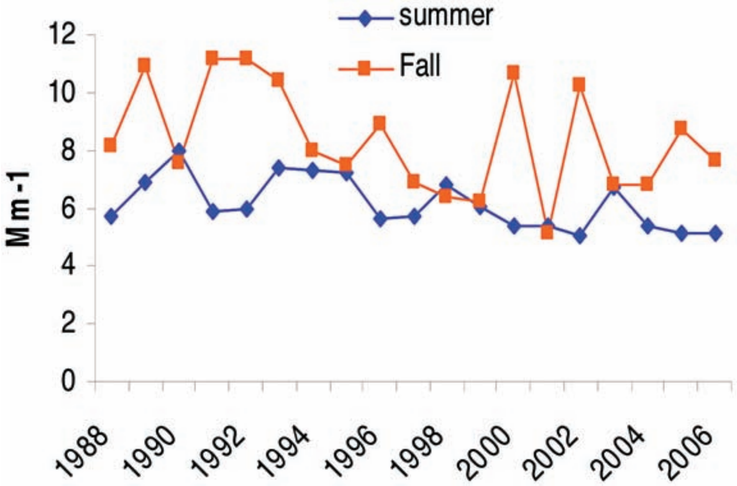

Figure 44—Seasonal trends in SO_4^{2-} at GLAC1 IMPROVE site.

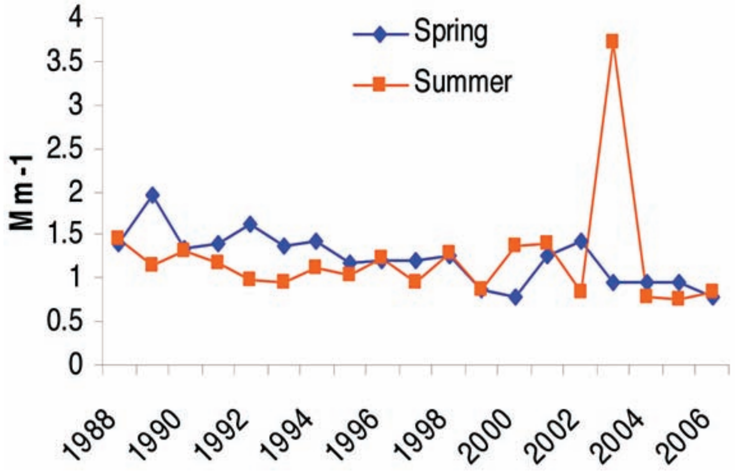

Figure 45—Seasonal trends in NO_3^- at GLAC1 IMPROVE site.

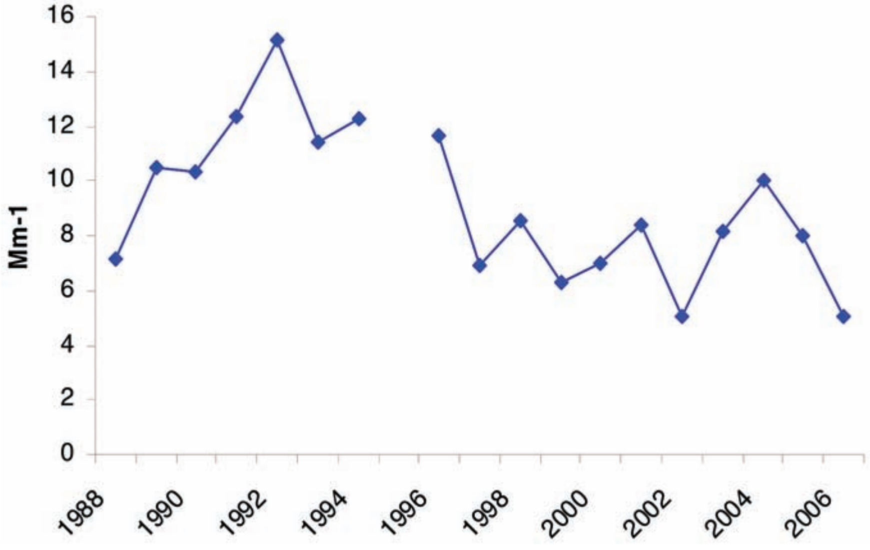

Figure 46—Winter trend in EOMC at GLAC1 IMPROVE site.

