United States
Department of
Agriculture

Forest Service

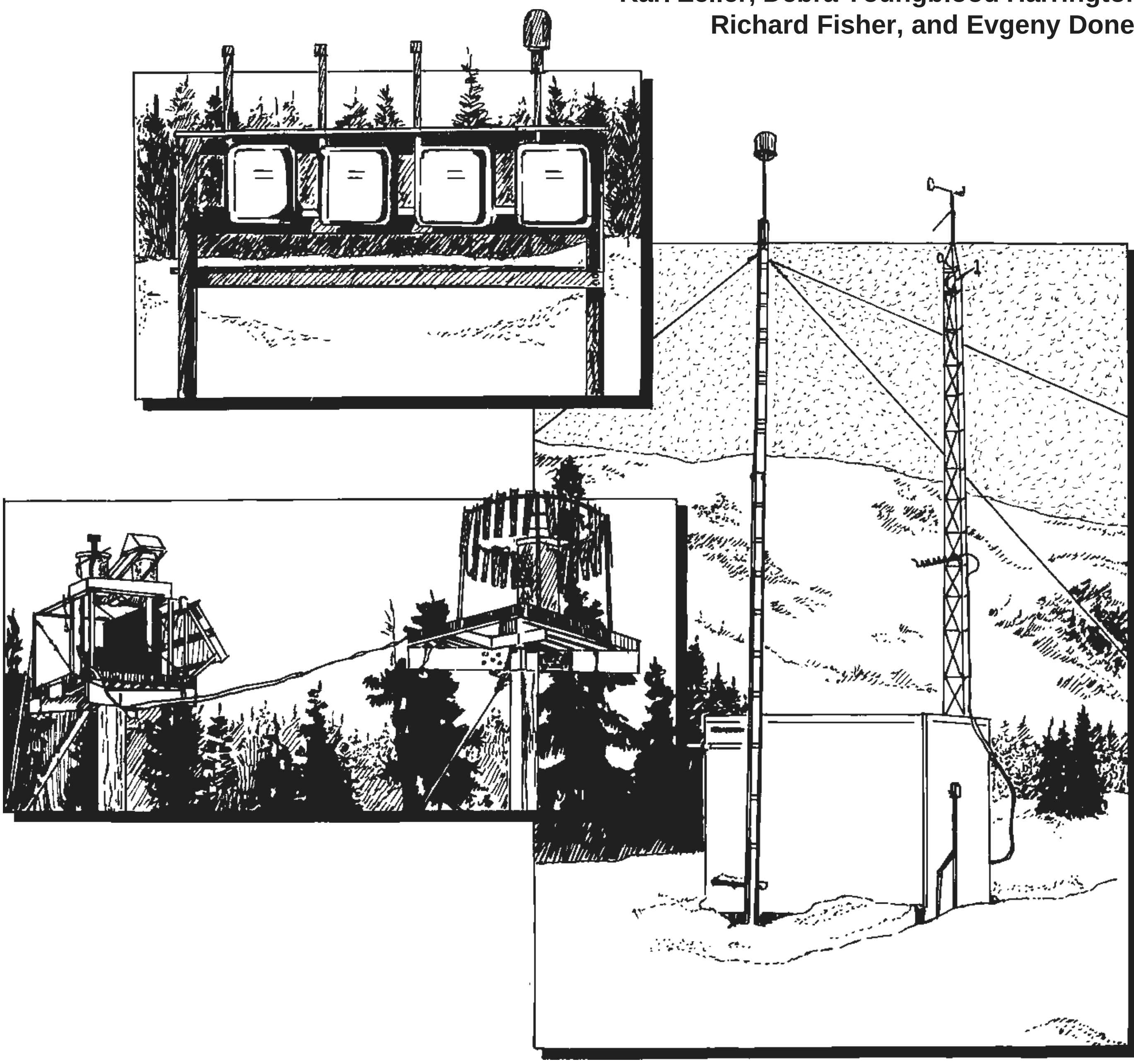
Rocky Mountain
Research Station

General Technical
Report RMRS–GTR–52

May 2000

Determining Atmospheric Deposition in Wyoming With IMPROVE and Other National Programs

Karl Zeller, Debra Youngblood Harrington,
Richard Fisher, and Evgeny Donev



Abstract

Zeller, Karl; Harrington, Debra Youngblood; Fisher, Richard; Donev, Evgeny. 2000. Determining atmospheric deposition in Wyoming with IMPROVE and other national programs. Gen. Tech. Rep. RMRS-GTR-52. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 34 p.

Atmospheric deposition is the result of air pollution gases and aerosols leaving the atmosphere as “dry” or “wet” deposition. Little is known about just how much pollution is deposited onto soils, lakes and streams. To determine the extent and trends of forest exposure to air pollution, various types of monitoring have been conducted. In this study, we evaluate data from different rural air monitoring programs to determine whether or not they may have wider applications in resource monitoring and protection. This report analyzes location-specific data collected by three national programs: The CASTNET (NDDN) Network supported by the Environmental Protection Agency, the IMPROVE (Interagency Monitoring of Protected Visual Environments) network supported by federal land managers, and the NADP/NTN program supported by many agencies.

Keywords: atmospheric deposition, sulfur and nitrogen deposition, dry deposition, wet deposition, NADP/NTN, CASTNET, IMPROVE, air resource

The Authors

Karl Zeller is a micrometeorologist with the Rocky Mountain Research Station and an American Meteorological Society certified consulting meteorologist (license #215).

Debra Youngblood Harrington is self-employed as a consultant, bookseller, and animal caretaker. She assisted in developing a bimodal aerosol model at the Atmospheric Department of Colorado State University. She continues to consult on results generated with this model.

Richard W. Fisher is an American Meteorological Society certified consulting meteorologist (license #479) and Air Program Manager for the USDA Forest Service. He is assigned to the Washington Office but works out of the Rocky Mountain Research Station in Fort Collins, CO. Rich advises the Chief of the Forest Service on policy matters related to air quality and provides technical leadership to field units on air quality issues. Rich holds an M.S. in earth sciences from Colorado State University and an M.A. in international and strategic studies from the Naval War College, Newport, RI.

Evgeny Donev is a professor in the Department of Meteorology at the University of Sofia in Bulgaria. He is the Bulgaria Project Manager of cooperative agreement #RMRS-98006-MDU between the Rocky Mountain Research Station, the Bulgarian Forest Research Institute, and Sofia University, Department of Meteorology. He and Dr. Zeller have coauthored several publications on N and S deposition and ozone behavior in the Rila Mountains of Bulgaria. Dr. Donev was a visiting scientist at the Rocky Mountain Research Station during the summer of 1992 and helped with GLEES research at that time.

You may order additional copies of this publication by sending your mailing information in label form through one of the following media. Please send the publication title and number.

Telephone	(970) 498-1392
E-mail	rschneider@fs.fed.us
FAX	(970) 498-1396
Mailing Address	Publications Distribution Rocky Mountain Research Station 240 West Prospect Road Fort Collins, CO 80526-2098

Determining Atmospheric Deposition in Wyoming With IMPROVE and Other National Programs

Karl Zeller, Debra Youngblood Harrington, Richard Fisher, and Evgeny Donev

Contents

Acknowledgments

The authors thank Roger Ames, Cooperative Institute for Research, Colorado State University Foothills Campus, for demonstrating the use of Glacier Lake National Park as an IMPROVE comparison site; and the Rocky Mountain Research Station Statistics Unit staff for their suggestions and timely review of this document.

Funding for this project was provided by the USDA Forest Service Watershed and Air Management, Washington, DC; Rocky Mountain Research Station, Research Work Unit 4451; and the Department of Meterology, Sofia University, Bulgaria.

Introduction

Air pollution can threaten visibility, aquatic ecosystems, and terrestrial ecosystems on national forests. Atmospheric deposition is the technical term for air pollution gases and aerosols that come down or leave the atmosphere and deposit as (a) "wet" deposition through precipitation; (b) "dry" deposition by transportation through the Earth's atmospheric boundary layer to surfaces, stomate openings, etc.; and (c) "occult" or "cloud" deposition by becoming an aerosol with water vapor (i.e., becoming part of a cloud) then depositing upon impact with surfaces. To determine the extent and trends of forest exposure to air pollution, various types of monitoring have been conducted.

In response to the Clean Air Act of 1977, remote parts of the national forests are monitored by the robust interagency ambient aerosol measurement program IMPROVE (Interagency Monitoring of Protected Visual Environments). IMPROVE monitors background and adverse changes to visibility, where visibility was the only measurable air quality related value (AQRV) specified for protection in the Clean Air Act. This report addresses the practical use of national monitoring program data and the feasibility of applying IMPROVE Forest Service data to atmospheric deposition. We provide information and recommendations specific to atmospheric deposition for land manager applications through the example of determining nitrogen (N) and sulfur (S) deposition in the Snowy Range of the Medicine Bow National Forest, Wyoming. Cloud deposition is important for west coast and eastern U.S. mountains, but because it has not been considered important for the site area studied here and because data are unavailable, it is not addressed.

Because ambient monitoring is expensive and because the IMPROVE visibility monitoring program is of high quality, the Forest Service is seeking ways to maximize the usefulness of the aerosol visibility data that have been or are now being collected. This report analyzes location-specific data collected by three national programs:

1. The CASTNET (Clean Air Status and Trends Network), a.k.a. National Dry Deposition Network (NDDN), supported by the Environmental Protection Agency (http://www.epa.gov/acidrain/castnet/). CASTNET measures "dry" deposited pollutants, but few monitoring sites exist.

2. The IMPROVE Module A (predecessor program: SFU: stacked filter unit) supported by the National Park Service (NPS), the United States Dept. of Agriculture Forest Service (USDA FS), and other cooperating agencies (http://crocker.ucdavis.edu/CNL/RESEARCH/AQG4.htm).

3. The NADP/NTN (National Atmospheric Deposition Program National Trends Network) (http://nadp.sws.uiuc.edu/). This program, supported by many governmental agencies, measures the "wet" deposition of atmospheric pollutants to the Earth's surface in the form of precipitation.

All three programs have been and are currently conducted at or near the USDA FS Glacier Lakes Ecosystem Experiments Site (GLEES) in the Snowy Range mountains (Zeller et. al, 2000).

Little is known about just how much pollution is deposited onto soils, lakes, and streams. If this information were available, we would be better able to relate pollutant exposure to effects on AQRVs such as soils, flora, and fauna. Measuring total atmospheric deposition is complicated because dry deposition cannot be accurately measured directly and because the variety of measurement protocols if used together reduce precision. Wet deposition measurements (Erisman et. al, 1994) are also sometimes difficult to intercompare because proper siting is often compromised by access considerations. The adoption of NADP/NTN protocols for most monitoring programs within the United States, however, has helped to simplify wet deposition data analysis. In our study, three closely located NADP sites are intercompared to address spatial representativeness. One of the sites is unusually rare due to its alpine location and year round access. Spatial representativeness for dry deposition is partially addressed by comparing the sulfur concentration results from two NDDN locations with SFU-IMPROVE results. Although IMPROVE program protocols were designed to address visibility and not deposition, the similarity in species monitored potentially makes it useful for deposition assessments. Scientists have been cautious about spatial representativeness of these data, especially in mountainous areas. We will evaluate data from different rural air monitoring programs to determine whether or not they may have wider applications in resource monitoring and protection.

Methods

Sites

The data presented here were taken from five separate sites in Wyoming within or close to the GLEES area in the Snowy Range of the Medicine Bow National Forest, Wyoming, about 65 km west of Laramie, Wyoming. The GLEES complex is described by Musselman (1994). The major tree species in the GLEES forest are *Picea engelmannii* (48%), *Abies lasiocarpa* (48%), and *Pinus contorta* (4%). The Snowy Range (SR) NADP site, (WY00), is located southwest of West Glacier Lake in the Snowy Range of Wyoming at an elevation of 3286 meters, which is the approximate tree line elevation for the forest. Samples have been collected at this site from 1986 to the present. The second NADP site, Nash Fork (NF), (WY96), is located 6.8 km southeast of the SR site at an elevation of 2856 m. Samples were collected at Nash Fork from 1987 to September 1992. In September of 1992, this site was relocated and given a new name and NADP calcode. The relocated NADP site, Brooklyn Lake, (BL), (WY95), is 2.4 km southeast of the SR site at an elevation of 3188 m. Samples have been collected at this site from September 1992 to the present.

NADP data are compared by both linear regression and paired difference. The paired difference analyses for the total (T) data set (SR-NF^T and SR-BL^T) were made because the regression offset is not always a good indication of bias for data comparisons with broad scatter. Further, 25% trimmed paired differences (SR-NF^{50} and SR-BL^{50}) were calculated to eliminate the effect of large outliers. The highest and lowest 25% of the data are culled in this procedure; hence 50% of the data are trimmed.

GLEES area CASTNET NDDN monitoring commenced July 1989 at an open dry meadow site near Centennial, Wyoming (CNT169), 12.2 km southeast of GLEES. During August 1991, CNT169 was relocated to GLEES in an open-sloped dry meadow location 138 m west southwest of the Brooklyn Lake tower IMPROVE site and approximately 50 m south-southeast of the Brooklyn Lake NADP site (WY95). The USDA IMPROVE site, located about 130 m east of BL NADP WY95, was not moved during the period of this study. Table 1 gives the location and relative horizontal distance from the Snowy Range NADP site. The three Brooklyn sites are all within 140 m horizontal distance of each other.

Wet Deposition

NADP was established in 1978 as a long-term atmospheric deposition monitoring network (CSU, 1991; Sisterson, 1991). Today, the program has approximately 200 rural stations in the United States that monitor wet deposition. The main goal of the program is to determine the spatial patterns and temporal trends in chemical precipitation deposition to support studies of the impact of chemical deposition on aquatic and terrestrial ecosystems. Weekly precipitation samples are collected from each site and sent to the Central Analytical Laboratory (CAL) for analysis. The samples are analyzed for SO_4^{2-}, NO_3^-, Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, H^+, pH, and conductivity.

The site comparisons in this study were completed for each year (1987 through 1997) using the weekly data at each site. The NADP data comparisons are made relative to the Snowy Range site. This report analyzes weekly deposition data in contrast to the NADP/NTN program, which does not report weekly deposition rather seasonal and yearly. The validity of weekly concentration samples, however, is determined by NADP/NTN. NADP data may be judged invalid for a number of reasons, including contamination, short or long sampling period (< 6 days or > 8 days), and laboratory error. Precipitation differences between the study sites greatly affected the weekly inter-site comparison of concentration and deposition values. Hence a "filtered" or "reduced" dataset (i.e., a subset of the valid weekly data) was also used. The data were reduced by culling a weekly sample when precipitation at the site was either less than 3 mm or when the precipitation difference, P_d, between two sites was greater than 100%.

$$P_d = 100\left(\frac{P_{SR} - P_i}{P_i}\right) \tag{1}$$

Here P_{SR} is the precipitation measured at SR, and P_i is the precipitation measured at either NF or BL. Table 2 shows the number of resulting data points used for each year for the valid dataset and the reduced dataset.

The weekly deposition values for this study were calculated using the weekly concentration and precipitation values reported by NADP:

$$D_i = C_i \frac{P_i}{100}, \tag{2}$$

where D_i is the deposition of sample i in kg ha^{-1} wk^{-1}, C_i is the concentration of sample i in mg l^{-1}, and P_i is the

Table 1. Monitoring sites, program, and location.

Name	Program	Elevation	Latitude	Longitude	Distance from SR
SR: Snowy Range (WY00)	NADP	3286 m	41° 22' 34"	106° 15' 34"	0.0 km
NF: Nash Fork (WY96)	NADP	2856	41° 20' 25"	106° 11' 27"	6.8
BL: Brooklyn Lake (WY95)	NADP	3188	41° 21' 53"	106° 14' 27"	2.4
CNT:BL 169: Brooklyn Lake	CASTNET (NDDN)	3180	41° 21' 50"	106° 14' 27"	2.5
CNT169: Centennial	CASTNET (NDDN)	2591	41° 18' 30"	106° 09' 10"	12.2
BT: Brooklyn Tower	IMPROVE	3186	41° 21' 53"	106° 14' 15"	2.6

precipitation amount of sample *i* in mm. Extensive regression analyses were made between the SR site and the other two sites by grouping the weekly data into separate years and seasons as well as for the whole data set. The differences in the concentration and deposition between two sites ([SR-NF] and [SR-BL]) were calculated using the reduced weekly dataset. The resulting differences were analyzed two ways: sorting the data by year and sorting the data by month. Using the data sorted by year or month, the average differences and standard deviations were also calculated for each species and each year or month.

Table 2. Number of weekly data points in each dataset.

Year	Comparison sites	Valid dataset	Reduced dataset
1987	SR-NF	31	24
1988	SR-NF	22	17
1989	SR-NF	34	25
1990	SR-NF	27	22
1991	SR-NF	41	29
1992a	SR-NF	28	23
1992b	SR-BL	3	3
1993	SR-BL	31	27
1994	SR-BL	27	24
1995	SR-BL	35	32
1996	SR-BL	28	24
1997	SR-BL	38	32

Dry Deposition

EPA CASTNET (NDDN). NDDN was established by EPA to obtain routine weekly ambient concentration measurements and dry deposition estimates of O_3, SO_4^{-2}, NO_3^-, NH_4^+, SO_2, and HNO_3 and to obtain meteorological parameters. Weekly filter pack samples are exchanged on Tuesday mornings in coordination with NADP protocol. NDDN was expanded to incorporate similar programs and is now called CASTNET although the NDDN sites are still so named. The dry deposition component of NDDN is a 3-stage serial filter pack: first, a 47 mm Teflon filter (Zefluor, 1µm) for SO_4^{2-} NH_4^+ and NO_3^- aerosols; second, a 47 mm nylon filter (Nylasorb, 1µm) for HNO_3; and third, a K_2CO_3 impregnated cellulose (Whatman no. 41) filter for SO_2. Ambient air from 10m height is continuously drawn through the filter pack at 1.5 l m^{-1}. Field and laboratory procedures are provided by ESE (1990a, 1990b).

Estimating dry deposition is a two step analysis: step 1–determine the vertical ambient concentration gradient, ($\bar{c}_z$ - $\bar{c}_o$), ($\bar{c}_z$: above ground concentration; $\bar{c}_o$: surface concentration) of the pollutant species of interest; step 2–model the applicable deposition velocity (Bytnerowicz et al., 1987; Hidy, 1999; Schmel, 1984; Wyers and Duyzer, 1997), V_d, and multiply it by ($\bar{c}_z$ - $\bar{c}_o$) to determine deposition, F_c (or vertical flux) equation 3 (Zeller and Hehn, 1996):

$$F_c = (\bar{c}_z - \bar{c}_o)\, V_d \tag{3}$$

In practice the value of $\bar{c}_o$ is often taken as 0.0. The deposition velocity, provided within the CASTNET protocol, is a multiple function of chemical species, atmospheric turbulence, vegetation, canopy structure, leaf wetness, etc. Hidy (1999) has recently prepared a summary document on dry deposition determination techniques specifically for federal lands. Appendix A, "NO_2 & SO_2 Deposition Velocity (V_d) Over Water," gives more detail specifics on how to evaluate the deposition velocity parameter and how to select specific values.

IMPROVE. The IMPROVE measurement program was designed and implemented to address visibility (background, visibility impairment species and trends) for federal land management and regulatory agencies (Malm et al. 1994; Sisler, 1996). An IMPROVE site can have up to four separate modules sampling in parallel: module A—a Teflon filter, for fine particulate (≤2.5µm diameter) mass; module B—a denuded nylon filter, for sulfate (SO_4^{2-}) and nitrate (NO_3^-) (≤2.5µm); module C—a quartz filter, for organic and light-absorbing carbon (C) (≤2.5µm); and module D for particulate mass ≤10.0 µm diameter. Sample measurements are made through 24-hour continuous filter sampling on Wednesdays and Saturdays of each week. The 2.5µm cutoff is achieved using a size selective inlet in addition to a cyclone separator. Sample flow rate is held at 22.7 l m^{-1} using a critical orifice. The IMPROVE program was established in March 1988 having replaced the earlier stacked filter unit (SFU) protocol originally fielded in 1979. At sites where the fine particulate module A replaced the SFU, fine mass and sulfur monitoring records are considered closely comparable to IMPROVE and are analyzed as single records. At GLEES, SFU measurements commenced at the Brooklyn Lake tower site (BRLA = BT), a 30 m diameter opening in the GLEES forest (Zeller and Hehn, 1996) on 25 July 1989 and ended 29 June 1993. IMPROVE module A BT measurements commenced 31 August 1993 through 20 August 1998 when it was relocated 10m northeast of the GLEES BL NDDN site. For this study the sulfur analysis results of Module A were used to estimate sulfate aerosol concentration.

The comparison "dry" results given below were obtained by assuming that the IMPROVE concentration average of the Wednesday 24-hr sample plus the Saturday 24-hr sample (total 48-hr sample) would be the best quantity to compare with the 7-day (168-hr sample) concentration average measured Tuesday to Tuesday by the NDDN sampler within the same sampled week. Sulfur concentration from module A is determined from a proton-induced X-ray emission (PIXE) analysis of mass divided by the total air volume passed through the filter (Sisler, 1996). SO_4 from module A is determined using the assumption that all the module A sulfur is sulfate: $SO_4 = 3 * S$, using the ratio of molecular weights. Neither a deposition velocity comparison analysis nor sulfate deposition comparison analysis could be made separately for the IMPROVE site because edited site specific meteorological parameters were not available for the IMPROVE BT site from the GLEES FS program.

Results and Discussion

Wet Deposition

Site comparisons. For each chemical species, the NF and BL annual, seasonal, and total (i.e., using data for all years) weekly NADP data were linearly regressed against the SR NADP data for both the complete valid data set and for the precipitation-filtered data set. Linear regressions (slopes and offset) were calculated, including standard errors and coefficients of determination (correlation squared) r^2 values. Paired differences, standard deviations of paired differences, and 25% trimmed paired differences (i.e., top and bottom 25% of data trimmed) were also calculated to evaluate bias. The complete results are presented in Appendix B. Figure 1 is an example of the weekly deposition "filtered" NADP data for SO_4 at BL and SR. The coefficients of determination for the filtered seasonal and annual concentration and deposition data from Appendix B are summarized in table 3.

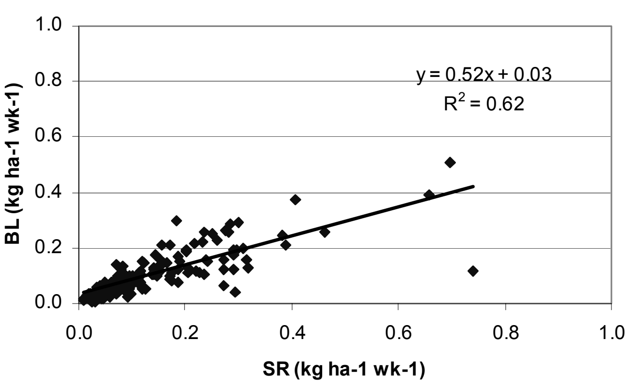


Figure 1. Scatter diagram of SO_4 wet deposition data culled for unrealistic values using precipitation quantity criteria.

Although the NADP program distinguishes four seasons in their data presentation, our site comparisons demonstrated only two distinct seasons: winter and summer defined by the average precipitation type; winter period - snow; and summer period - rain. The GLEES summer season extends from May 1 to September 30 (although complete snow pack melt above 3150 m does not typical occur until late June), while the winter season extends from October 1 to April 30. Precipitation amounts measured at NF were typically 70% of SR during the summer and dropped to 50% during winter and at BL they were 90% year round compared to SR.

The annual coefficients of determination for both concentration and deposition were not uniformly improved by filtering the weekly data for high and low precipitation (see Appendix B). In such cases it was typical that the specific culled data value(s) was significantly higher than average and falsely improved the coefficient of determination. We believe that the filtered data results give more realistic statistics for the site comparisons. From table 3, generally the BL site has better r^2 values for both concentration and deposition data; also the summer season comparisons at both BL and NF do better than the winter season. Interestingly, the deposition coefficients of determination are generally slightly higher than concentration at BL and visa versa at SR. This was not unexpected because BL is more similar to SR in both elevation and precipitation amount. Since wet deposition measurements are precipitation quantity dependent, precipitation amount may account for the weaker NF deposition coefficients compared to concentration. Measured concentrations were often higher at the lower sites but deposition is always greater at SR compared to NF and BL (see Appendix C).

Comparisons of the annual averages (6 data points for NF and 5 for BL) are also included (in parenthesis) in table 3 for SR vs. NF and for SR vs. BL. In most cases, r^2 values improve significantly when annual averages are used. Cl concentration comparisons at both sites and the annual averaged K concentration comparison at BL stand out with lack of any correlation.

Annual weekly average concentration, annual weekly average deposition, and annual total deposition amounts as reported by NADP, including the averages of all years, are given in Appendix C. Note that the values for 1992 are combined NF (January to September) and BL (September to December). The regression results of comparing the annual total depositions from Appendix C are given in Appendix D. The r^2 values of the precipitation filtered annual values in table 3 (in parenthesis) are for the most part higher than those using NADP reported data as listed in Appendix C.

Table 3. Coefficients of determination (r^2) for precipitation filtered seasonal weekly and annual weekly data (and annual averaged weekly data in parenthesis) between NADP sites (see Appendix B).

	1987 to Sept. 1992 (SR vs. NF) concentration & deposition			Sept. 1992 to 1997 (SR vs. BL) concentration & deposition		
Species	**Summer**	**Winter**	**All weeks (yearly averages)**	**Summer**	**Winter**	**All weeks (yearly averages)**
NH_4^+ (conc.)	0.54	0.07	0.45 (0.96)	0.59	0.31	0.47 (0.74)
" (dep.)	0.47	0.12	0.16 (0.66)	0.71	0.48	0.49 (0.91)
NO_3^- (conc.)	0.64	0.51	0.47 (0.64)	0.81	0.55	0.72 (0.74)
" (dep.)	0.41	0.32	0.19 (0.36)	0.84	0.54	0.60 (0.94)
Cl^- (conc.)	0.28	0.12	0.27 (0.06)	0.64	0.14	0.26 (0.00)
" (dep.)	0.24	0.19	0.15 (0.80)	0.88	0.50	0.51 (0.36)
SO_4^{2-} (conc.)	0.61	0.43	0.45 (0.95)	0.82	0.51	0.70 (0.81)
" (dep.)	0.38	0.43	0.33 (0.64)	0.78	0.60	0.62 (0.95)
Ca^{2+} (conc.)	0.60	0.79	0.35 (0.17)	0.75	0.59	0.63 (0.92)
" (dep.)	0.71	0.45	0.42 (0.93)	0.84	0.67	0.75 (0.92)
Mg^{2+} (conc.)	0.67	0.61	0.42 (0.53)	0.77	0.70	0.73 (0.77)
" (dep.)	0.65	0.37	0.37 (0.98)	0.79	0.71	0.73 (0.96)
K^+ (conc.)	0.34	0.19	0.22 (0.83)	0.45	0.06	0.38 (0.08)
" (dep.)	0.27	0.08	0.13 (0.64)	0.46	0.18	0.26 (0.52)
Na^+ (conc.)	0.45	0.09	0.22 (0.59)	0.48	0.18	0.22 (0.44)
" (dep.)	0.26	0.16	0.17 (0.54)	0.78	0.36	0.47 (0.34)

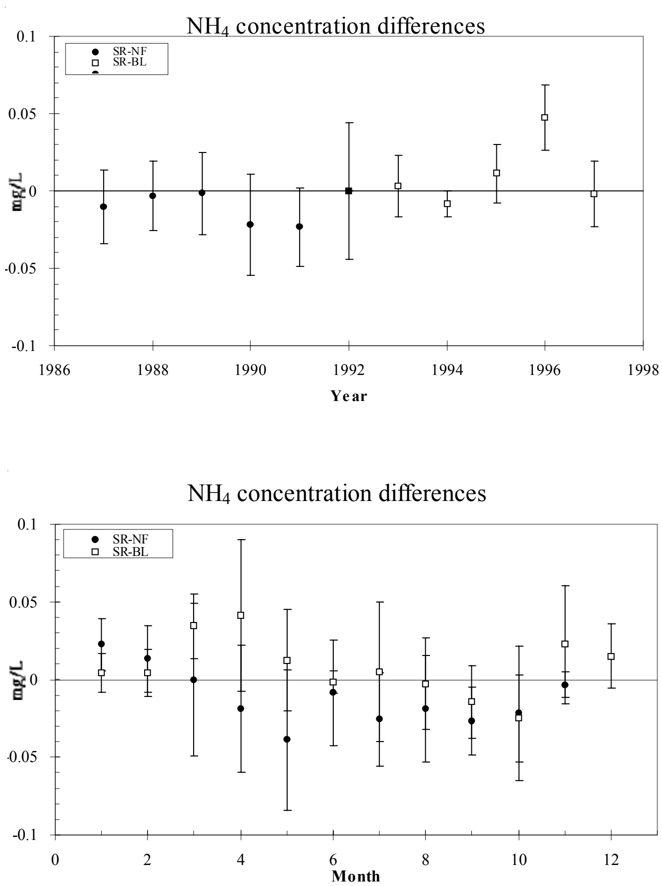


Figure 2. The average and standard deviation of weekly wet concentration difference between Snowy Range (SR) and Nash Fork (NF) or Brooklyn Lake (BL) NADP sites: (a) by year; and (b) by month.

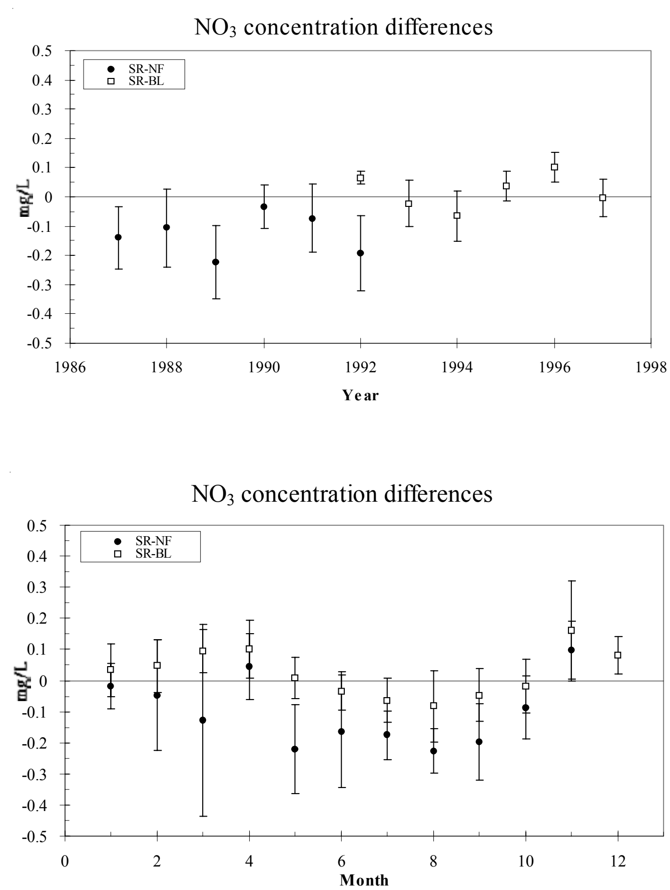


Figure 3. The average and standard deviation of weekly wet concentration difference between Snowy Range (SR) and Nash Fork (NF) or Brooklyn Lake (BL) NADP sites: (a) by year; and (b) by month

Figures 2 through 7 present the trimmed paired average weekly difference concentration and deposition results distributed by (a) year (values plotted at end of year) and (b) by month for NH_4^+, NO_3^-, and SO_4^{2-}. The concentration differences pattern (figures 2-4) for the three species change in 1992 and show that NF concentrations tend to be greater than SR while BL concentrations are mostly lower but can also be higher. The concentration difference distribution by month also demonstrate the two-season annual cycle where concentrations at SR compared to both NF and BL are likely to be higher during the winter season and lower during the summer season. The annual cycles (i.e., distributions by month) of concentration differences between SR and BL are more smoothly sinusoidal than those between SR and NF. Deposition differences (figures 5 – 7) show that SR is almost always higher than both NF and BL and that BL deposition is closer to SR than NF. The deposition at both NF and BL is closer to SR during the summer season. Note the standard deviations are also smaller during the summer season. In table 4, the results of the overall annual average percent ratio of the 25% paired species difference (i.e., all years SR-NF^{50} and SR-BL^{50}) from Appendix B are compared to the all years' average weekly values for SR listed in Appendix C. Hence this ratio is a measure of the average overall percent difference in each species concentration and deposition between sites. Except for Cl and Na concentrations (which are very small), the BL site differences are much lower compared to SR. While average concentration differences are typically less than 11% at both NF and BL (except for NO_3 at SR), average species deposition differences are consistently much less at BL (7 to 21%) compared to NF (25 to 60%). These differences are similar to the difference in total precipitation noted above.

Wet sulfur and nitrogen deposition. Wet deposited nitrogen and sulfur were calculated from the SR SO_4^{-2}, NO_3^- and NH_4^+ values based on molecular weight. Figure 8 shows the total wet sulfur and total wet nitrogen

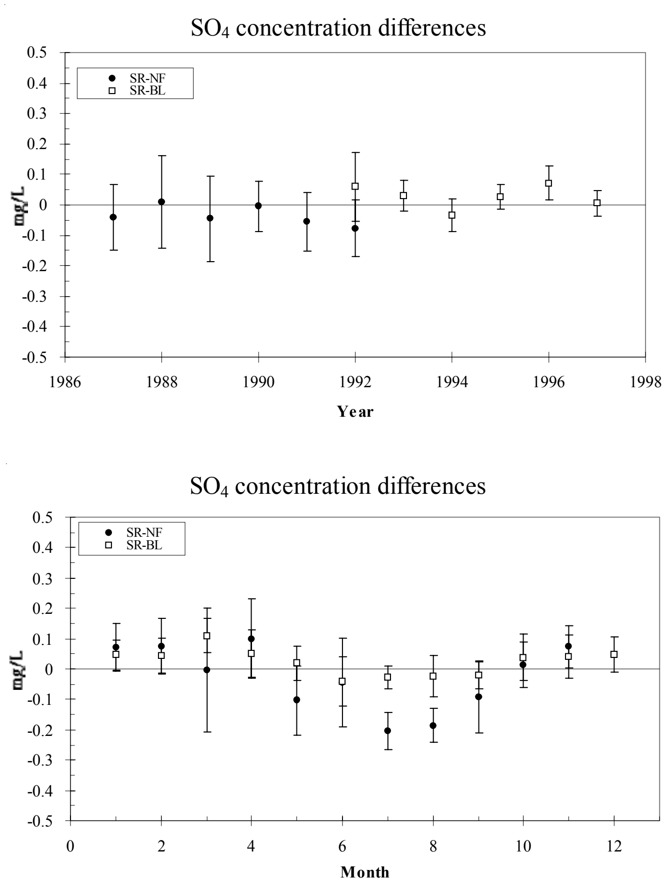


Figure 4. The average and standard deviation of weekly wet concentration difference between Snowy Range (SR) and Nash Fork (NF) or Brooklyn Lake (BL) NADP sites: (a) by year; and (b) by month.

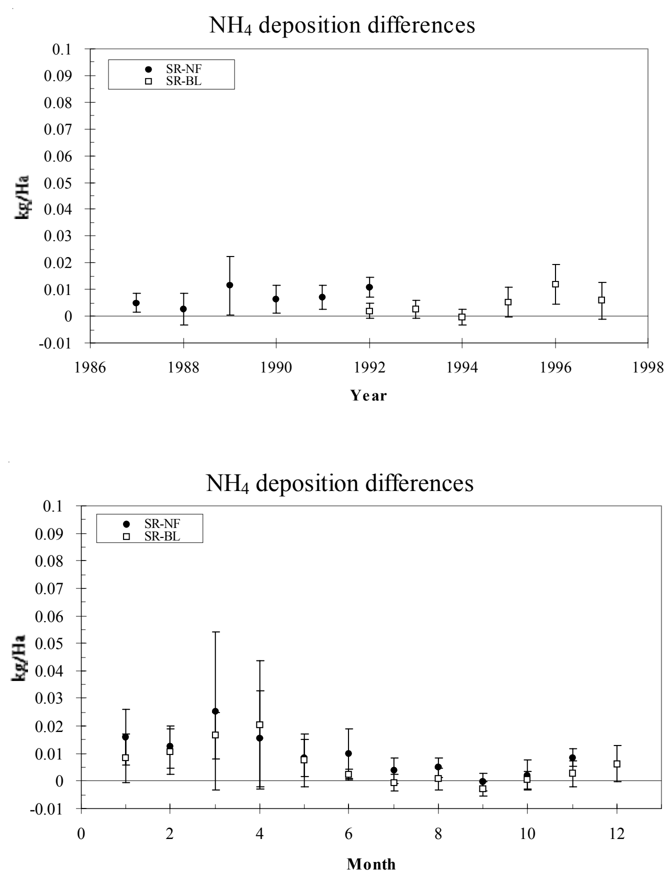


Figure 5. The average and standard deviation of weekly wet deposition difference between Snowy Range (SR) and Nash Fork (NF) or Brooklyn Lake (BL) NADP sites: (a) by year; and (b) by month.

Table 4. Ratio of annual average paired concentration and annual average paired deposition differences to the SR annual average concentration and deposition for the 25% trimmed data.