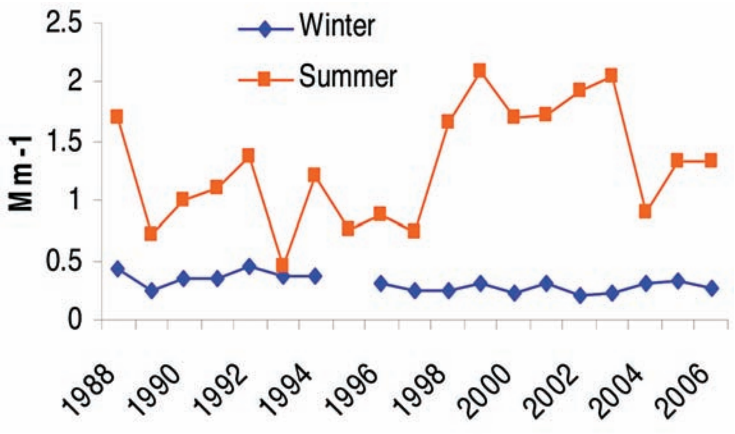

Figure 47—Seasonal trends in Esoil at GLAC1 IMPROVE site.

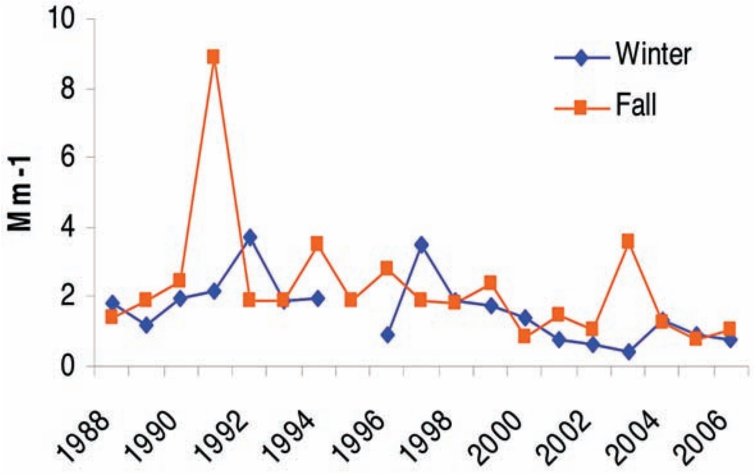

Figure 48—Seasonal trends in ECM at GLAC1 IMPROVE site.

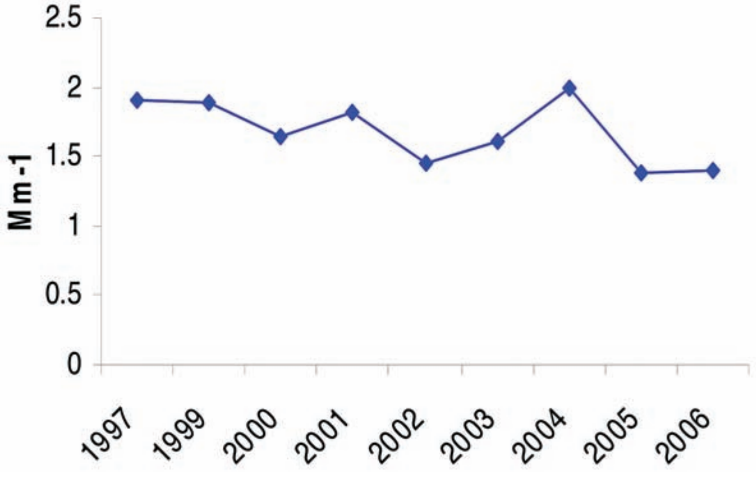

Figure 49—Seasonal winter trend in EOMC at YELL2 IMPROVE site.