	1987 to Sept. 1992 (SR - NF)		Sept. 1992 to 1997 (SR – BL)	
Species	**Conc. (%)**	**Dep. (%)**	**Conc. (%)**	**Dep. (%)**
NH_4^+	-11	28	6	13
NO_3^-	-17	60	3	21
Cl^-	1	32	3	14
SO_4^{2-}	-6	40	4	13
Ca^{2+}	-6	25	-1	7
Mg^{2+}	-2	33	-1	10
K^+	-5	33	0	13
Na^+	3	25	7	18

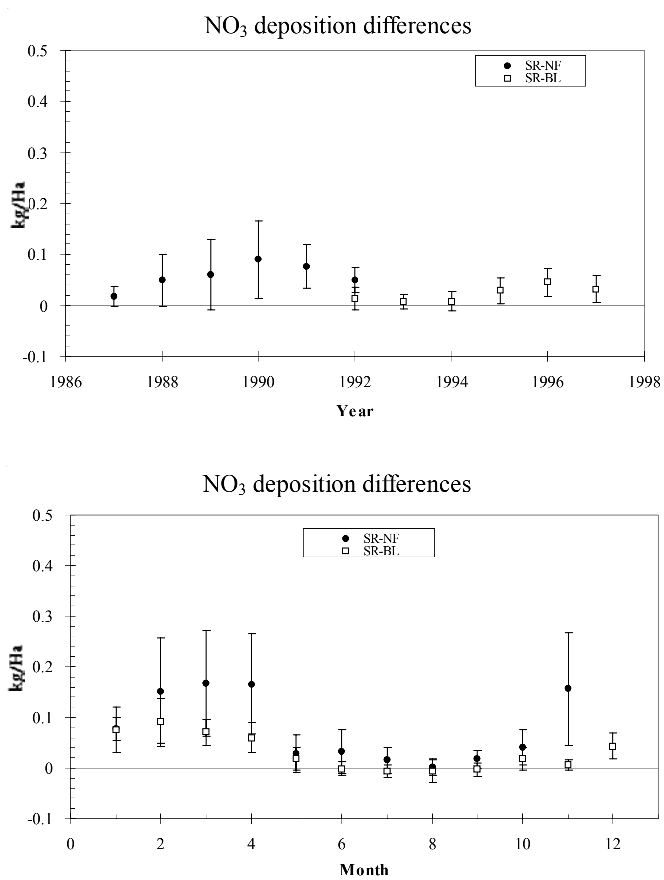


Figure 6. The average and standard deviation of weekly wet deposition difference between Snowy Range (SR) and Nash Fork (NF) or Brooklyn Lake (BL) NADP sites: (a) by year; and (b) by month.

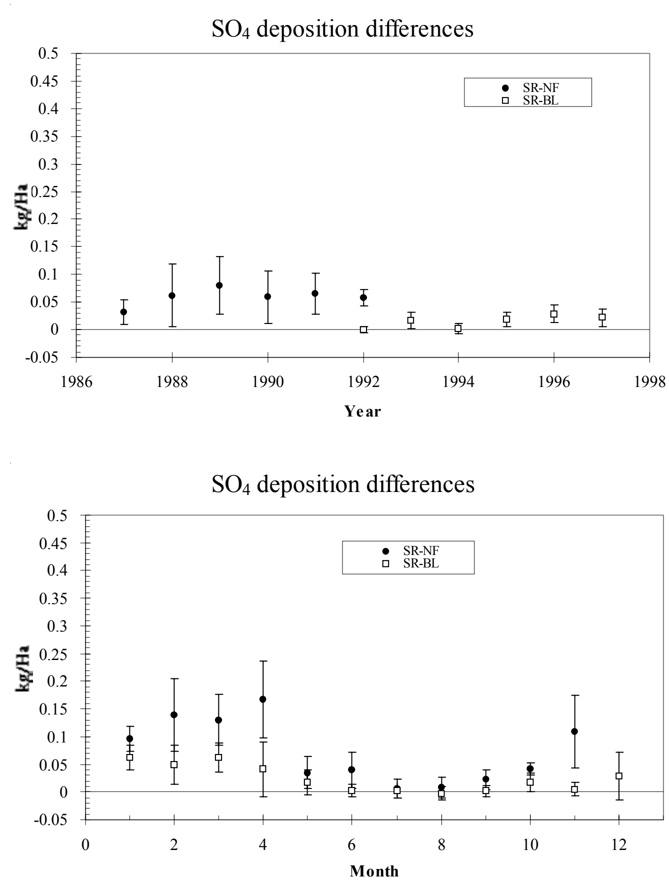


Figure 7. The average and standard deviation of weekly wet deposition difference between Snowy Range (SR) and Nash Fork (NF) or Brooklyn Lake (BL) NADP sites: (a) by year; and (b) by month.

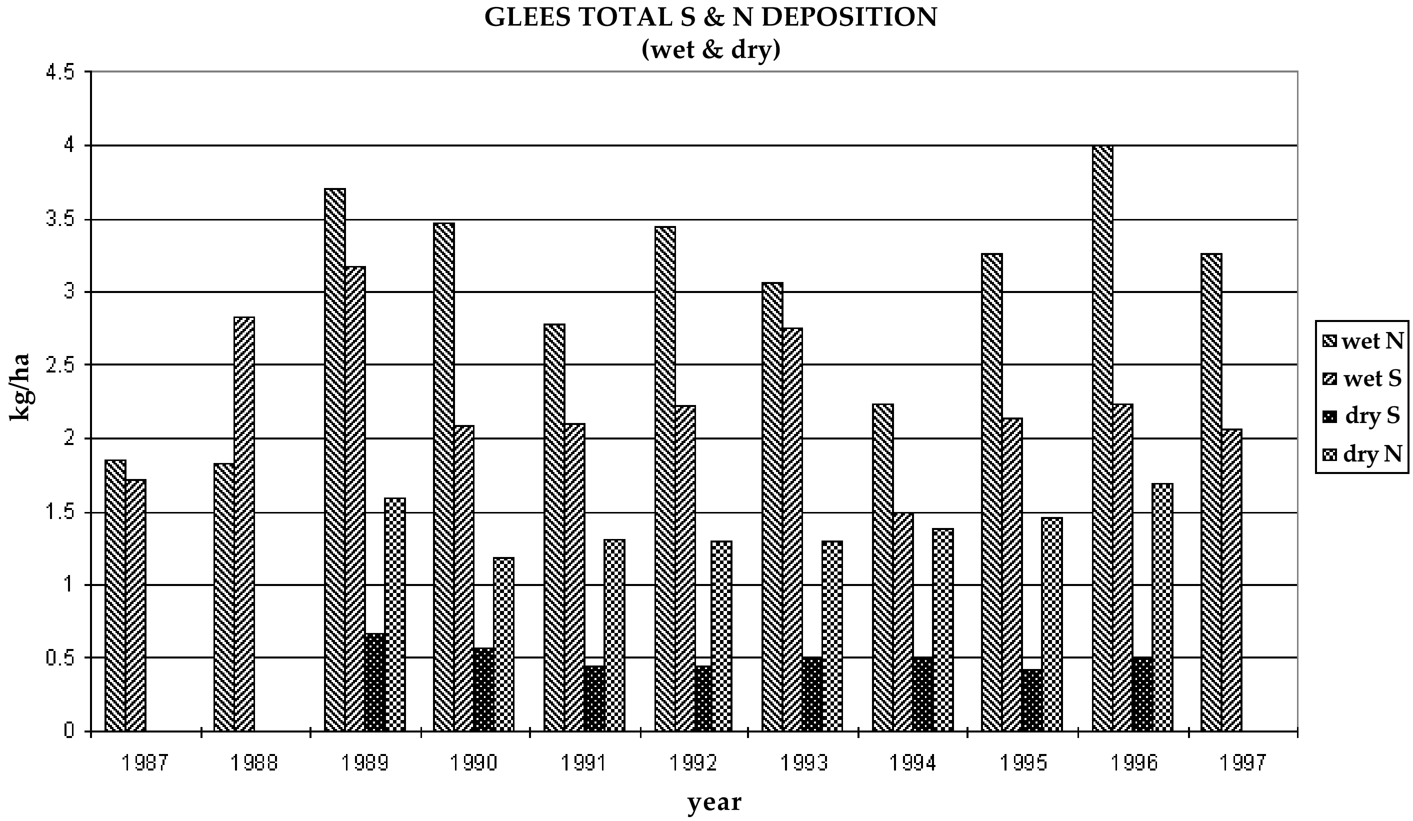


Figure 8. Annual total wet and dry nitrogen and sulfur atmospheric deposition taken from available NADP and NDDN data from 1987 to 1997.

deposition at the GLEES area for the years, 1987 – 1997. The dry deposition results in figure 8 are discussed below. There is no clear trend to the wet S and N deposition data except that there appears to be a maximum every four to five years in both S and N and the two species seem to track each other annually.

Dry Deposition

As presented in equation 3, the determination of dry deposition is a measurement plus modeling exercise. Concentration is the measurement portion of the dry deposition assessment that both NDDN and IMPROVE provide, hence the comparison of these two concentration measurements (not deposition), specifically for SO_4, is discussed here. Figure 9a, b, and c are scatter plots of the weekly sulfate concentration data measured by SFU and IMPROVE (average of Wednesday + Saturday) compared to NDDN for the three distinct sampling periods: July 1989 through August 1991, August 1991 through June 1993, and September 1993 through September 1996, as explained previously. The coefficients of determination (figure 9), 0.41, 0.63, and 0.72, improved when NDDN was moved to the Brooklyn Lake area closer to the BT SFU/IMPROVE site and improved again when the SFU protocols were replaced with the IMPROVE protocols. These correlations are very good considering IMPROVE was originally designed to only measure visibility parameters and that samples only include two-sevenths of the period sampled by NDDN. The linear regression slopes for SFU and IMPROVE located at Brooklyn were both 0.63 with similar offsets 0.09 and 0.11, indicating consistent results for both protocols at the same sites (138 m distance). The slope for the period, October 1989 to August 1991, when NDDN was located in Centennial, WY, (10 km southeast of BT) was 0.52. The SFU and IMPROVE measurements were made in a forested opening while the NDDN measurements were always made in open dry meadows, hence it is possible that if the IMPROVE measurements were also taken in the open the regression slope may become larger than 0.63. Figure 10 shows the SO_4 concentration difference statistics between NDDN and SFU/IMPROVE for each year separated by the three periods. Figure 11a, b, and c shows the monthly difference distributions corresponding to figure 10. The 25% trimmed analysis made for the difference data presented in figure 11 did not produce different results as it did for the NADP data, hence it is not shown. The overall average differences between NDDN and SFU/IMPROVE (averages of data shown in figure 10) compared to NDDN were 31%, 26%, and 22% for the three distinct periods.

Only the BT SFU concentration data are available for comparison to provide an insight of spatial separation effects on dry deposition. Similar to the wet concentration data that were higher on the average at NF (the lowest elevation NADP site), the dry concentration differences also show that the NDDN data collected at Centennial (lower elevation relative to BL) was slightly higher (i.e., a larger average difference seen in figure 10) compared to the NDDN data collected at BL. Unfortunately, without the meteorological information to calculate deposition velocities a spatial dry deposition cannot be made. As an educated guess, however, greater wind speeds at the higher elevations would yield larger deposition velocity values (equation 3 and see Appendix A); hence calculated dry deposition values might be very similar.

Table 5 gives the annual dry deposition results in kg ha^{-1} yr^{-1} reported by EPA using the NDDN data. Nitric acid, HNO_3, accounts for the greatest contribution to dry nitrogen deposition. The annual dry deposition does not appear to vary much from year to year, nor between the

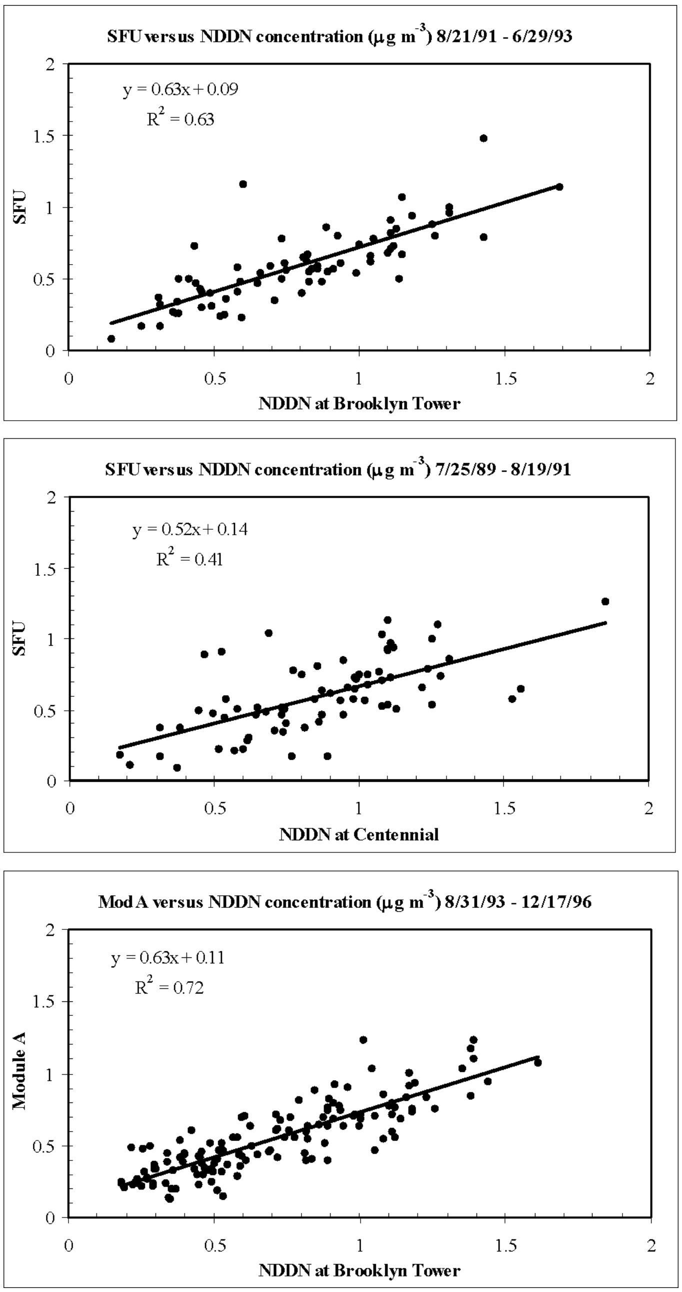


Figure 9. Scatter plots of SO_4 concentration: (a) SFU (BT) vs. NDDN (Centennial, WY); (b) SFU (BT) vs. NDDN (BL); and (c) IMPROVE module A. (BT) vs. NDDN (BL).

Table 5. NDDN site 169 Annual dry deposition (kg ha^{-1} yr^{-1}).

Year	SO_4^{-2}	SO_2	NH_4^+	NO_3^-	HNO_3
Centennial: CNT169					
1989	0.63	0.92	0.26	0.14	6.10
1990	0.71	0.69	0.19	0.13	4.51
1991*	0.56	0.53	0.22	0.14	4.98
Brooklyn: CNT:BL169					
1992	0.64	0.47	0.22	0.13	4.93
1993	0.57	0.62	0.19	0.10	5.06
1994	0.59	0.59	0.19	0.14	5.45
1995	0.47	0.53	0.19	0.10	5.76
1996	0.65	0.55	0.24	0.19	6.54

* combined Centennial, WY and BL locations

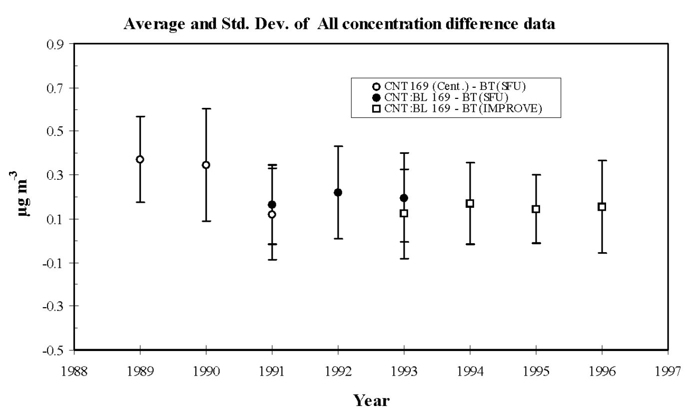


Figure 10. SO_4 annual monthly concentration difference between GLEES area NDDN and SFU/IMPROVE for the three distinct sampling periods.

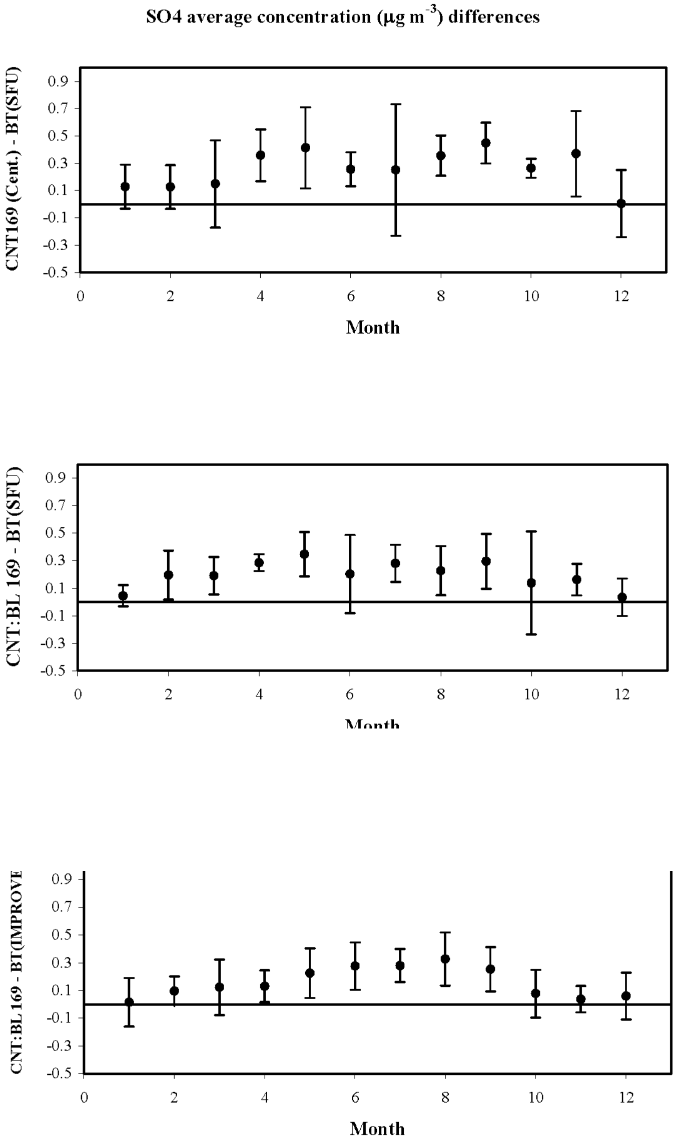


Figure 11. a, b, and c. The monthly concentration differences between GLEES area NDDN and SFU/IMPROVE difference distributions corresponding to figure 10.

two sites. Unfortunately simultaneous dry deposition assessments using IMPROVE were not possible.

Glacier National Park IMPROVE/NDDN comparison

How representative are the GLEES NDDN – IMPROVE results? A similar analysis of NDDN and IMPROVE SO_4 module A data collected at the collocated Glacier National Park sites is presented in figure 12a and b covering the period April 11, 1989, to March 21, 1995. Glacier National Park NDDN (GNP168) is located at Lat. 48° 30′ 36″; Long. 114° and IMPROVE (GLAC1) is located at Lat. 48° 30′ 38″; Long. 113° 59′ 44″; elevation 3213 m. Compared to the Brooklyn module A (figure 9c), there appears to be slightly more data dispersion and $r^2 = 0.57$ compared to 0.72. However, the overall difference for SO_4 between the Glacier National Park programs is only 2.6% compared to 22% for Brooklyn. The regression slope, 0.8 for Glacier National Park is much closer to 1:1; however, the offset, 0.14, is similar to BL results. Figure 12b annual difference statistics shows that for some years, IMPROVE module A average concentrations actually exceed NDDN averages. This never happened at Brooklyn, but the annual standard deviations for both locations (figures 10 and 12b) are very similar.

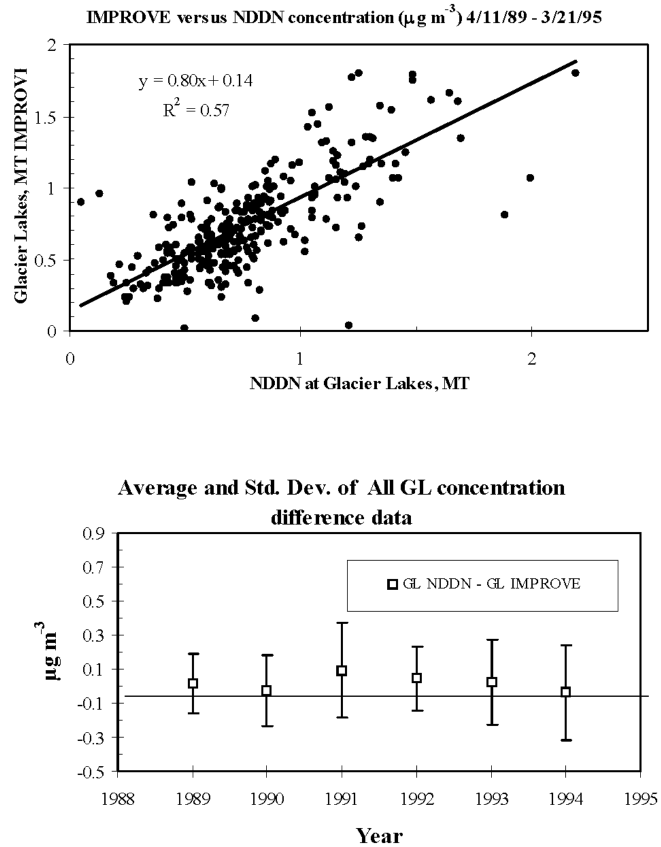


Figure 12. (a) SO_4 annual monthly concentration difference between Glacier National Park, MT, NDDN and SFU/IMPROVE for the period 4/11/89 to 3/21/95; and (b) the monthly concentration differences between Glacier National Park, MT, NDDN and SFU/IMPROVE difference distributions for the same period.

Total Sulfur and Nitrogen Deposition

Figure 13 displays the annual wet plus dry sulfur and the annual wet plus dry nitrogen deposition at the GLEES area for the years 1989-1996 when complete data sets

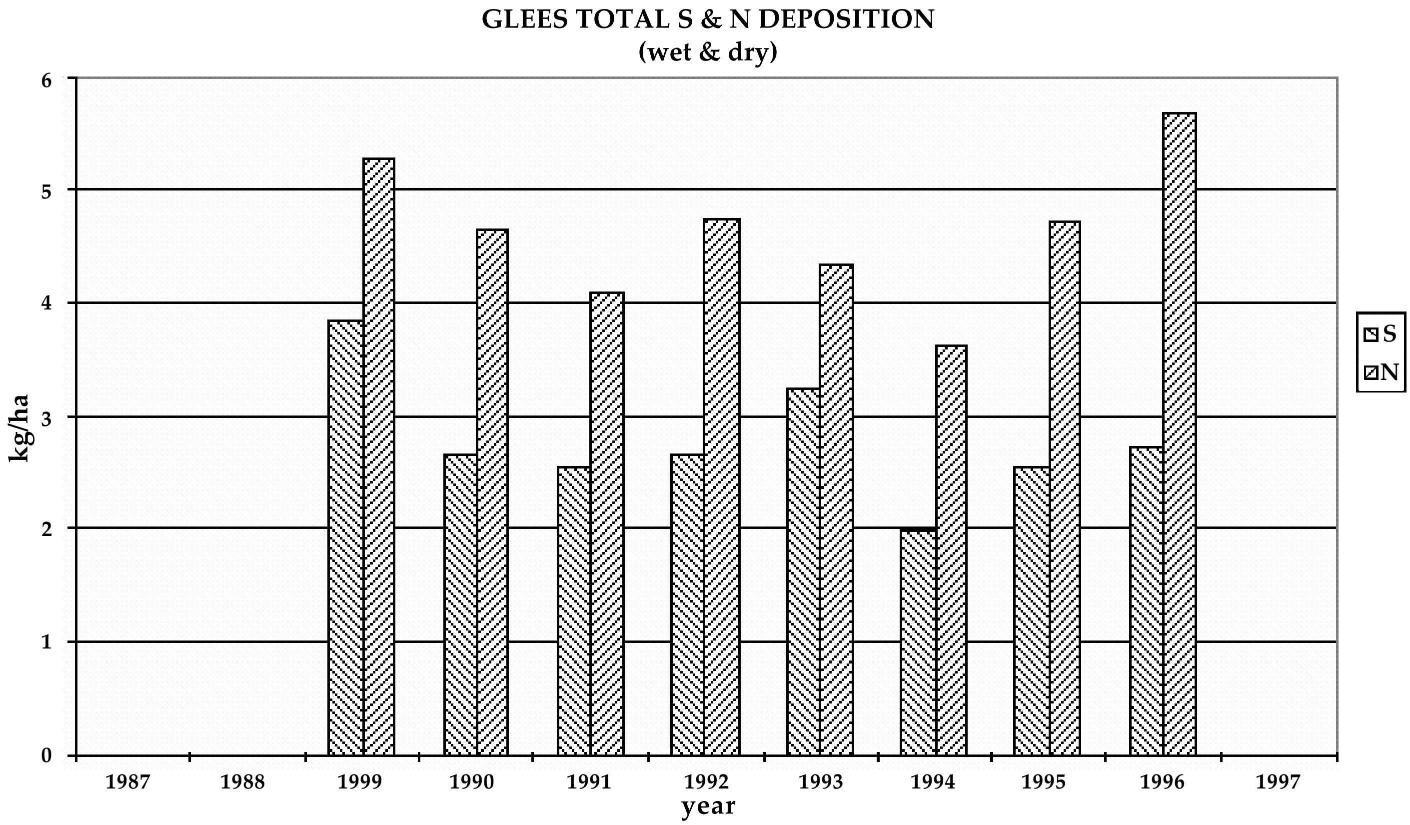


Figure 13. Total wet and dry nitrogen and sulfur deposition at GLEES for 1989 to 1996.

were available. As stated above, wet deposited nitrogen and wet deposited sulfur were calculated from SO_4^{-2}, NO_3^-, and NH_4^+ values at SR based on molecular weight. Dry deposited nitrogen and dry deposited sulfur were also calculated from the NDDN CNT169 SO_4^{-2}, NO_3^-, SO_2, NH_4^+, and HNO_3 values based on molecular weight. Different site locations were used for wet and for dry deposition, based on the small average annual differences shown in figures 5, 6, and 7. Concentrations at separate dry sites in table 5 are similar. Despite all of this, figure 13 represents a reasonable characterization of the total nitrogen and sulfur atmospheric deposition in the surrounding GLEES subalpine area.

Conclusion

Deposition at separate sites within the Medicine Bow National Forest in Wyoming have been analyzed for spatial representativeness and to assess total annual atmospheric nitrogen and sulfur deposition. The results indicate that for both wet and dry deposition, spatial differences are to be expected in the Snowy Range area and higher elevation wet deposition is greater even though higher elevation wet concentration values can be lower. Wet deposition and wet concentration values between sites are not comparable on a weekly basis and these differences vary widely; but on an annual basis, results are similar with greater wet deposition at higher elevations. The spatial comparison of dry deposition, limited to concentrations, also showed that the measured concentrations tend to be slightly higher at the lower elevation. Data for a spatial comparison of dry deposition was not available. Air resource managers can use results from closely located NADP and NDDN sites to evaluate total deposition on annual time scales with the caveat that spatial variability is expected. A practical application might be to use data from these programs to establish historical deposition values prior to any new upwind facility expected to impact AQRVs through increased deposition.

Wet deposition assessed using SR NADP data accounts for a little under 2 to 4 kg ha^{-1} yr^{-1} for nitrogen and a little under 2 to a little over 3 kg ha^{-1} yr^{-1} for sulfur, but there are no trends. Dry deposition assessed using CASTNET

(NDDN) ranges from 1.2 to 1.7 kg ha^{-1} yr^{-1} and accounts for about 30% of total deposition for nitrogen. It ranges 0.45 to 0.71 kg ha^{-1} yr^{-1} and accounts for about 20% of total deposition for sulfur. There is no trend for either element. The limited eight-year record (figure 13) wet plus dry for nitrogen and sulfur does not show a trend but still reflects the four- to five-year peak deposition in both elements. Total nitrogen deposition ranges from 3.7 to 5.7 kg ha^{-1} yr^{-1} and sulfur ranges from 2 to 3.8 kg ha^{-1} yr^{-1}.

Comparisons between NDDN and IMPROVE sulfur concentrations suggest that IMPROVE data may be useful for estimating the dry concentration component used for estimating dry deposition. Although IMPROVE and NDDN protocols are different, sulfate concentrations do correlate well. However, there appears to be site specific differences as shown by the comparison between the Snowy Range sites and the Glacier National Park sites. Additional research toward expanding the use of IMPROVE data may prove useful for dry atmospheric deposition assessments. For example, the limited analysis presented here indicates that IMPROVE concentrations could be used with valid deposition velocities to estimate lower limits to dry deposition because IMPROVE concentrations are lower compared to NDDN. Appendix E provides air resource managers with recommendations specific to the use of IMPROVE module A data for SO_4 concentration and deposition estimates.

References

Bytnerowicz, A., Miller, P, & Olyzyk, D. 1987. Dry deposition of nitrate, ammonium and sulfate to a *Ceanothus crassifolius* canopy and surrogate surfaces, Atm. Envir. 21:8 1749-1757.

Colorado State University, NADP/NTN Annual Data Summary. Precipitation chemistry in the United States - 1991. Ft. Collins, CO: Nat'l Res. Ecology Labr., CSU. 1992.

Erisman, J.W., C. Beier, G.Draaijers, S. Lindberg. 1994. Review of deposition monitoring methods, Tellus, 46 B, 79-93.

ESE, Inc. No. 86612-0212-3170. 1990a. National dry deposition network: Laboratory operations manual, EPA Contract No. 68-02-4451, EPA/AREAL, RTP, NC 27791, August 1990.

ESE, Inc. No. 86612-0108-2110. 1990b. National dry deposition network: Field operations manual, EPA Contract No. 68-02-4451, EPA/AREAL, RTP, NC 27791, July 1990.

Hidy, G., Dry deposition relevant to National Parks and wilderness, contract report to CIRA, CSU, Ft. Collins CO. 30p.

Malm, W.C., Sisler, J.F., Cahill, L., Eldred, R.A., and Pitchford, M. 1994. Spatial and seasonal trends in particle concentration and optical extinction in the U.S., JGR, 99 (D1), 1347-1370.

Musselman, R. C., (Ed.). 1994. The Glacier Lakes ecosystem experiments site (GLEES): an alpine global change research study area. Gen. Tech. Rep. RM-249. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 94 p.

Sisler, J.F., 1996. Spatial and seasonal patterns and long term variability of the composition of the haze in the U.S.: An analysis of data from the IMPROVE network, CIRA, CSU, Ft. Collins, CO. July, ISSN: 0737-5352-32.

Sisterson, D.L., 1991. Report 6: Deposition monitoring: methods and results, Acidic Deposition: state of science and Technology ed. P. M. Irving, NAPAP 722 Jackson Place NW, Wash. DC, 20503, Sept. 1991.

Schmel, G. 1984. Chapter 12: Deposition and resuspension, In: D. Randerson ed., Atmospheric Science and Power Production, DOE/TIC-27601 (DE84005177), 533-583.

Wyers, G.P., Duyzer, J.H. 1997. Micrometeorological measurement of the dry deposition flux of sulfate and nitrate aerosols to coniferous forests, Atm. Envir. 31 (3), 333-343.

Zeller, K. and T. Hehn. 1996. Measurements of upward turbulent ozone fluxes above a subalpine spruce-fir forest, GRL, 23 (8), 841-844.

Zeller, K., Cerny, M., Bytnerowicz, A., Smith, L., Sestak, M., Michalec, M., Pernegr, V. & Kucera, J. 1997. Air pollution status of a representative site in the Czech Republic Brdy mountains. Environmental Pollution, 98 (3), 291-297.

Zeller, K., Harrington, D., Riebau, A. and Donev, E. 2000. Annual wet and dry deposition of sulfur and nitrogen in the Snowy Range, Wyoming. Environmental Pollution 34(1) 1713-1722.

Appendix A. NO_2 & SO_2 Deposition Velocity (V_d) Over Water

Introduction: SO_2 – NO_2 Deposition

The discussion in this appendix was generated as a result of a USDA FS Region 2 request for advice in choosing a reasonable deposition velocity value for calculating NO_2 and SO_2 deposition from their concentrations. The NPS generally uses a value of 0.5 cm s^{-1} while the FS Region 2 generally uses a suggested value of 0.7 cm s^{-1} for over water NO_2 V_d. The NPS generally uses a value of 5.0 cm s^{-1} verses the FS Region 2 recommendation of 2.4 cm s^{-1} for over water SO_2 V_d. Unfortunately there is not just one answer to the question "What is the best deposition velocity for acid gases sulfur dioxide (SO_2) and nitrogen dioxide (NO_2)?" because it is a very variable parameter. The term deposition is broadly used to account for the transfer of trace gases or aerosols from the atmosphere to vegetation, soil, or other surfaces. Since NO_2 is photochemically reactive (e.g., it can be converted to NO by reacting with O_3 or other oxidants) (de Arellano, 1995), some of the measured NO_2 deposition may be due to chemical conversion in the atmosphere rather than to actual deposition to a surface. Deposition of NO_2 is not always downward. Depending on the ambient NO_2 concentration, NO_2 may also be emitted from a vegetated surface (Rondo et al., 1993). At Pawnee National Grassland, we (Stocker et al., 1993; Padro, 1998) measured increasing upward NO_2 fluxes immediately after rainstorms. SO_2 also converts chemically to a sulfate aerosol in the atmosphere. A trace gas or aerosol flux, F_c, (or deposition) is a product of deposition velocity (V_d) and the species concentration gradient between atmosphere and the surface. The concentration gradient, ($\bar{c}_z - \bar{c}_o$) may either be positive or negative, while the deposition velocity is always positive. Typically the surface concentration, $\bar{c}_o$, is assumed to be zero.

Deposition Velocity

Deposition velocity (V_d) is a parameter that quantifies the rate of transfer of an aerosol or a trace gas molecule between ambient air and the surface (such as vegetation canopy, soil, etc.). As an example, for a molecule of NO_2 to pass from free air into a leaf stomata, it will first meet resistance from the turbulent air it travels through (r_a), then it will meet a resistance from the laminar boundary layer adjacent at the leaf surface (r_b) and finally it will meet a resistance from the stomatal opening (r_c) on the leaf surface. Mathematically:

$$V_d = (r_a + r_b + r_c)^{-1}. \qquad \text{(A-1)}$$

The above equation is an electrical resistance analogy that applies better to gases than to aerosols, although in practice it is used for both (Venkatram, 1999). Note that this formulation will be more complicated for complex canopies.

Resistances

There are different formulations for computing the resistance, Equation A-2 (Hicks, 1991) is one, using standard meteorological measurements that are commonly used for aerodynamic resistance, r_a:

$$r_a = 9/(\sigma_\theta^2 \overline{u}) \text{ for } R_t > 10, \text{ (daytime)} \qquad \text{(A-2)}$$

$$r_a = 4/(\sigma_\theta^2 \overline{u}) \text{ for } R_t \leq 10, \text{ (nighttime)}$$

where R_t is total solar radiation in Watts m^{-2}; σ_θ is the standard deviation of wind direction in radians (i.e., degrees × π/180°); and $\overline{u}$ is the average wind speed in m s^{-1}. Equation A-3 can be used to calculate the boundary layer resistance:

$$r_b = 2 \ (1/ku_*) \ (Sc/Pr)^{2/3} \qquad \text{(A-3)}$$

$$\text{simplified: } r_b(NO_2) = 6.4 \ u_*^{-1}$$

$$r_b(SO_2) = 7.1 u_*^{-1}$$

where k = 0.4 is the von Karman constant; $u_* = \sqrt{\overline{u}/r_a}$ is the friction velocity in m s^{-1}; Sc is the Schmidt number, the ratio of air viscosity to molecular diffusivity (Sc = 1.25 for SO_2 and 1.07 for NO_2) (note: Bill Massman [1998] has prepared a useful review of diffusivities for typical atmospheric trace gases); and Pr is the Prandlt number, a ratio between momentum diffusivity and thermal diffusivity (Pr = 0.74 for air; Bird et al., 1960) (Massman [1999] recommends Pr = 0.71). The canopy physiological resistance, r_c, ranges

Table A1. Meteorological conditions defining Pasquill's stability categories.

Wind speed $m\ s^{-1}$	Daytime insolation			Nighttime	
	Strong	Moderate	Slight	>= 50% Clouds	<= 38% clouds
< 2	A*	A-B	B	-	-
2	A-B	B	C	E	F
4	B	B-C	C	D	E
6	C	C-D	D	D	D
> 6	C	D	D	D	D

* A: extremely unstable; B: moderately unstable; C: slightly unstable; D: near neutral (heavy overcast day or night); E: slightly stable; F: moderately stable.

Table A2. Conversion from Pasquill stability category to standard deviation of wind direction (σ_θ).