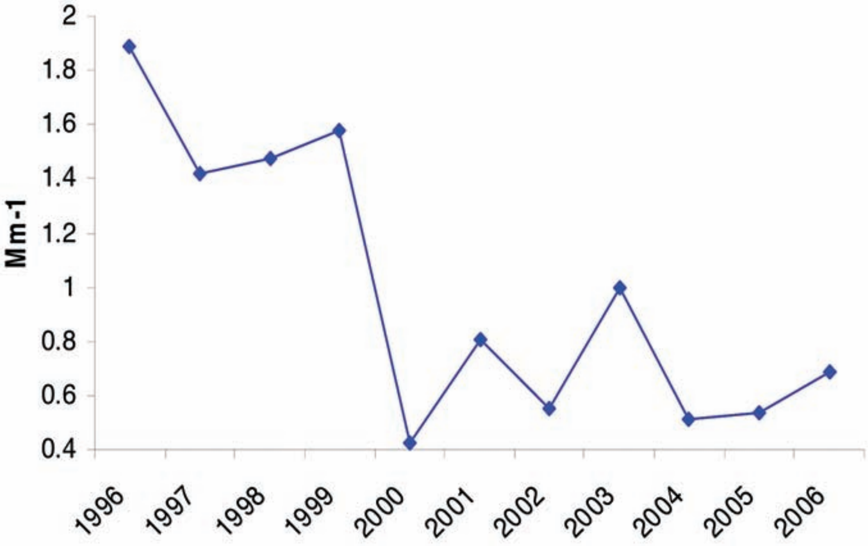

Figure 50—Seasonal fall trend in ECM at YELL2 IMPROVE site.

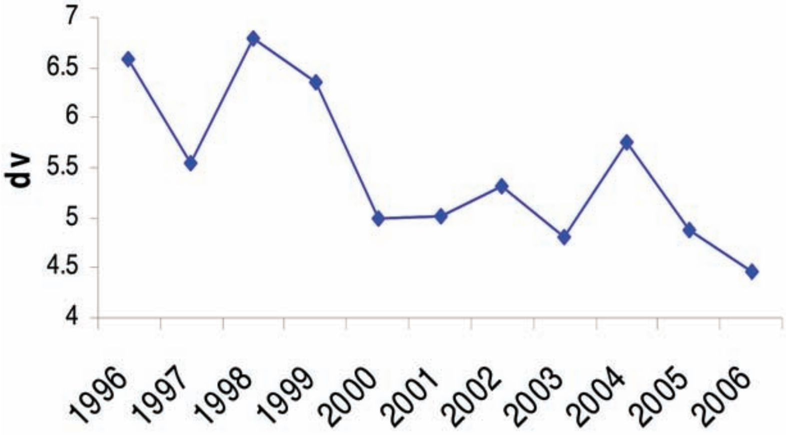

Figure 51—Seasonal fall dv trend at YELL2 IMPROVE site.

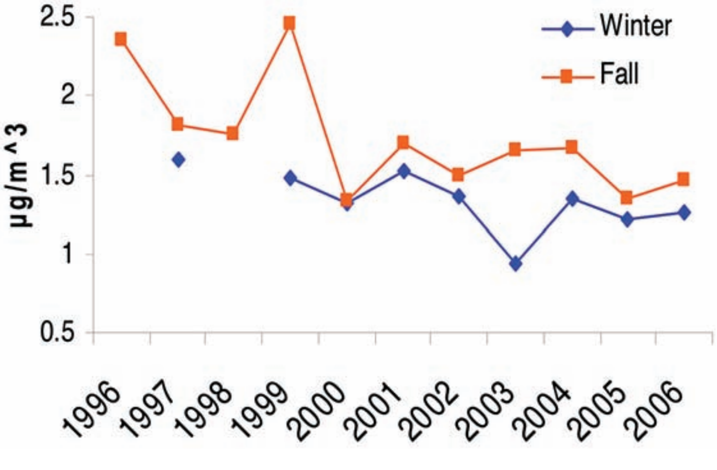

Figure 52—Seasonal trends in MF at YELL2 IMPROVE site.

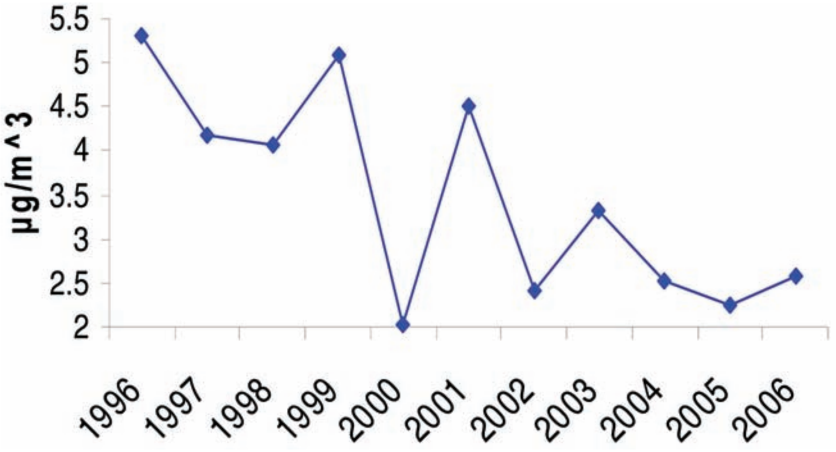

Figure 53—Seasonal fall MT trend at YELL2 IMPROVE site.