Pasquill stability category	σ_θ (degrees)
A	σ_θ >= 22.5
B	17.5 <= σ_θ < 22.5
C	12.5 <= σ_θ < 17.5
D	7.5 <= σ_θ < 12.5
E	3.8 <= σ_θ < 7.5
F	σ_θ < 3.8

from about 0.70 s cm^{-1} to infinity and is very site specific and time specific. Over water, $r_c = 0.0$ for SO_2. It is beyond the scope of this short treatise to further describe r_c.

Note on meteorological data for resistance calculation: In the event σ_θ data is not available σ_θ can be estimated by first selecting a Pasquill (1974) stability category from table A1, then choosing a value for σ_θ from table A2 (Irwin, 1980).

Effect of Vegetation on Deposition Velocity

Since plant stomates respond to diurnal changes in the environment and NO_2 and SO_2 are "sparingly soluble" gases (Hidy, 1999)*, V_d rates will change throughout the day (note: Hidy's report on dry deposition is specifically for air resource managers). For example, measurements suggest that stomatal function is the most significant factor controlling NO_2 deposition to vegetation (Pilegaard et al. 1998). Thus, the physiological resistance r_c has been found to be typically an order of magnitude larger than other resistances in equation A-1. If stomates are controlling NO_2 deposition (and SO_2), then the more stomates, the more deposition. Another vegetation parameter that has been found to strongly affect NO_2 deposition on an ecosystem level is the leaf area index (LAI). LAI is the area of leaf surface above a unit area of ground: hence a LAI of 2 $m^2\ m^{-2}$ means that the ground is covered twice by leaf surface and would have twice the number of stomates compared to a LAI of 1 $m^2\ m^{-2}$. LAI is used in biophysical models of pollutant deposition (e.g., Nikolov 1997, Zeller and Nikolov 2000) to scale leaf fluxes to a canopy and landscape level. On a regional scale, spatial variation of LAI is one of the most critical factors controlling landscape pattern of deposition velocity. Sometimes V_d is reported as V_d per leaf surface. As an example we found that a representative summertime midday V_d for NO_2 at the Pawnee Grassland was 0.07 cm s^{-1} (Stocker et al., 1993) and that the LAI of the sparse grassland about the same time was 0.6 $m^2\ m^{-2}$ (Zeller and Hazlett, 1989) giving a V_d per LAI of 0.07/0.6 = 0.12 cm s^{-1} LAI^{-1}.

Experimental NO_2 & SO_2 Deposition Velocities

Tables A3 and A4 give sample summaries of V_d from some NO_2 and some SO_2 deposition studies and experiments. The background on deposition velocity was presented above to give air resource managers an idea of what a V_d is and of just how tenuous the numbers in tables 1 and 2 really are. Simply selecting a value for V_d and multiplying it by a concentration to estimate NO_2 or SO_2 deposition might lead to an erroneous conclusion. For a valid estimate, one must take into consideration vegetation type (e.g., species composition), canopy structure (i.e. LAI), season, concentration gradient (not just concentration), and weather conditions.

Table A3. A summary of V_d from some NO_2 deposition experiments.

Lead author	Canopy	Technique	NO_2 V_d ($cm\ s^{-1}$)	NO_2 V_d / LAI ($cm\ s^{-1}$)	NO_2 r_c ($s\ cm^{-1}$)
Pilegaard '98	Agric. w/ forest patches	EC	0.35 (max)	NA	200-1000
Nielson '96	vegetation	NA	0.2	NA	NA
Erisman '94	Elspectsche Veld	NA	0.1 TO 0.4	NA	NA
Rondo '93 (2@forests)	Spruce (F#1) Pine (F#1) Pine (F#2)	CH	NA	0.15 ± 0.13 0.14 ± 0.11 0.08 ± 0.07	NA
Coe '92	Dry heather moor	EC	0.1 TO 0.35	NA	548 (mean)
Hicks '86	grassland	EC	1.0		0.4 to 0.8
Hesterberg '96	Meadow	EC	0.11 TO 0.24	NA	NA
Stocker '93	Dry grassland	EC	0.07	0.12	NA

EC: eddy covariance; CH: chamber

Table A4. A summary of V_d from some SO_2 deposition experiments.

Lead Author	Canopy or surface	Technique	SO_2 V_d ($cm\ s^{-1}$)	SO_2 V_d / LAI ($cm\ s^{-1}$)	SO_2 r_c ($s\ cm^{-1}$)
Sheih '79	Water	estimate	0.2 to 0.3	NA	0.0
Walcek '86	Conifer Water	model "	NA	NA	0 0 to 1000 0.0
Wesely '77	All	model	0.1 to 10 depends on r_c	NA	NA
Hicks '86	Grassland	EC	0.8	NA	1.0
Matt '87	Deci. Forest	EC	0.2 to 1.4	NA	50 to 150
Davis '85	Field?	GR	<0.1 to 5.0	NA	NA
Granat '95	Pine	CH	0.033	0.011	3
Brueggemann '99	Melpitz site	GR	0.16 to 0.37	NA	NA
Erismann '99	Speulder forest	GR	1.5 (annual average)	NA	NA
Xu '98	Forest Agric. Grassland Ocean Ocean	model	0.4 0.2 0.5 0.8 (summer) 0.5 (winter)	NA	NA
Brandy '96	Ocean	GR	0.68	NA	NA
Houmand '96	Spruce	TF	1.1	NA	NA
Padro '93	Deci. Forest	EC	0.5 (day) 0.1 (nite)	NA	NA

EC: eddy covariance; CH: chamber; GR: gradient; TF: throughfall

Discussion

Given that the NPS uses 0.5 cm s^{-1} vs. 0.7 cm s^{-1} for the FS for over-water NO_2 V_d, and since table A3 does not have an over-water example, and also assuming r_c for NO_2 over water will be very small (possible zero), the best approach would be to use equation A-1., assume $r_c = 0.0$, and calculate r_a and r_b from the actual meteorology and model V_d as a varying value. Another approach would be to calculate V_d for a small spectrum of likely meteorological scenarios and take an average value. The NPS and FS values for SO_2 over-water v_d, 5.0 and 2.4 cm s^{-1}, seem high compared to the over ocean values in table A4; however, fresh water most likely would have a higher V_d value.

Table A5. Meteorology and deposition velocity for NO_2 over water (r_c = 0; 30% σ_θ) and vegetation [r_c = 250 s cm^{-1} (day); 1000 s cm^{-1} (night)].

JD	HHMM	WS m s^{-1}	θ Deg.	σ_θ Deg.	Temp °C	Rad Watt m^{-2}	r_a s cm^{-1}	u_* m s^{-1}	r_b s cm^{-1}	V_{dH2O} cm s^{-1}	V_{dveg} cm s^{-1}
178	0	1.6	240	13	6.5	1	49	0.18	35	0.15	0.09
178	30	1.3	239	15	6.5	1	45	0.17	38	0.16	0.09
178	100	1	239	31	6.2	1	14	0.27	24	0.43	0.10
178	130	1.8	244	20	5.8	1	18	0.31	20	0.37	0.10
178	200	2.2	234	16	6.1	1	23	0.31	21	0.30	0.10
178	230	2.2	236	15	6.1	1	27	0.29	22	0.27	0.10
178	300	2.4	236	13	6.2	1	32	0.27	23	0.23	0.09
178	330	2.8	234	14	6	1	24	0.34	19	0.30	0.10
178	400	3.7	229	11	5.9	1	29	0.36	18	0.26	0.10
178	430	4.4	227	12	5.8	1.5	21	0.46	14	0.36	0.10
178	500	3.8	236	13	5.8	14	46	0.29	22	0.17	0.31
178	530	3.3	236	11	6	75.7	74	0.21	30	0.11	0.28
178	600	3.5	238	12	6.4	128.3	59	0.24	26	0.14	0.30
178	630	3.2	245	15	6.5	165.6	41	0.28	23	0.19	0.32
178	700	4.3	227	13	7	342.4	41	0.33	20	0.19	0.32
178	730	4.9	221	14	7.4	440.2	31	0.40	16	0.25	0.34
178	800	5.8	218	17	7.6	536.1	18	0.57	11	0.43	0.36
178	830	5.4	217	18	7.8	627.7	17	0.57	11	0.44	0.36
178	900	4.5	218	19	8.3	711.8	18	0.50	13	0.41	0.36
178	930	4.3	209	19	8.7	792.5	19	0.48	13	0.39	0.35
178	1000	4.7	209	20	9.2	857	16	0.55	12	0.47	0.36
178	1030	4.5	202	24	9.6	916.5	11	0.63	10	0.62	0.37
178	1100	4.7	200	22	9.8	906	13	0.60	11	0.56	0.37
178	1130	5.1	187	18	10.1	840	18	0.53	12	0.42	0.36
178	1200	4.5	197	16	10.5	1013	26	0.42	15	0.30	0.34
178	1230	4.9	207	25	10.9	996.5	10	0.71	9	0.73	0.37
178	1300	4.2	195	20	11.2	850.5	18	0.49	13	0.42	0.36
178	1330	4.5	178	18	11.1	753.4	20	0.47	14	0.37	0.35
178	1400	3.4	190	17	10.8	550.3	30	0.34	19	0.25	0.33
178	1430	4.3	185	20	11.3	497.5	17	0.50	13	0.43	0.36
178	1500	4.6	186	17	11.1	595.9	22	0.45	14	0.34	0.35
178	1530	4	190	19	11.3	614.7	20	0.44	14	0.36	0.35
178	1600	4	195	17	11.2	541.5	26	0.40	16	0.30	0.34
178	1630	4.1	197	17	11.3	616.5	25	0.41	16	0.30	0.34
178	1700	4.4	159	17	10.9	181.9	23	0.44	15	0.33	0.35
178	1730	7.8	131	15	9	70.4	17	0.68	9	0.46	0.36
178	1800	3.8	158	18	8.2	27.3	24	0.40	16	0.31	0.34
178	1830	3.2	209	20	5.9	38.1	23	0.37	17	0.31	0.34
178	1900	2.4	330	10	5.9	62.6	123	0.14	46	0.07	0.24
178	1930	2.4	317	10	5.8	30.1	123	0.14	46	0.07	0.24
178	2000	2.7	220	24	6.4	2	8	0.57	11	0.76	0.10
178	2030	3.6	228	12	5.5	1	25	0.38	17	0.30	0.10
178	2100	2.2	190	15	5.6	1	27	0.29	22	0.27	0.10
178	2130	2.4	139	15	5.2	1	24	0.31	20	0.30	0.10
178	2200	1.1	183	31	4.3	1	12	0.30	21	0.48	0.10
178	2230	2.2	221	13	4.6	1	35	0.25	26	0.21	0.09
178	2300	2.7	235	9	5	1	60	0.21	30	0.13	0.09
178	2330	3.3	238	12	5.3	1	28	0.35	19	0.27	0.10
Day 178	**Avg.**	**=**								**0.32**	**0.24**
Day 179	**Avg.**	**=**								**0.30**	**0.24**
Day 180	**Avg.**	**=**								**0.63**	**0.26**

The same approaches as recommended for NO_2 above, assuming $r_c = 0.0$, would be the most credible.

As an example for NO_2 using actual meteorology data, table A5 gives a few days of half-hour average summertime meteorology over a six-day period as measured above an alpine forest canopy. The canopy resistance term for the over-water calculation of $V_{dH2O}(NO_2)$ was taken as $r_c = 0.0$, and since over-water stability is usually classified below C (table A1), the σ_θ values measured above trees were reduced by 70% to simulate typical over-water σ_θ. The canopy resistance for the vegetation was simply estimated as 250 s cm^{-1} during the day and 1000 s cm^{-1} at night. Table A5 demonstrates the different half hourly and daily average and six-day average for these two hypothetical estimates. Table A5 is presented as an exercise to demonstrate V_d variability and behavior for two different applications and not as a specific recommendation.

Table A5. (Cont'd.)

JD	HHMM	WS m s^{-1}	θ Deg.	σ_θ Deg.	Temp °C	Rad Watt m^{-2}	r_a s cm^{-1}	u_* m s^{-1}	r_b s cm^{-1}	V_{dH2O} cm s^{-1}	V_{dveg} cm s^{-1}
181	0	7.1	297	13	0.8	0.9	11	0.81	8	0.68	0.10
181	30	7.5	294	16	0.7	0.9	7	1.05	6	1.04	0.10
181	100	6.7	291	15	0.6	0.9	9	0.88	7	0.83	0.10
181	130	7.4	287	16	0.5	0.9	7	1.03	6	1.02	0.10
181	200	7.6	281	18	0.7	0.9	5	1.19	5	1.30	0.10
181	230	8.1	284	18	0.4	0.9	5	1.27	5	1.38	0.10
181	300	9.4	286	15	0	0.8	6	1.23	5	1.16	0.10
181	330	9.1	288	15	-0.5	0.9	6	1.19	5	1.12	0.10
181	400	9.6	286	16	-0.6	0.8	5	1.34	5	1.33	0.10
181	430	10	283	16	-0.6	1.4	5	1.40	5	1.38	0.10
181	500	9.9	282	16	-0.7	13.2	12	0.92	7	0.66	0.37
181	530	10.5	277	17	-0.5	73.4	10	1.04	6	0.78	0.38
181	600	10.3	280	17	-0.5	162.1	10	1.02	6	0.76	0.38
181	630	10.5	276	17	-0.3	254.2	10	1.04	6	0.78	0.38
181	700	9.4	273	16	0.1	353.4	12	0.87	7	0.62	0.37
181	730	8.9	273	19	0.6	453.3	9	0.98	6	0.81	0.38
181	800	7.7	268	19	1.1	550.7	11	0.85	8	0.70	0.37
181	830	7.5	268	20	1.6	645	10	0.87	7	0.75	0.37
181	900	7.9	272	22	2	731.5	8	1.01	6	0.94	0.38
181	930	6.7	268	21	2.7	810	10	0.82	8	0.73	0.37
181	1000	7.1	252	20	2.8	878	10	0.83	8	0.71	0.37
181	1030	7.7	260	17	3	933.5	13	0.76	8	0.57	0.37
181	1100	7.6	253	17	3.5	978	13	0.75	9	0.56	0.37
181	1130	7.6	250	19	3.8	1006.5	11	0.84	8	0.69	0.37
181	1200	7.2	259	20	4.3	1022	10	0.84	8	0.72	0.37
181	1230	6.4	245	19	4.7	1026.5	13	0.71	9	0.58	0.37
181	1300	5.5	236	22	5.3	1020	11	0.70	9	0.65	0.37
181	1330	6.1	245	21	5.8	1000.5	11	0.75	9	0.66	0.37
181	1400	5.7	247	25	6.2	966	8	0.83	8	0.85	0.38
181	1430	5.1	245	22	6.6	915.5	12	0.65	10	0.60	0.37
181	1500	4.3	252	30	6.8	854.5	8	0.75	9	0.88	0.38
181	1530	3.9	256	30	7.2	784	8	0.68	9	0.80	0.37
181	1600	3.4	241	31	7.5	702.6	9	0.61	10	0.74	0.37
181	1630	3.9	263	25	7.8	614.8	12	0.57	11	0.58	0.37
181	1700	3.8	237	24	7.9	518.3	13	0.53	12	0.53	0.36
181	1730	3	235	29	8.1	422.4	12	0.51	13	0.58	0.36
181	1800	3.6	225	17	7.9	324.2	28	0.36	18	0.27	0.34
181	1830	2.8	215	17	8	229	37	0.28	23	0.21	0.32
181	1900	2.1	222	16	7.9	45.7	55	0.20	33	0.14	0.30
181	1930	1.4	235	16	7.2	12.7	82	0.13	49	0.09	0.26
181	2000	1.5	241	21	6	4.9	20	0.27	23	0.34	0.10
181	2030	3.4	123	17	5.3	1	13	0.50	13	0.52	0.10
181	2100	3.1	104	20	4.8	1	11	0.54	12	0.64	0.10
181	2130	2.7	84	13	4.8	1	29	0.31	21	0.26	0.10
181	2200	2.1	42	14	4.9	0.9	32	0.26	25	0.23	0.09
181	2230	2.1	51	13	5.1	0.9	37	0.24	27	0.20	0.09
181	2300	2	27	14	5.1	1	33	0.24	26	0.22	0.09
181	2330	2.4	22	7	5.1	1	112	0.15	44	0.07	0.09
Day 181	**Avg.**	**=**								**0.68**	**0.26**

Table A5. (Cont'd.)

JD	HHMM	WS $m\ s^{-1}$	θ Deg.	σ_θ Deg.	Temp °C	Rad Watt m^{-2}	r_a $s\ cm^{-1}$	u_* $m\ s^{-1}$	r_b $s\ cm^{-1}$	V_{dH2O} $cm\ s^{-1}$	V_{dveg} $cm\ s^{-1}$
182	0	2.2	18	7	5.1	0.9	122	0.13	48	0.07	0.09
182	30	1.5	7	9	5	0.9	108	0.12	54	0.07	0.09
182	100	0.5	336	37	4.5	0.9	19	0.16	40	0.29	0.09
182	130	0.7	286	22	4.3	0.9	39	0.13	48	0.17	0.09
182	200	1.9	273	13	4.9	0.9	41	0.22	30	0.18	0.09
182	230	3.2	272	7	5	0.9	84	0.20	33	0.10	0.09
182	300	4.2	273	9	5	0.9	39	0.33	19	0.20	0.09
182	330	4.6	278	8	5.3	0.9	45	0.32	20	0.18	0.09
182	400	4.5	279	9	5.5	0.9	36	0.35	18	0.22	0.09
182	430	3.7	277	9	5.5	1.3	44	0.29	22	0.18	0.09
182	500	3.7	280	8	5.5	12.4	125	0.17	37	0.07	0.24
182	530	2.9	245	11	5.5	70.9	84	0.19	34	0.10	0.27
182	600	1.8	236	8	5.7	160.6	256	0.08	76	0.03	0.17
182	630	2.9	226	13	6	251.7	60	0.22	29	0.13	0.29
182	700	3.2	222	14	6	350.3	47	0.26	25	0.17	0.31
182	730	2.6	238	23	6.7	449.8	21	0.35	18	0.33	0.34
182	800	3.9	252	19	7.1	547.6	21	0.43	15	0.35	0.35
182	830	4.6	254	21	7.4	640.3	15	0.56	11	0.50	0.36
182	900	5.3	263	23	7.6	725.5	11	0.71	9	0.68	0.37
182	930	4.7	259	24	7.9	803	11	0.66	10	0.65	0.37
182	1000	4.4	256	27	8.1	872	9	0.69	9	0.75	0.37
182	1030	5	254	20	8.3	925.5	15	0.58	11	0.50	0.36
182	1100	4.7	266	31	8.9	970.5	7	0.85	8	1.02	0.38
182	1130	4.7	255	25	8.9	997	10	0.68	9	0.70	0.37
182	1200	5	258	24	9.2	1011.5	10	0.70	9	0.69	0.37
182	1230	5.5	246	27	9.4	1022	7	0.86	7	0.94	0.38
182	1300	5.1	251	30	9.7	1013	6	0.89	7	1.05	0.38
182	1330	5.3	251	24	10.1	991	10	0.74	9	0.73	0.37
182	1400	5.4	259	25	10.3	959.5	9	0.79	8	0.80	0.37
182	1430	5.5	257	23	10.3	917	10	0.74	9	0.71	0.37
182	1500	6.2	266	23	10.3	841.5	9	0.83	8	0.80	0.37
182	1530	6	268	21	10.5	785.5	11	0.73	9	0.65	0.37
182	1600	5.3	249	26	10.6	703	8	0.80	8	0.85	0.38
182	1630	5.4	250	24	10.7	623.3	9	0.75	8	0.75	0.37
182	1700	4.5	255	26	10.7	448.9	10	0.68	9	0.72	0.37
182	1730	5.2	277	24	10.7	435.2	10	0.73	9	0.72	0.37
182	1800	5.6	276	22	10.7	348.2	11	0.72	9	0.66	0.37
182	1830	5.4	274	21	10.7	304.5	12	0.66	10	0.59	0.37
182	1900	4.6	283	19	10.5	70.8	18	0.51	13	0.42	0.36
182	1930	4.5	281	15	9.7	19.2	29	0.39	16	0.26	0.34
182	2000	3.7	290	14	9	5	18	0.45	14	0.40	0.10
182	2030	4	293	13	8.6	1	19	0.45	14	0.38	0.10
182	2100	3.8	311	10	8.3	1	35	0.33	19	0.22	0.09
182	2130	4	309	10	8.1	1	33	0.35	18	0.23	0.10
182	2200	4	305	8	8.1	0.9	51	0.28	23	0.15	0.09
182	2230	3.4	303	8	8.2	1	60	0.24	27	0.13	0.09
182	2300	4.3	314	7	7.8	0.9	62	0.26	24	0.13	0.09
182	2330	4.2	317	4	7.2	1	195	0.15	44	0.04	0.08
Day 182	**Avg.**	**=**								**0.43**	**0.25**
Day 183	**Avg.**	**=**								**0.48**	**0.26**
6-Day	**Avg.**	**=**								**0.47**	**0.25**

References

Bandy, A.; Thornton, D. C.; Blomquist, B. W.; Chen, S.; Wade, T. P.; Ianni, J. C.; Mitchell, G. M.; Nadler, W. 1996, Chemistry of dimethyl sulfide in the equatorial Pacific atmosphere. Geophysical Research Letters. 23(7): 741-744.

Bird, R. B.; Stewart, W. E.; Lightfoot, E. N. 1960. Transport phenomena. New York: J. Wiley & Sons. 780 p.

Brueggemann, E.; Spindler, G. 1999. Wet and dry deposition of sulphur at the site Melpitz in East Germany, in memorium dedicated to Wolfgang Rolle. Water, Air, and Soil Pollution. 109(1-4): 81-99.

Coe, H.; Gallagher, M. W. 1992. Measurements of dry deposition of NO_2 to a Dutch heathland using the eddy-correlation technique. Quarterly Journal of the Royal Meteorological Society. 118(506): 767-786.

Davis, C.; Wright, R. 1985. Sulfur dioxide deposition velocity by a concentration gradient measurement system. Journal of Geophysical Research. 90(D1): 2091-2095.

De Arellano, J. V-G.; Duynkerke, P.; Zeller, K. 1995. Atmospheric surface layer similarity theory applied to chemical reactive species. Journal of Geophysical Research. 100(D1): 1397-1408.

Erisman, J. W.; Hogenkamp, J. E. M.; Van Putten. E. M.; Uiterwijk, J. W.; Kemkers, E.; Wiese, C. J.; Mennen, M. G. 1999. Long-term continuous measurements of SO2 dry deposition over the Speulder forest. Water, Air, and Soil Pollution. 109(1-4): 237-262.

Erisman, J. W.; Vanelzakker, B. G.; Mennen, M. G.; Hogenkamp, J.; Zwart, E.; Vandenbeld, L.; Romer, F. G.; Bobbink, R; Hheil, G.; Raessen, M.; Duyzer, J. H.; Verhage, H.; Wyers, G. P.; Otjes, R. P.; Mols, J. J. 1994. The elspeetsche veld experiment on surface exchange of trace gases - summary of results. Atmospheric Environment. 28(3): 487-496.

Granat L.; Richter A. 1995. Dry deposition to pine of sulfur-dioxide and ozone at low concentration. Atmospheric Environment. 29(14): 1677-1683.

Hesterberg, R.; Blatter, A.; Fahrni, M.; Rosset, M.; Neftel, A.; Eugster, W.; Wanner, H. 1996. Deposition of nitrogen-containing compounds to an extensively managed grassland in central Switzerland. Environmental Pollution. 91(1): 21-34.

Hicks, B.; Hosker, R.; Meyers, T.; Womack, J. 1991. Dry deposition inferential measurement techniques-I. Design and tests of a prototype meteorological and chemical system for determining dry deposition. Atmospheric Environment. 25A: 2345-2359.

Hicks, B.; Wesely, M.; [and others]. 1986. An experimental study of sulfur and NO_x fluxes over grassland. Bdy. Lay. Meteor. 34: 103-121.

Hidy, G. 1998. Dry deposition relevant to the national parks and wilderness. Colorado State University Cooperative Institure for Research in the Atmosphere; Fort Collins contract. November: 30 p.

Hovmand, M. F.; Kemp, K. 1996. Downward trends of sulphur deposition to Danish spruce forest. Atmospheric Environment. 30(17): 2989-2999.

Pasquill, F. 1974. Atmospheric diffusion. New York: John Wiley & Sons.

Pilegaard, K.; Hummelshoj, P.; Jensen, N. O. 1998. Fluxes of ozone and nitrogen dioxide measured by eddy correlation over a harvested wheat field. Atmospheric Environment. 32(7): 1167-1177.

Massman, W. 1998. A review of the molecular diffusivities of H_2O, CO_2, CH_4, CO, O_3, SO_2, NH_3, N_2O, NO, and NO_2, in air, O_2, and N_2 near STP. Atmospheric Environment. 32(6): 1111-1127.

Massman, W. 1999. Molecular diffusivities of Hg vapor in air, O_2, and N_2 near STP and kinematic viscosity and thermal diffusivity of air near STP. Atmospheric Environment. 33: 453-457.

Matt, D.; McMillen, R.; Womack, J.; Hicks, B. 1987. A comparison of estimated and measured SO_2 deposition velocities. Water, Air, and Soil Pollution. 36: 331-347.

Neubert, A.; Kley, D.; Wildt, J.; Segschneider, H. J.; Forstel, H. 1993. Uptake of NO, NO_2 and O_3 by sunflower (helianthus-annuus l) and tobacco plants (nicotiana-tabacum-l) - dependence on stomatal conductivity, Part A – General Topics. Atmospheric Environment. 27(14): 2137-2145.

Nielsen, T.; Pilegaard, K.; Egelov, A. H.; Granby, K.; Hummelshoj, P.; Jensen, N. O.; Skov, H. 1996. Atmospheric nitrogen compounds: occurrence, composition and deposition. Science of the Total Environment. 190: 459-465.

Nikolov, N. T. 1997. Mathematical modeling of seasonal biogeophysical interactions in forest ecosystems. Fort Collins, CO: Colorado State University. 149 p. Dissertation.

Padro, J.; Zhang, L.; Massman, W. 1998. An analysis of measurements and modelling of air-surface exchange of NO-NO_2-O_3 over grass. Atmospheric Environment. 32(8): 1365-1375.

Padro J.; Neumann, H. H.; Denhartog, G. 1993. Dry deposition velocity estimates of SO_2 from models and measurements over a deciduous forest in winter. Water, Air, and Soil Pollution. 68(3-4): 325-339.

Rondon, A.; Johansson, C.; Granat, L. 1993. Dry deposition of nitrogen-dioxide and ozone to coniferous forests. Journal of Geophysical Research-Atmospheres. 98(D3): 5159-5172.

Stocker, D.; Stedman, D.; Zeller, K.; Massman, W.; Fox, D. 1993. Fluxes of NO_2 and O_3 measured by eddy correlation over a shotgrass praire. Journal of Geophysical Research. 98(D7): 12,619-12,630.

Sheih, C.; Wesely, M.; 1979. Hicks, B. Estimated dry deposition velocities of sulfur over the eastern U.S. and surrounding regions. Atmospheric Environment. 13: 1361-1368.

Venkatram, A.; Pleim, J. 1999. The electrical analogy does not apply to modeling dry deposition of particals. Atmospheric Environment. 33: 3075-3076.

Walcek, C.; Brost, R.; Chang, J.; Wesely, M. 1986. SO_2, sulfate and HNO_3 deposition velocities computed using regional landuse and meteorological data. Atmospheric Environment. 20(5): 949-964.

Wesely, M.; Hicks, B. 1977. Some factors that affect the deposition rates of sulfur dioxide and similar gases on vegetation. Journal of the Air Pollution Control Association. 27(11): 1110-1116.

Xu, Y. W.; Carmichael, G. R. 1998. Modeling the dry deposition velocity of sulfur dioxide and sulfate in Asia, Part 1. Journal of Applied Meteorology. 37(10): 1084-1099.

Zeller, K.; Hazlett, D. 1989. O_3 deposition and leaf area index at the Pawnee National Grassland for the 1988 growing season. In: Olson, R.; LeFohn, A. (eds.). Trans.: Effects of air pollution on western forests. AWMS ISBN 0-923204-03-2: 177-192.

Zeller, K; Nikolov, N.T. 2000. Quantifying simultaneous fluxes of ozone, carbon dioxide and water vapor above a subalpine forest ecosystem. Environmental Pollution. 107:1-20.

Appendix B. NADP Statistics for SO_4^{2-}, NO_3^-, Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, and NH_4^+ Concentration and Deposition

NF versus SR Sulfate concentration (mg/L)

	Complete valid weekly dataset					Precip-filtered weekly dataset					
Year	Slope	Offset	R^2	N		Slope	Offset	SR–NF^T	SR-NF^{50}	R^2	N
1987	0.42 ± 0.06	0.47 ± 0.08	0.63	31		0.28 ± 0.14	0.57 ± 0.13	-0.01 ± 0.54	-0.041	0.16	24
1988	1.27 ± 0.29	-0.02 ± 0.31	0.48	22		1.10 ± 0.32	0.02 ± 0.31	-0.11 ± 0.58	0.01	0.44	17
1989	1.01 ± 0.09	0.08 ± 0.11	0.78	34		0.83 ± 0.17	0.19 ± 0.15	-0.06 ± 0.33	-0.045	0.50	25
1990	1.93 ± 0.28	-0.38 ± 0.26	0.66	27		1.41 ± 0.15	-0.19 ± 0.09	-0.04 ± 0.21	-0.005	0.83	22
1991	1.13 ± 0.13	-0.01± 0.09	0.65	41		1.17 ± 0.18	-0.04 ± 0.12	-0.06 ± 0.30	-0.055	0.60	29
1992	1.05 ± 0.12	0.03 ± 0.12	0.75	28		0.93 ± 0.18	0.16 ± 0.16	-0.11 ± 0.33	-0.08	0.56	23
Summer 87-92	1.38 ± 0.13	-0.08 ± 0.13	0.55	89		1.02 ± 0.10	0.13 ± 0.09	-0.15 ± 0.29	-0.129	0.61	72
Winter 87-92	1.04 ± 0.07	-0.02 ± 0.06	0.73	85		0.97 ± 0.15	0.02 ± 0.10	0.00 ± 0.40	0.055	0.43	61
All years 87-92	0.90 ± 0.06	0.19 ± 0.07	0.52	183		0.81 ± 0.08	0.19 ± 0.06	-0.06 ± 0.38	-0.039	0.45	140

BL versus SR Sulfate concentration (mg/L)

Year	Slope	Offset	R^2	N		Slope	Offset	SR–BL^T	SR-BL^{50}	R^2	N
1992	1.07 ± 0.17	-0.07 ± 0.12	0.98	3		1.07 ± 0.17	-0.07 ± 0.12	0.03 ± 0.08	-	0.98	3
1993	0.68 ± 0.15	0.15 ± 0.09	0.58	31		0.57 ± 0.13	0.22 ± 0.10	0.07 ± 0.29	0.03	0.43	27
1994	1.00 ± 0.17	0.07 ± 0.13	0.59	27		0.85 ± 0.11	0.09 ± 0.08	0.00 ± 0.24	-0.034	0.74	24
1995	0.92 ± 0.06	0.01 ± 0.04	0.87	35		0.92 ± 0.09	0.01 ± 0.05	0.03 ± 0.10	0.028	0.78	32
1996	1.05 ± 0.08	-0.12 ± 0.06	0.86	28		0.85 ± 0.12	-0.01 ± 0.07	0.09 ± 0.14	0.073	0.71	24
1997	1.39 ± 0.07	-0.17 ± 0.05	0.91	38		0.98 ± 0.07	0.00 ± 0.04	0.01 ± 0.11	0.006	0.88	32
Summer 92-97	1.21 ± 0.08	-0.11 ± 0.07	0.78	75		0.95 ± 0.06	0.04 ± 0.04	-0.03 ± 0.15	-0.02	0.82	63
Winter 92-97	0.53 ± 0.06	0.13 ± 0.03	0.51	79		0.53 ± 0.06	0.13 ± 0.03	0.09 ± 0.20	0.067	0.51	73
All Years 92-97	1.04 ± 0.05	-0.04 ± 0.04	0.73	162		0.83 ± 0.05	0.06 ± 0.03	0.04 ± 0.18	0.022	0.70	142

NF versus SR Sulfate deposition (kg/Ha)

	Valid dataset					Reduced dataset					
Year	Slope	Offset	R^2	N		Slope	Offset	SR–NF^T	SR-NF^{50}	R^2	N
1987	0.36 ± 0.10	0.04 ± 0.01	0.32	31		0.28 ± 0.12	0.06 ± 0.02	0.05 ± 0.08	0.032	0.20	24
1988	0.27 ± 0.10	0.07 ± 0.03	0.26	22		0.28 ± 0.12	0.06 ± 0.04	0.12 ± 0.21	0.062	0.27	17
1989	0.22 ± 0.04	0.04 ± 0.01	0.51	34		0.22 ± 0.04	0.06 ± 0.02	0.16 ± 0.27	0.08	0.54	25
1990	0.25 ± 0.07	0.04 ± 0.01	0.35	27		0.25 ± 0.08	0.04 ± 0.02	0.09 ± 0.13	0.059	0.34	22
1991	0.18 ± 0.10	0.05 ± 0.02	0.08	41		0.15 ± 0.11	0.06 ± 0.02	0.10 ± 0.14	0.065	0.07	29
1992	0.67 ± 0.10	0.00 ± 0.02	0.62	28		0.70 ± 0.09	-0.01 ± 0.01	0.06 ± 0.04	0.057	0.75	23
Summer 87-92	0.34 ± 0.05	0.06 ± 0.01	0.34	89		0.33 ± 0.05	0.06 ± 0.01	0.04 ± 0.10	0.021	0.38	72
Winter 87-92	0.24 ± 0.03	0.02 ± 0.01	0.40	85		0.25 ± 0.04	0.02 ± 0.01	0.16 ± 0.20	0.106	0.43	61
All years 87-92	0.25 ± 0.03	0.05 ± 0.01	0.30	183		0.25 ± 0.03	0.05 ± 0.01	0.10 ± 0.16	0.056	0.33	140

BL versus SR Sulfate deposition (kg/Ha)

Year	Slope	Offset	R^2	N		Slope	Offset	SR–BL^T	SR-BL^{50}	R^2	N
1992	1.14 ± 0.18	0.00 ± 0.01	0.98	3		1.14 ± 0.18	0.00 ± 0.01	0.09 ± 0.16	-	0.98	3
1993	0.27 ± 0.11	0.08 ± 0.02	0.18	31		0.27 ± 0.09	0.07 ± 0.02	0.05 ± 0.13	0.016	0.26	27
1994	0.47 ± 0.07	0.04 ± 0.01	0.62	27		0.45 ± 0.08	0.04 ± 0.01	0.02 ± 0.06	0.003	0.58	24
1995	0.65 ± 0.09	0.03 ± 0.02	0.59	35		0.69 ± 0.10	0.02 ± 0.02	0.03 ± 0.06	0.018	0.59	32
1996	0.62 ± 0.07	0.01 ± 0.01	0.75	28		0.60 ± 0.08	0.02 ± 0.01	0.04 ± 0.06	0.028	0.71	24
1997	0.59 ± 0.05	0.03 ± 0.01	0.82	38		0.62 ± 0.04	0.01 ± 0.01	0.05 ± 0.07	0.022	0.91	32
Summer 92-97	0.78 ± 0.07	0.03 ± 0.01	0.63	75		0.77 ± 0.05	0.02 ± 0.01	0.00 ± 0.03	0.002	0.78	63
Winter 92-97	0.45 ± 0.05	0.03 ± 0.01	0.55	79		0.47 ± 0.05	0.02 ± 0.01	0.06 ± 0.10	0.045	0.60	73
All years 92-97	0.51 ± 0.04	0.04 ± 0.01	0.56	162		0.52 ± 0.03	0.03 ± 0.01	0.04 ± 0.08	0.017	0.62	142

Appendix B. (Cont'd.)