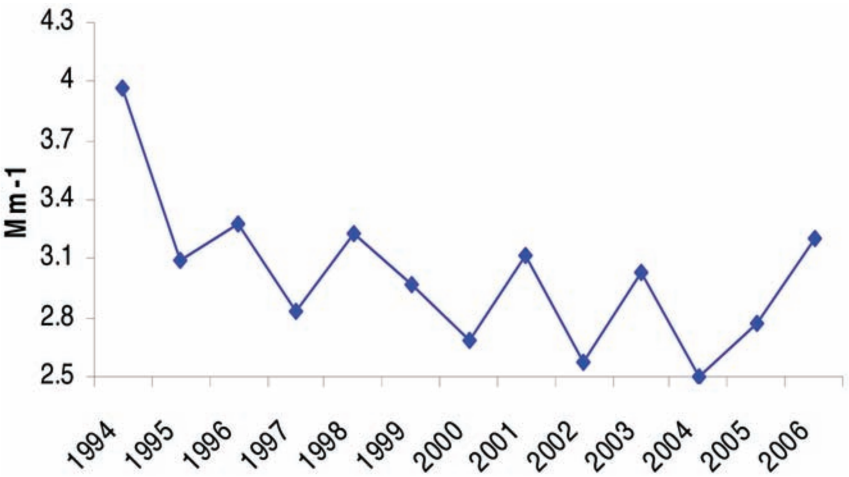

Figure 54—Seasonal summer trend in SO_4^{2-} at SULA1 IMPROVE site.

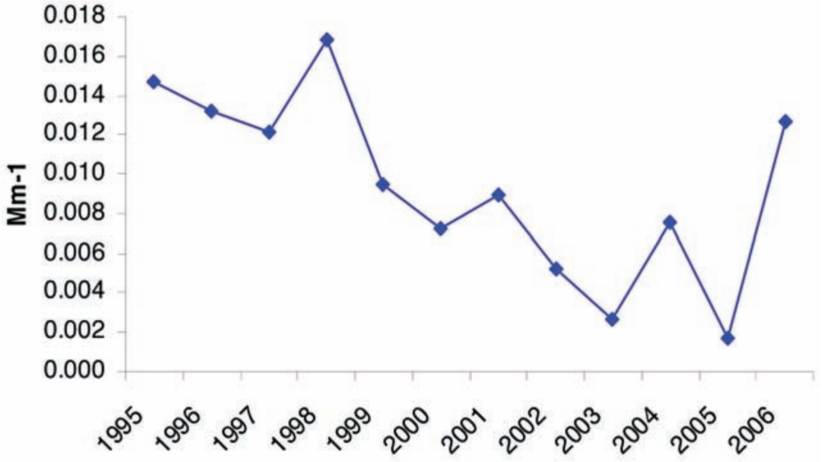

Figure 55—Seasonal spring trend in salt at SULA1 IMPROVE site.

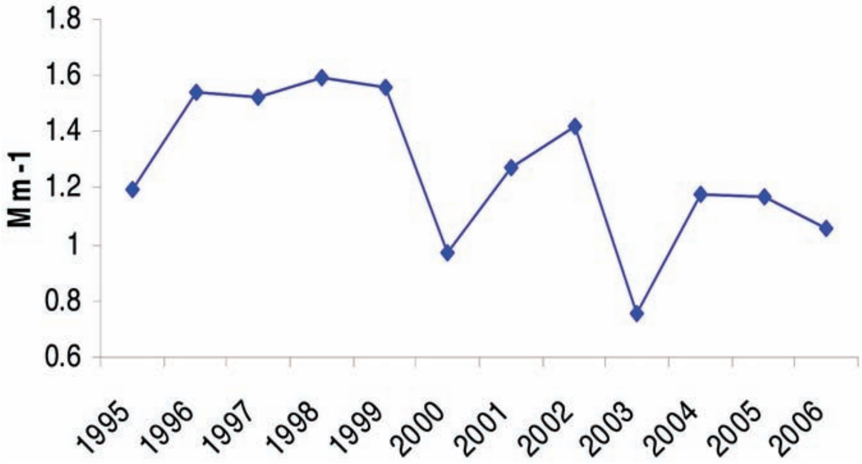

Figure 56—Seasonal winter trend of MF at SULA1 IMPROVE site.