NF versus SR Nitrate concentration (mg/L)										
	Complete valid weekly dataset				Precip-filtered weekly dataset					
Year	Slope	Offset	R^2	N	Slope	Offset	SR–NF^T	SR-NF^{50}	R^2	N
1987	0.34 ± 0.05	0.60 ± 0.08	0.60	31	0.27 ± 0.10	0.68 ± 0.12	-0.08 ± 0.70	-0.14	0.25	24
1988	1.40 ± 0.15	-0.15 ± 0.18	0.80	22	1.17 ± 0.16	-0.06 ± 0.16	-0.08 ± 0.37	-0.106	0.78	17
1989	1.24 ± 0.09	0.07 ± 0.12	0.85	34	0.74 ± 0.14	0.37 ± 0.12	-0.19 ± 0.32	-0.222	0.56	25
1990	2.01 ± 0.25	-0.70 ± 0.30	0.73	27	1.23 ± 0.16	-0.15 ± 0.15	-0.05 ± 0.30	-0.035	0.74	22
1991	1.34 ± 0.17	-0.11 ± 0.15	0.63	41	1.27 ± 0.20	-0.07 ± 0.16	-0.13 ± 0.38	-0.073	0.61	29
1992	0.91 ± 0.17	0.32 ± 0.19	0.53	28	1.06 ± 0.21	0.22 ± 0.21	-0.27 ± 0.42	-0.192	0.55	23
Summer 87-92	1.54 ± 0.13	-0.19 ± 0.15	0.61	89	1.14 ± 0.10	0.12 ± 0.10	-0.26 ± 0.35	-0.198	0.64	72
Winter 87-92	1.25 ± 0.06	-0.09 ± 0.07	0.82	85	0.88 ± 0.11	0.13 ± 0.08	-0.04 ± 0.34	-0.017	0.51	61
All years 87-92	0.92 ± 0.06	0.27 ± 0.08	0.53	183	0.76 ± 0.07	0.33 ± 0.07	-0.13 ± 0.44	-0.122	0.47	140
BL versus SR Nitrate concentration (mg/L)										
Year	Slope	Offset	R^2	N	Slope	Offset	SR–BL^T	SR-BL^{50}	R^2	N
1992	1.05 ± 0.10	-0.15 ± 0.11	0.99	3	1.05 ± 0.10	-0.15 ± 0.11	0.012 ± 0.19	-	0.99	3
1993	0.76 ± 0.10	0.18 ± 0.10	0.67	31	0.80 ± 0.18	0.18 ± 0.14	0.122 ± 0.20	-0.022	0.44	27
1994	1.29 ± 0.22	-0.10 ± 0.22	0.58	27	0.93 ± 0.10	0.12 ± 0.10	0.042 ± 0.14	-0.066	0.79	24
1995	0.86 ± 0.07	0.05 ± 0.06	0.70	35	0.85 ± 0.09	0.06 ± 0.06	-0.06 ± 0.26	0.038	0.76	32
1996	1.04 ± 0.09	-0.16 ± 0.10	0.85	28	0.86 ± 0.09	-0.006 ± 0.09	-0.04 ± 0.35	0.101	0.79	24
1997	1.30 ± 0.08	-0.22 ± 0.08	0.88	38	0.96 ± 0.08	0.01 ± 0.07	0.10 ± 0.05	-0.004	0.84	32
Summer 92-97	1.14 ± 0.09	-0.08 ± 0.106	0.71	75	0.97 ± 0.06	0.07 ± 0.06	0.06 ± 0.22	-0.048	0.81	63
Winter 92-97	0.65 ± 0.07	0.16 ± 0.05	0.52	79	0.66 ± 0.07	0.15 ± 0.05	0.08 ± 0.23	0.076	0.55	73
All years 92-97	1.06 ± 0.05	-0.05 ± 0.05	0.71	162	0.89 ± 0.05	0.06 ± 0.04	0.02 ± 0.24	0.020	0.72	142

NF versus SR Nitrate deposition (kg/Ha)										
	Valid dataset				Reduced dataset					
Year	Slope	Offset	R^2	N	Slope	Offset	SR–NF^T	SR-NF^{50}	R^2	N
1987	0.42 ± 0.11	0.041 ± 0.017	0.34	31	0.29 ± 0.14	0.071 ± 0.023	0.035 ± 0.089	-	0.17	24
1988	0.05 ± 0.11	0.085 ± 0.023	0.01	22	0.06 ± 0.10	0.081 ± 0.025	0.088 ± 0.165	0.003	0.33	17
1989	0.16 ± 0.05	0.063 ± 0.017	0.27	34	0.17 ± 0.05	0.077 ± 0.020	0.138 ± 0.266	0.011	0.33	25
1990	0.22 ± 0.08	0.066 ± 0.02	0.26	27	0.20 ± 0.09	0.074 ± 0.027	0.137 ± 0.178	0.006	0.22	22
1991	0.21 ± 0.10	0.063 ± 0.025	0.10	41	0.26 ± 0.12	0.059 ± 0.033	0.113 ± 0.149	0.007	0.15	29
1992	0.54 ± 0.12	0.025 ± 0.022	0.44	28	0.52 ± 0.13	0.026 ± 0.025	0.059 ± 0.071	0.011	0.45	23
Summer 87-92	0.46 ± 0.06	0.060 ± 0.012	0.39	89	0.45 ± 0.07	0.059 ± 0.014	0.030 ± 0.088	0.018	0.41	72
Winter 87-92	0.14 ± 0.03	0.046 ± 0.009	0.24	85	0.15 ± 0.03	0.053 ± 0.010	0.174 ± 0.207	0.122	0.32	61
All years 87-92	0.19 ± 0.03	0.067 ± 0.008	0.17	183	0.20 ± 0.03	0.074 ± 0.009	0.096 ± 0.168	0.051	0.19	140
BL versus SR Nitrate deposition (kg/Ha)										
Year	Slope	Offset	R^2	N	Slope	Offset	SR–BL^T	SR-BL^{50}	R^2	N
1992	-3.13 ± 1.8	0.462 ± 0.196	0.76	3	-3.13 ± 1.8	0.462 ± 0.196	0.099 ± 0.149	0.002	0.76	3
1993	0.48 ± 0.18	0.081 ± 0.037	0.20	31	0.52 ± 0.19	0.065 ± 0.039	0.014 ± 0.133	0.003	0.23	27
1994	0.48 ± 0.08	0.054 ± 0.013	0.56	27	0.43 ± 0.10	0.062 ± 0.016	0.013 ± 0.067	-0.0004	0.48	24
1995	0.72 ± 0.10	0.030 ± 0.022	0.63	35	0.77 ± 0.10	0.014 ± 0.025	0.035 ± 0.070	0.005	0.66	32
1996	0.69 ± 0.08	0.014 ± 0.021	0.74	28	0.68 ± 0.09	0.019 ± 0.027	0.055 ± 0.096	0.012	0.71	24
1997	0.60 ± 0.06	0.045 ± 0.015	0.74	38	0.66 ± 0.05	0.020 ± 0.015	0.055 ± 0.079	0.006	0.84	32
Summer 92-97	0.87 ± 0.06	0.025 ± 0.011	0.77	75	0.87 ± 0.05	0.021 ± 0.010	-0.004 ± 0.038	-0.001	0.84	63
Winter 92-97	0.52 ± 0.06	0.045 ± 0.016	0.50	79	0.56 ± 0.06	0.030 ± 0.017	0.065 ± 0.109	0.060	0.54	73
All years 92-97	0.61 ± 0.04	0.044 ± 0.010	0.57	162	0.64 ± 0.04	0.036 ± 0.011	0.036 ± 0.093	0.024	0.60	142

Appendix B. (Cont'd.)

NF versus SR Chlorine concentration (mg/L)

	Complete valid weekly dataset				Precip-filtered weekly dataset					
Year	Slope	Offset	R^2	N	Slope	Offset	SR–NF^{T}	SR-NF^{50}	R^2	N
1987	0.16 ± 0.03	0.08 ± 0.01	0.57	31	0.16 ± 0.02	0.07 ± 0.009	0.07 ± 0.36	0.0008	0.71	24
1988	1.66 ± 0.11	-0.06 ± 0.02	0.91	22	1.23 ± 0.24	-0.02 ± 0.03	-0.006 ± 0.04	-0.007	0.63	17
1989	0.73 ± 0.08	0.05 ± 0.03	0.72	34	0.27 ± 0.13	0.07 ± 0.02	0.02 ± 0.08	0.004	0.15	25
1990	3.91 ± 2.17	-0.14 ± 0.41	0.12	27	-0.004 ± 0.08	0.10 ± 0.01	0.03 ± 0.13	0.009	0.00	22
1991	0.52 ± 0.17	0.08 ± 0.03	0.20	41	0.50 ± 0.16	0.04 ± 0.02	0.002 ± 0.04	0.0007	0.26	29
1992	0.50 ± 0.15	0.06 ± 0.02	0.30	28	0.46 ± 0.16	0.07 ± 0.03	0.006 ± 0.10	-0.007	0.28	23
Summer 87-92	4.32 ± 1.09	-0.30 ± 0.15	0.15	89	0.47 ± 0.09	0.06 ± 0.01	-0.005 ± 0.06	-0.007	0.28	72
Winter 87-92	0.68 ± 0.06	0.04 ± 0.02	0.59	85	0.22 ± 0.08	0.06 ± 0.01	0.03 ± 0.10	0.014	0.12	61
All years 87-92	0.59 ± 0.20	0.10 ± 0.05	0.05	183	0.18 ± 0.03	0.08 ± 0.006	0.02 ± 0.17	0.001	0.27	140

BL versus SR Chlorine concentration (mg/L)

Year	Slope	Offset	R^2	N	Slope	Offset	SR–BL^{T}	SR-BL^{50}	R^2	N
1992	-1.6 ± 2.14	0.22 ± 0.14	0.34	3	-1.55 ± 2.1	0.22 ± 0.14	-0.05 ± 0.07	-	0.34	3
1993	0.32 ± 0.06	0.05 ± 0.01	0.52	31	0.17 ± 0.07	0.06 ± 0.01	0.03 ± 0.10	0.005	0.20	27
1994	0.57 ± 0.27	0.03 ± 0.02	0.16	27	0.47 ± 0.17	0.03 ± 0.01	0.009 ± 0.04	0.002	0.25	24
1995	0.64 ± 0.10	0.016 ± 0.01	0.55	35	0.53 ± 0.11	0.02 ± 0.01	0.01 ± 0.03	0.007	0.42	32
1996	3.41 ± 0.95	-0.24 ± 0.14	0.33	28	0.51 ± 0.13	0.03 ± 0.02	0.02 ± 0.04	0.010	0.40	24
1997	1.76 ± 0.17	-0.05 ± 0.01	0.75	38	0.84 ± 0.13	0.01 ± 0.01	-0.002 ± 0.02	0.000	0.60	32
Summer 92-97	1.51 ± 0.35	-0.03 ± 0.05	0.21	75	0.71 ± 0.07	0.02 ± 0.007	0.0005 ± 0.03	-0.003	0.64	63
Winter 92-97	0.20 ± 0.05	0.05 ± 0.006	0.17	79	0.17 ± 0.05	0.05 ± 0.006	0.02 ± 0.07	0.011	0.14	73
All years 92-97	0.99 ± 0.18	0.002 ± 0.02	0.16	162	0.32 ± 0.05	0.05 ± 0.005	0.012 ± 0.054	0.003	0.26	142

NF versus SR Chlorine deposition (kg/Ha)

	Valid dataset				Reduced dataset					
Year	Slope	Offset	R^2	N	Slope	Offset	SR–NF^{T}	SR-NF^{50}	R^2	N
1987	0.12 ± 0.02	0.006 ± 0.001	0.47	31	0.10 ± 0.02	0.008 ± 0.001	0.014 ± 0.03	0.005	0.49	24
1988	0.18 ± 0.06	0.008 ± 0.002	0.34	22	0.20 ± 0.06	0.007 ± 0.002	0.02 ± 0.03	0.010	0.45	17
1989	0.07 ± 0.02	0.009 ± 0.002	0.20	34	0.08 ± 0.03	0.010 ± 0.002	0.04 ± 0.06	0.014	0.29	25
1990	0.00 ± 0.04	0.016 ± 0.004	0.00	27	0.009 ± 0.03	0.014 ± 0.003	0.03 ± 0.08	0.014	0.00	22
1991	0.01 ± 0.04	0.010 ± 0.002	0.00	41	0.14 ± 0.06	0.007 ± 0.002	0.02 ± 0.02	0.010	0.18	29
1992	0.06 ± 0.04	0.009 ± 0.001	0.09	28	0.05 ± 0.04	0.010 ± 0.001	0.02 ± 0.03	0.008	0.09	23
Summer 87-92	0.15 ± 0.05	0.01 ± 0.001	0.10	89	0.17 ± 0.04	0.010 ± 0.001	0.007 ± 0.04	0.003	0.24	72
Winter 87-92	0.05 ± 0.01	0.008 ± 0.001	0.12	85	0.06 ± 0.02	0.009 ± 0.001	0.04 ± 0.06	0.020	0.19	61
All years 87-92	0.05 ± 0.01	0.01 ± 0.0009	0.07	183	0.07 ± 0.01	0.010 ± 0.0008	0.022 ± 0.047	0.009	0.15	140

BL versus SR Chlorine deposition (kg/Ha)

Year	Slope	Offset	R^2	N	Slope	Offset	SR–BL^{T}	SR-BL^{50}	R^2	N
1992	-2.66 ± 3.3	0.04 ± 0.02	0.40	3	-2.66 ± 3.3	0.04 ± 0.02	0.001 ± 0.003	-	0.40	3
1993	0.23 ± 0.06	0.01 ± 0.003	0.36	31	0.25 ± 0.05	0.010 ± 0.003	0.01 ± 0.03	0.003	0.48	27
1994	0.34 ± 0.08	0.005 ± 0.001	0.45	27	0.32 ± 0.09	0.005 ± 0.002	0.005 ± 0.01	0.001	0.39	24
1995	0.46 ± 0.11	0.007 ± 0.003	0.34	35	0.51 ± 0.11	0.005 ± 0.003	0.007 ± 0.01	0.003	0.43	32
1996	0.57 ± 0.08	0.005 ± 0.003	0.64	28	0.59 ± 0.07	0.004 ± 0.003	0.008 ± 0.01	0.005	0.73	24
1997	0.48 ± 0.06	0.006 ± 0.002	0.62	38	0.54 ± 0.06	0.004 ± 0.002	0.005 ± 0.01	0.002	0.74	32
Summer 92-97	0.84 ± 0.06	0.003 ± 0.001	0.73	75	0.86 ± 0.04	0.001 ± 0.001	0.0005 ± 0.001	0.0004	0.88	63
Winter 92-97	0.28 ± 0.04	0.009 ± 0.001	0.44	79	0.30 ± 0.03	0.008 ± 0.001	0.01 ± 0.02	0.007	0.50	73
All years 92-97	0.37 ± 0.03	0.008 ± 0.001	0.44	162	0.39 ± 0.03	0.007 ± 0.001	0.007 ± 0.02	0.003	0.51	142

Appendix B. (Cont'd.)

NF versus SR Sodium concentration (mg/L)

	Complete valid weekly dataset					Precip-filtered weekly dataset					
Year	Slope	Offset	R^2	N		Slope	Offset	SR–NF^T	SR-NF^{50}	R^2	N
1987	0.16 ± 0.05	0.07 ± 0.02	0.29	31		0.14 ± 0.05	0.07 ± 0.02	0.05 ± 0.31	0.002	0.28	24
1988	1.02 ± 0.23	0.01 ± 0.04	0.49	22		1.06 ± 0.40	0.006 ± 0.05	-0.01 ± 0.09	-0.0003	0.33	17
1989	0.62 ± 0.07	0.04 ± 0.04	0.69	34		0.05 ± 0.08	0.11 ± 0.03	0.07 ± 0.29	0.012	0.02	25
1990	0.45 ± 0.17	0.04 ± 0.02	0.23	27		0.22 ± 0.12	0.04 ± 0.01	0.02 ± 0.08	0.003	0.14	22
1991	0.53 ± 0.19	0.06 ± 0.03	0.16	41		0.22 ± 0.16	0.05 ± 0.01	0.01± 0.06	0.005	0.07	29
1992	0.71 ± 0.11	0.02 ± 0.02	0.61	28		0.71 ± 0.12	0.02 ± 0.02	0.02 ± 0.09	0.007	0.63	23
Summer 87-92	0.68 ± 0.08	0.04 ± 0.01	0.43	89		0.59 ± 0.08	0.04 ± 0.01	0.003 ± 0.07	-0.001	0.45	72
Winter 87-92	0.62 ± 0.05	0.03 ± 0.02	0.62	85		0.16 ± 0.06	0.07 ± 0.02	0.04 ± 0.19	0.015	0.09	61
All years 87-92	0.50 ± 0.04	0.05 ± 0.01	0.50	183		0.22 ± 0.05	0.06 ± 0.01	0.03 ± 0.19	0.004	0.22	140

BL versus SR Sodium concentration (mg/L)

Year	Slope	Offset	R^2	N		Slope	Offset	SR–BL^T	SR-BL^{50}	R^2	N
1992	0.40 ± 0.53	0.08 ± 0.06	0.36	3		0.40 ± 0.53	0.08 ± 0.06	-0.02 ± 0.05	-	0.36	3
1993	0.49 ± 0.05	0.02 ± 0.01	0.78	31		0.11 ± 0.06	0.06 ± 0.01	0.04 ± 0.12	0.008	0.11	27
1994	0.07 ± 0.15	0.04 ± 0.01	0.01	27		0.19 ± 0.12	0.03 ± 0.007	0.01 ± 0.03	0.004	0.11	24
1995	0.29 ± 0.10	0.03 ± 0.008	0.21	35		0.29 ± 0.10	0.03 ± 0.008	0.02 ± 0.04	0.009	0.20	32
1996	0.97 ± 0.11	-0.01 ± 0.01	0.73	28		0.44 ± 0.10	0.03 ± 0.01	0.02 ± 0.04	0.012	0.45	24
1997	1.23 ± 0.21	-0.01 ± 0.01	0.48	38		0.57 ± 0.11	0.02 ± 0.007	0.003 ± 0.02	-0.0006	0.49	32
Summer 92-97	0.64 ± 0.04	0.03 ± 0.007	0.79	75		0.51 ± 0.07	0.03 ± 0.005	0.004 ± 0.035	0.001	0.48	63
Winter 92-97	0.15 ± 0.04	0.04 ± 0.004	0.16	79		0.16 ± 0.04	0.04 ± 0.005	0.024 ± 0.07	0.012	0.18	73
All years 92-97	0.53 ± 0.03	0.02 ± 0.005	0.62	162		0.23 ± 0.04	0.04 ± 0.004	0.015 ± 0.06	0.005	0.22	142

NF versus SR Sodium deposition (kg/Ha)

	Valid dataset					Reduced dataset					
Year	Slope	Offset	R^2	N		Slope	Offset	SR–NF^T	SR-NF^{50}	R^2	N
1987	0.16 ± 0.05	0.005 ± 0.002	0.26	31		0.15 ± 0.06	0.007 ± 0.002	0.011 ± 0.03	0.003	0.24	24
1988	0.25 ± 0.10	0.007 ± 0.004	0.28	22		0.26 ± 0.11	0.006 ± 0.006	0.020 ± 0.03	0.011	0.29	17
1989	0.06 ± 0.02	0.009 ± 0.002	0.22	34		0.05 ± 0.02	0.011 ± 0.003	0.062 ± 0.012	0.018	0.21	25
1990	0.06 ± 0.04	0.006 ± 0.002	0.10	27		0.05 ± 0.04	0.007 ± 0.002	0.020 ± 0.05	0.007	0.07	22
1991	0.06 ± 0.04	0.006 ± 0.002	0.05	41		0.13 ± 0.05	0.006 ± 0.002	0.017 ± 0.03	0.008	0.19	29
1992	0.07 ± 0.03	0.006 ± 0.001	0.14	28		0.06 ± 0.04	0.007 ± 0.001	0.014 ± 0.03	0.006	0.13	23
Summer 87-92	0.17 ± 0.03	0.006 ± 0.0007	0.27	89		0.16 ± 0.03	0.007 ± 0.001	0.007 ± 0.02	0.002	0.26	72
Winter 87-92	0.07 ± 0.02	0.007 ± 0.001	0.15	85		0.07 ± 0.02	0.008 ± 0.002	0.04 ± 0.09	0.019	0.16	61
All years 87-92	0.07 ± 0.01	0.007 ± 0.008	0.16	183		0.08 ± 0.01	0.008 ± 0.001	0.024 ± 0.062	0.007	0.17	140

BL versus SR Sodium deposition (kg/Ha)

Year	Slope	Offset	R^2	N		Slope	Offset	SR–BL^T	SR-BL^{50}	R^2	N
1992	-0.40 ± 2.3	0.018 ± 0.02	0.03	3		-0.40 ± 2.3	0.018 ± 0.02	-0.005 ± 0.007	-	0.03	3
1993	0.22 ± 0.10	0.010 ± 0.003	0.15	31		0.26 ± 0.10	0.008 ± 0.003	0.008 ± 0.018	0.003	0.21	27
1994	0.34 ± 0.07	0.003 ± 0.001	0.49	27		0.32 ± 0.08	0.003 ± 0.001	0.004 ± 0.008	0.001	0.44	24
1995	0.43 ± 0.10	0.005 ± 0.003	0.34	35		0.42 ± 0.12	0.005 ± 0.003	0.007 ± 0.013	0.004	0.31	32
1996	0.47 ± 0.06	0.004 ± 0.002	0.68	28		0.45 ± 0.07	0.005 ± 0.002	0.009 ± 0.014	0.006	0.64	24
1997	0.46 ± 0.04	0.004 ± 0.001	0.77	38		0.47 ± 0.05	0.004 ± 0.001	0.005 ± 0.010	0.008	0.77	32
Summer 92-97	0.75 ± 0.06	0.002 ± 0.001	0.72	75		0.75 ± 0.05	0.002 ± 0.001	0.001 ± 0.005	0.0006	0.78	63
Winter 92-97	0.31 ± 0.04	0.006 ± 0.001	0.39	79		0.31 ± 0.05	0.006 ± 0.002	0.010 ± 0.016	0.007	0.36	73
All years 92-97	0.41 ± 0.04	0.005 ± 0.0008	0.46	162		0.41 ± 0.04	0.005 ± 0.001	0.006 ± 0.013	0.003	0.47	142

Appendix B. (Cont'd.)