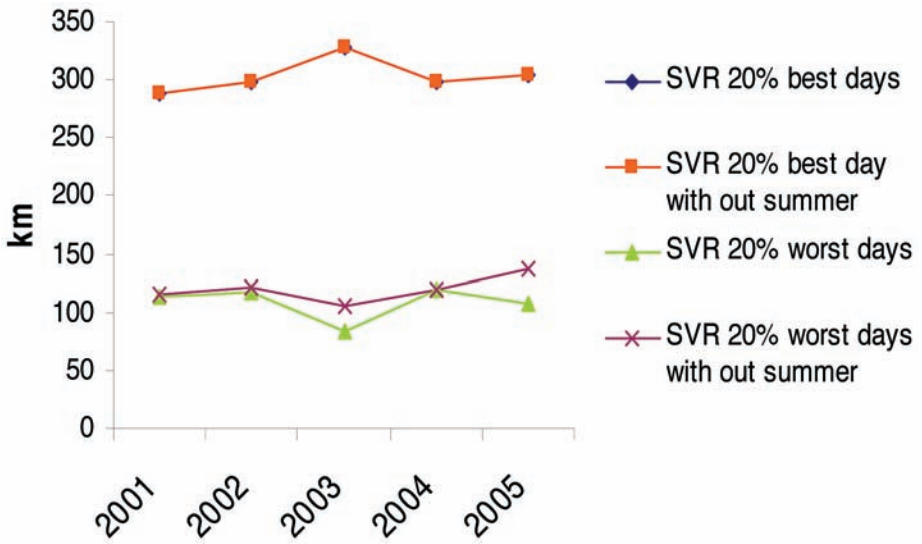

Figure 57—SULA1 SVR 20% best and worst days. *Not statistically validated because only 6 observations are available (at least 8 observations are needed for statistical significance). For this graph summer includes the months of July, August, and September.

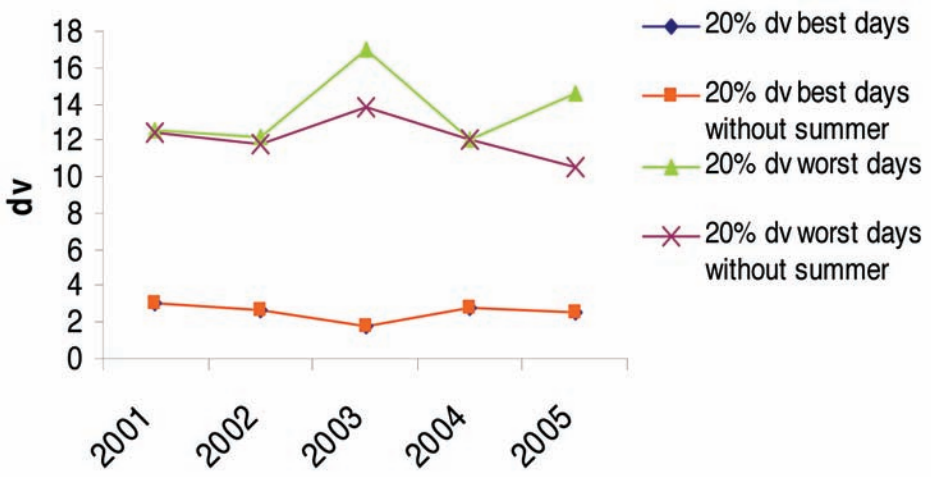

Figure 58—SULA1 dv 20% best and worst days. *Not statistically validated since only 5 observations are available (at least 8 observations are needed for statistical significance). For this graph summer includes the months of July, August, and September.

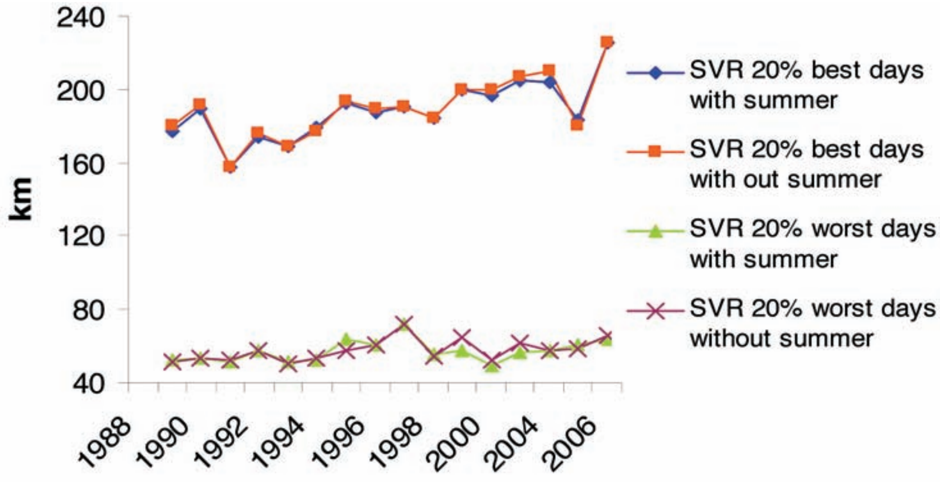

Figure 59—GLAC1 SVR 20% best and worst days. For this graph summer includes the months of July, August, and September.

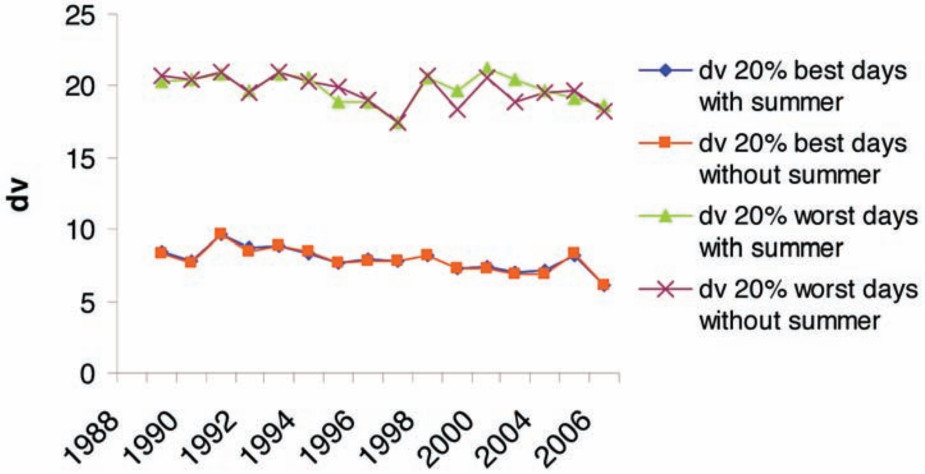

Figure 60—GLAC1 dv 20% best and worst days. For this graph summer includes the months of July, August, and September.

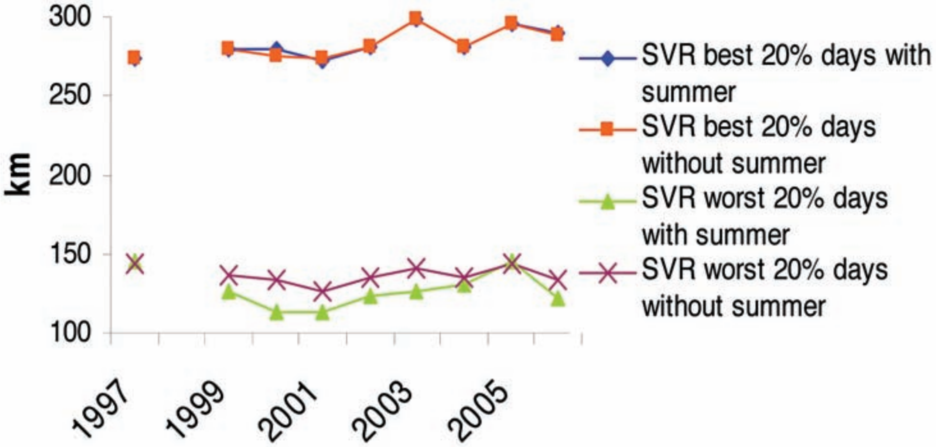

Figure 61—YELL2 SVR 20% best and worst days. For this graph summer includes the months of July, August, and September.

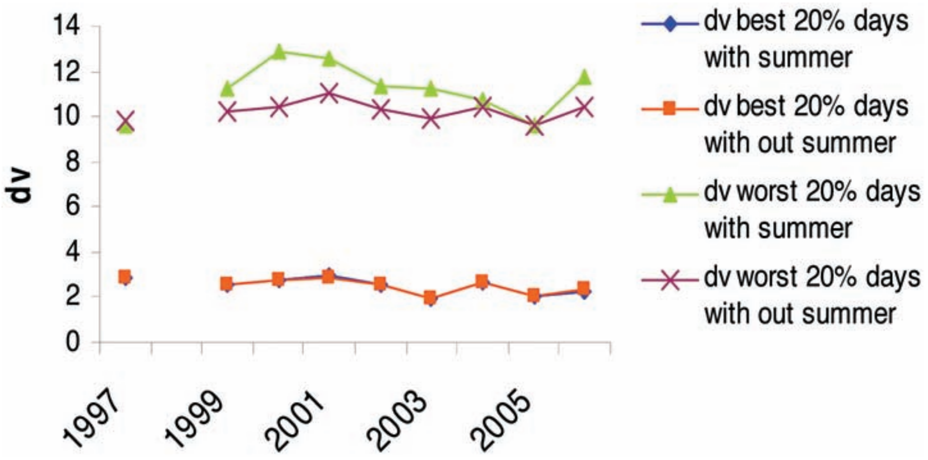

Figure 62—YELL2 dv 20% best and worst days. For this graph summer includes the months of July, August, and September.

IMPROVE Data Discussion

The USFS R1 IMPROVE data provided evidence of improving visibility through the period of record. A consistent reduction in dv and increase in SVR occurred at all sites and for all seasons analyzed. The analysis also documented a general decrease in SO_4^{2-}, NO_3^-, ECM, fine soil, EOMC, MF ($PM_{2.5}$), and MT (PM_{10}). Generally the lowest visibility (highest RB_{ext} and highest dv) occurred in 2000 and 2003, which were robust wildland fire years in Idaho and Montana. IMPROVE data from the massive wildland fire years of 2006 and 2007 in Montana and Idaho were not available at the time of this report.

The USFS R1 analysis is generally consistent with EPA (2008) findings that no Class 1 IMPROVE sites had statistically significant upward trends for any of the extinction parameters evaluated. Visibility during the 20 percent best, median, and worst days improved at all sites except at Glacier NP, where visibility deteriorated during the worst 20 percent of days, presumably due to the massive Glacier NP wildfires in 2000 and 2003. Green and Xu (2006) concluded that Glacier NP had reduced extinction coefficients for the 20 percent best visibility days and middle 60 percent days, but increased extinction coefficients for the 20 percent worst days. The Green and Xu (2006) analysis also concluded that Glacier NP had an increasing trend in organic carbon, fine soil, and nitrate on the 20 percent worst days. The EPA (1996) indicated that the greatest concentration of organic carbon and associated particulate extinction that occurred in the northwestern United States (with 50 to 60 percent of extinction due to carbon) was at SULA1 and MONT1.

Decreasing seasonal R_{bext} trends were present during winter and fall at GLAC1 and fall at YELL2. The EPA (1996) reported that the Rb_{ext} in the northwestern United States urban regions peaked in the winter due to increased light scattering from ammonium nitrite and organics (presumably due to winter inversions). The ammonium sulfate light scattering in the northwestern United States is unique in that it does not peak in the summer months; in Boise, Idaho, and Missoula, Montana, sulfate light scattering peaks in the coldest months (Debelle 2006). These general decreasing Rb_{ext} trends are consistent with the overall pattern of increasing SVR and decreasing dv in the northwestern United States.

Overall Conclusions

Due to limited sampling dates, period of record, and/or lack of seasonal data, trend interpretation is difficult for much of the USFS R1 lake monitoring. Lake ANC decrease was not statistically validated except at Stepping Stone Lake. The pH increasing trend and decrease in lake cation trends are not readily explained. Continued monitoring and expansion of the period of record may allow clearer trend definitions of lake chemistry in the future.

The most consistent finding in the data analysis was the consistent ammonia increase trend at NADP sites. This trend is occurring over much of the western United States and may be partially due to increased agriculture emissions such as feedlots in Montana, Idaho, eastern Washington, and eastern Oregon. The nitrate increases at the NADP sites and in the lakes is not as consistent as the ammonia increase at the NADP sites.

The decrease in SO_4^{2-} at NADP sites in R1 is consistent with overall U.S. trends during the last two decades coinciding with reduced industrial sulfate, largely due to reductions in powerplant emissions.

Visbility improvements, evidenced by increased SVR, decreased dv, and reduced light extinction were observed at most of the IMPROVE sites. The decreasing SVR at some of the sites on the 20 percent worst days corresponded to years with large wildland fires (regional and local) since 2000 and periodic significant visibility reduction due to smoke. Overall, IMPROVE chemistry and visibility trend data correlated well with wildland fire emissions.

The trends reported above should be used only as indicators of possible current and future changes in air quality, water chemistry, and ecosystem health. Because the periods of record for the datasets are short, the trends identified may change in the future as more data is collected. Continued analysis will be required to monitor current trends and help determine their causes.

Considerations

High elevation lakes in USFS R1 may remain frozen through much of the year and initial ice-free conditions can vary from mid-June to early August. This, along with difficult access, makes multiple sampling during different hydroperiods each year logistically difficult. A recommended solution to deal with seasonality that affects lake chemistry is to sample each lake once during the same hydroperiod each year. To gain a more comprehensive and accurate knowledge of lake chemistry flux dynamics, samples of each lake's inlet, outlet, and hypolimnion could be added to the current sampling protocol. This would be most physically appropriate for North Kootenai Lake, Lower Libby Lake, and the NE inlet and outlet of Twin Island Lake. Coring of lake sediments shows promise to understanding trends of metal accumulation from atmospheric deposition sources and nitrogen critical loads (Baron and others 1986). Recent research has explored the utility of high-elevation lake sediment coring and the relationship between shifting diatom communities, hindcasting nitrogen emissions and population growth, and then deriving critical loads (Baron 2006). Coring of at least one of the Phase 3 lakes in each of the ABW, CMW, and SBW for metal, diatom, and nitrogen analysis could be diagnostic of long-term air quality trends and help determine critical load values for sensitive ecosystems in USFS R1.

In USFS R1, NADP provides the largest dataset for air-quality analysis. Although trends were analyzed, there is much analysis that could be done with the data at the site and regional level. For example, NADP deposition (kg/ha) data can be used in conjunction with critical load levels of nitrogen and sulfur for R1 to better identify and predict ecosystem health and anthropogenic threats. Continued monitoring of the Lost Trail Pass NADP site is recommended since the site is the only high elevation NADP site in Idaho or Montana and a key atmospheric deposition site for several R1 Class I and Class II wilderness areas. Although not directly tied to USFS R1 funding, the other NADP sites evaluated in this report are particularly valuable to the USFS R1 air quality program.

IMPROVE monitoring provides an invaluable historic and current look at visibility conditions (including wildland fire smoke) that can be useful in assessing impacts on and visibility violations of Class I and II airsheds and for regional haze analysis. Currently most of the IMPROVE sites do not have enough data to undergo rigorous statistical analysis. It is highly recommended that all the USFS R1 IMPROVE sites continue to be operated. In 2010, the data from R1 IMPROVE sites should be re-analyzed for statistically validated trends. IMPROVE is a very important tool to monitor forest ecosystem health, especially in the R1 Wilderness areas where visibility is the main AQRV.

This report did not review the USFS R1 air quality (AQRV) lichen monitoring (Story and others 2008) or the USGS snow chemistry sampling network along the Rocky Mountains (Ingersoll and others 2008). Lichens are useful indicators of long term pollution impacts, and are typically sampled every 5 to 8 years. Lichens were initially sampled from 1992 to 1994, were re-sampled from 2000 to 2003, and are currently (2007 to 2010) being re-sampled again. Lichens can provide useful air quality information, specifically on sulfur and nitrogen compounds and metals. The lichen data are a valuable addition to the lake chemistry, deposition, and visibility information in this report.

The USFS Snow Chemistry sampling network provides the only air quality related sampling directly adjacent to some of the USFS Wilderness areas and is useful for winter bulk deposition analysis. It is recommended the USFS R1 continue support of and coordination with the USGS Snow Chemistry sampling program (Ingersoll and others 2008).

Additional information for both programs can be found at USFS R1 air quality website (http://www.fs.fed.us/r1/gallatin/resources/air/aq_plans/).

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