NF versus SR Potassium concentration (mg/L)

	Complete valid weekly dataset				Precip-filtered weekly dataset					
Year	Slope	Offset	R^2	N	Slope	Offset	SR–NF^{T}	SR-NF^{50}	R^2	N
1987	0.20 ± 0.07	0.02 ± 0.006	0.20	31	0.19 ± 0.09	0.019 ± 0.007	0.008 ± 0.07	-0.003	0.19	24
1988	1.38 ± 0.23	-0.001 ± 0.006	0.65	22	1.40 ± 0.20	-0.006 ± 0.005	-0.001 ± 0.02	0.0004	0.77	17
1989	1.15 ± 0.27	0.004 ± 0.007	0.37	34	0.81 ± 0.21	0.003 ± 0.004	0.0003 ± 0.01	0.000	0.40	25
1990	63.2 ± 16.8	-0.66 ± 0.34	0.36	27	0.41 ± 0.17	0.005 ± 0.003	0.003 ± 0.01	-0.0005	0.23	22
1991	0.63 ± 0.06	0.008 ± 0.004	0.71	41	0.76 ± 0.09	0.004 ± 0.002	-0.0007 ± 0.01	-0.0009	0.70	29
1992	0.10 ± 0.10	0.02 ± 0.004	0.03	28	0.08 ± 0.11	0.02 ± 0.005	0.001 ± 0.04	-0.003	0.02	23
Summer 87-92	3.67 ± 2.8	0.02 ± 0.11	0.02	89	0.56 ± 0.09	0.01 ± 0.003	-0.001 ± 0.03	-0.003	0.34	72
Winter 87-92	0.54 ± 0.06	0.008 ± 0.002	0.50	85	0.60 ± 0.16	0.005 ± 0.003	-0.0004 ± 0.01	0.0005	0.19	61
All years 87-92	1.27 ± 1.03	0.04 ± 0.05	0.01	183	0.27 ± 0.05	0.013 ± 0.002	0.002 ± 0.03	-0.0009	0.22	140

BL versus SR Potassium concentration (mg/L)

Year	Slope	Offset	R^2	N	Slope	Offset	SR–BL^{T}	SR-BL^{50}	R^2	N
1992	1.80 ± 0.09	0.002 ± 0.002	1.00	3	1.80 ± 0.09	0.002 ± 0.002	-0.013 ± 0.01	-	1.00	3
1993	1.20 ± 0.29	-0.002 ± 0.004	0.57	31	0.93 ± 0.19	0.001 ± 0.003	-0.0002 ± 0.01	-0.0004	0.48	27
1994	1.50 ± 0.24	-0.002 ± 0.006	0.61	27	1.48 ± 0.25	-0.002 ± 0.006	-0.007 ± 0.02	-0.0023	0.62	24
1995	1.64 ± 0.25	-0.005 ± 0.006	0.56	35	2.05 ± 0.43	-0.01 ± 0.007	-0.003 ± 0.03	0.0003	0.43	32
1996	0.80 ± 0.17	0.005 ± 0.005	0.45	28	0.44 ± 0.19	0.01 ± 0.005	0.0009 ± 0.02	0.002	0.20	24
1997	2.66 ± 0.15	-0.02 ± 0.005	0.90	38	0.57 ± 0.21	0.005 ± 0.004	0.0008 ± 0.01	0.002	0.20	32
Summer 92-97	2.17 ± 0.14	-0.016 ± 0.005	0.76	75	1.46 ± 0.20	-0.002 ± 0.005	-0.008 ± 0.03	-0.002	0.45	63
Winter 92-97	0.25 ± 0.11	0.006 ± 0.002	0.06	79	0.25 ± 0.11	0.006 ± 0.002	0.003 ± 0.01	0.002	0.06	73
All Years 92-97	1.95 ± 0.10	-0.012 ± 0.003	0.70	162	1.17 ± 0.13	-0.001 ± 0.003	-0.002 ± 0.02	0.000	0.38	142

NF versus SR Potassium deposition (kg/Ha)

	Valid dataset				Reduced dataset					
Year	Slope	Offset	R^2	N	Slope	Offset	SR–NF^{T}	SR-NF^{50}	R^2	N
1987	0.11 ± 0.09	0.002 ± 0.0006	0.05	31	0.08 ± 0.10	0.002 ± 0.0008	0.001 ± 0.007	0.0004	0.03	24
1988	0.25 ± 0.07	0.001 ± 0.0005	0.38	22	0.28 ± 0.06	0.001 ± 0.0005	0.003 ± 0.004	0.001	0.57	17
1989	0.19 ± 0.06	0.001 ± 0.0003	0.25	34	0.21 ± 0.07	0.001 ± 0.0004	0.003 ± 0.004	0.002	0.32	25
1990	-0.18 ± 0.4	0.005 ± 0.003	0.01	27	0.05 ± 0.04	0.001 ± 0.0004	0.004 ± 0.007	0.001	0.07	22
1991	0.19 ± 0.07	0.001 ± 0.0004	0.17	41	0.20 ± 0.06	0.001 ± 0.0004	0.003 ± 0.005	0.001	0.30	29
1992	0.17 ± 0.08	0.002 ± 0.0005	0.14	28	0.15 ± 0.09	0.002 ± 0.0006	0.002 ± 0.004	0.001	0.12	23
Summer 87-92	0.09 ± 0.19	0.003 ± 0.001	0.00	89	0.20 ± 0.04	0.002 ± 0.0003	0.002 ± 0.004	0.0004	0.27	72
Winter 87-92	0.12 ± 0.04	0.001 ± 0.0003	0.08	85	0.12 ± 0.05	0.001 ± 0.0004	0.003 ± 0.005	0.002	0.08	61
All years 87-92	0.09 ± 0.08	0.002 ± 0.0006	0.01	183	0.14 ± 0.03	0.002 ± 0.0002	0.003 ± 0.005	0.001	0.13	140

BL versus SR Potassium deposition (kg/Ha)

Year	Slope	Offset	R^2	N	Slope	Offset	SR–BL^{T}	SR-BL^{50}	R^2	N
1992	1.84 ± 0.90	0.0006 ± 0.001	0.81	3	1.84 ± 0.90	0.0006 ± 0.001	0.0001 ± 0.002	-	0.81	3
1993	0.93 ± 0.22	0.0004 ± 0.001	0.39	31	0.90 ± 0.13	0.000 ± 0.006	0.0009 ± 0.002	0.0002	0.66	27
1994	0.70 ± 0.20	0.001 ± 0.0008	0.34	27	0.68 ± 0.22	0.001 ± 0.001	0.0003 ± 0.002	-0.0001	0.31	24
1995	1.30 ± 0.26	-0.001 ± 0.001	0.44	35	1.35 ± 0.28	-0.001 ± 0.001	0.0008 ± 0.002	0.0003	0.44	32
1996	0.31 ± 0.12	0.002 ± 0.0009	0.23	28	0.27 ± 0.13	0.003 ± 0.001	0.002 ± 0.006	0.0007	0.17	24
1997	0.33 ± 0.10	0.001 ± 0.0006	0.23	38	0.34 ± 0.12	0.001 ± 0.0007	0.002 ± 0.004	0.0009	0.22	32
Summer 92-97	1.04 ± 0.14	0.001 ± 0.0007	0.45	75	1.04 ± 0.14	0.0006 ± 0.001	-0.001 ± 0.004	-0.0002	0.46	63
Winter 92-97	0.20 ± 0.05	0.001 ± 0.0003	0.19	79	0.20 ± 0.05	0.001 ± 0.0003	0.002 ± 0.004	0.001	0.18	73
All years 92-97	0.56 ± 0.07	0.001 ± 0.0004	0.26	162	0.55 ± 0.08	0.001 ± 0.0004	0.0006 ± 0.004	0.0004	0.26	142

Appendix B. (Cont'd.)

NF versus SR Calcium concentration (mg/L)

	Complete valid weekly dataset					Precip-filtered weekly dataset					
Year	**Slope**	**Offset**	**R^2**	**N**		**Slope**	**Offset**	**SR–NF^T**	**SR-NF^{50}**	**R^2**	**N**
1987	0.22 ± 0.03	0.16 ± 0.03	0.68	31		0.19 ± 0.03	0.15 ± 0.03	0.13 ± 0.86	-0.01	0.69	24
1988	0.95 ± 0.16	0.06 ± 0.06	0.63	22		0.84 ± 0.15	0.05 ± 0.05	-0.006 ± 0.15	0.02	0.67	17
1989	1.35 ± 0.08	-0.02 ± 0.04	0.90	34		1.42 ± 0.15	-0.05 ± 0.04	-0.06 ± 0.2	-0.006	0.89	25
1990	1.39 ± 0.32	-0.01 ± 0.08	0.43	27		0.67 ± 0.23	0.05 ± 0.05	0.01 ± 0.13	-0.005	0.29	22
1991	1.61 ± 0.15	-0.04 ± 0.04	0.76	41		1.50 ± 0.27	-0.04 ± 0.05	-0.042 ± 0.19	-0.005	0.54	29
1992	0.96 ± 0.12	0.05 ± 0.04	0.72	28		0.96 ± 0.13	0.07 ± 0.04	-0.06 ± 0.15	-0.004	0.73	23
Summer 87-92	1.09 ± 0.11	0.07 ± 0.03	0.53	89		0.93 ± 0.09	0.07 ± 0.03	-0.05 ± 0.15	-0.02	0.60	72
Winter 87-92	1.34 ± 0.05	-0.03 ± 0.02	0.89	85		1.35 ± 0.09	-0.04 ± 0.02	-0.024 ± 0.175	0.001	0.79	61
All years 87-92	0.50 ± 0.05	0.16 ± 0.03	0.39	183		0.36 ± 0.04	0.15 ± 0.02	-0.005 ± 0.4	-0.01	0.35	140

BL versus SR Calcium concentration (mg/L)

Year	**Slope**	**Offset**	**R^2**	**N**		**Slope**	**Offset**	**SR–BL^T**	**SR-BL^{50}**	**R^2**	**N**
1992	0.99 ± 0.01	0.005 ± 0.005	1.00	3		0.99 ± 0.01	0.005 ± 0.005	-0.003 ± 0.005	-	1.00	3
1993	0.74 ± 0.15	0.04 ± 0.03	0.46	31		0.62 ± 0.20	0.06 ± 0.04	0 ± 0.13	-0.006	0.28	27
1994	0.87 ± 0.19	0.04 ± 0.03	0.45	27		0.70 ± 0.12	0.05 ± 0.02	-0.008 ± 0.08	-0.025	0.61	24
1995	0.92 ± 0.07	0.002 ± 0.01	0.84	35		0.90 ± 0.08	0.004 ± 0.01	0.007 ± 0.053	0.003	0.83	32
1996	1.04 ± 0.11	-0.03 ± 0.04	0.77	28		0.53 ± 0.08	0.05 ± 0.02	0.03 ± 0.09	0.007	0.67	24
1997	1.57 ± 0.11	-0.04 ± 0.02	0.86	38		1.06 ± 0.09	0.000 ± 0.01	-0.006 ± 0.04	-0.006	0.82	32
Summer 92-97	1.19 ± 0.08	-0.01 ± 0.02	0.75	75		0.99 ± 0.07	0.02 ± 0.01	-0.02 ± 0.06	-0.012	0.75	63
Winter 92-97	0.59 ± 0.06	0.02 ± 0.01	0.60	79		0.59 ± 0.06	0.03 ± 0.01	0.02 ± 0.09	0.004	0.59	73
All Years 92-97	0.99 ± 0.05	0.005 ± 0.01	0.69	162		0.75 ± 0.05	0.03 ± 0.01	0.003 ± 0.08	-0.002	0.63	142

NF versus SR Calcium deposition (kg/Ha)

	Valid dataset					Reduced dataset					
Year	**Slope**	**Offset**	**R^2**	**N**		**Slope**	**Offset**	**SR–NF^T**	**SR-NF^{50}**	**R^2**	**N**
1987	0.13 ± 0.04	0.015 ± 0.003	0.30	31		0.12 ± 0.04	0.017 ± 0.004	0.02 ± 0.08	0.004	0.29	24
1988	0.37 ± 0.11	0.013 ± 0.008	0.36	22		0.41 ± 0.12	0.007 ± 0.01	0.03 ± 0.04	0.02	0.43	17
1989	0.33 ± 0.05	0.008 ± 0.005	0.57	34		0.34 ± 0.06	0.011 ± 0.005	0.03 ± 0.06	0.013	0.62	25
1990	0.54 ± 0.07	0.000 ± 0.006	0.68	27		0.55 ± 0.08	-0.002 ± 0.008	0.03 ± 0.04	0.016	0.69	22
1991	0.37 ± 0.08	0.008 ± 0.006	0.33	41		0.38 ± 0.10	0.008 ± 0.008	0.02 ± 0.05	0.01	0.35	29
1992	0.26 ± 0.09	0.013 ± 0.004	0.23	28		0.23 ± 0.10	0.015 ± 0.005	0.01 ± 0.03	0.01	0.20	23
Summer 87-92	0.59 ± 0.04	0.008 ± 0.003	0.67	89		0.61 ± 0.05	0.007 ± 0.003	0.008 ± 0.03	0.004	0.71	72
Winter 87-92	0.30 ± 0.04	0.005 ± 0.003	0.42	85		0.32 ± 0.04	0.004 ± 0.004	0.04 ± 0.05	0.02	0.45	61
All years 87-92	0.31 ± 0.03	0.011 ± 0.002	0.40	183		0.32 ± 0.03	0.011 ± 0.003	0.03 ± 0.05	0.01	0.42	140

BL versus SR Calcium deposition (kg/Ha)

Year	**Slope**	**Offset**	**R^2**	**N**		**Slope**	**Offset**	**SR–BL^T**	**SR-BL^{50}**	**R^2**	**N**
1992	1.05 ± 0.01	0.001 ± 0.000	1.00	3		1.05 ± 0.01	0.001 ± 0.000	-0.002 ± 0.001	-	1.00	3
1993	0.82 ± 0.18	0.006 ± 0.008	0.41	31		0.79 ± 0.14	0.003 ± 0.006	0.004 ± 0.02	0	0.57	27
1994	0.37 ± 0.10	0.01 ± 0.003	0.37	27		0.34 ± 0.10	0.011 ± 0.004	0.004 ± 0.02	-0.002	0.33	24
1995	0.96 ± 0.06	-0.002 ± 0.003	0.88	35		0.98 ± 0.07	-0.003 ± 0.003	0.004 ± 0.013	0.005	0.88	32
1996	0.66 ± 0.05	0.005 ± 0.003	0.86	28		0.65 ± 0.06	0.006 ± 0.004	0.01 ± 0.022	0.005	0.85	24
1997	0.73 ± 0.05	0.003 ± 0.002	0.88	38		0.74 ± 0.05	0.001 ± 0.002	0.006 ± 0.013	0.003	0.88	32
Summer 92-97	0.83 ± 0.06	0.006 ± 0.003	0.73	75		0.81 ± 0.05	0.006 ± 0.002	-0.001 ± 0.01	-0.001	0.84	63
Winter 92-97	0.63 ± 0.05	0.003 ± 0.002	0.67	79		0.64 ± 0.05	0.002 ± 0.003	0.01 ± 0.02	0.006	0.67	73
All years 92-97	0.74 ± 0.04	0.004 ± 0.002	0.69	162		0.74 ± 0.04	0.003 ± 0.002	0.005 ± 0.02	0.002	0.75	142

Appendix B. (Cont'd.)

NF versus SR Magnesium concentration (mg/L)											
	Complete valid weekly dataset					Precip-filtered weekly dataset					
Year	Slope	Offset	R^2	N		Slope	Offset	SR–NF^T	SR-NF^{50}	R^2	N
1987	0.28 ± 0.04	0.02 ± 0.004	0.62	31		0.24 ± 0.05	0.02 ± 0.004	0.008 ± 0.065	-0.001	0.54	24
1988	1.10 ± 0.17	0.0004 ± 0.007	0.69	22		0.91 ± 0.15	0.002 ± 0.006	0.001 ± 0.015	0.002	0.71	17
1989	1.33 ± 0.09	-0.006 ± 0.006	0.87	34		1.09 ± 0.11	-0.001 ± 0.005	-0.002 ± 0.016	0.0003	0.82	25
1990	1.57 ± 0.31	-0.009 ± 0.01	0.51	27		0.67 ± 0.24	0.005 ± 0.007	0.004 ± 0.016	0.001	0.28	22
1991	1.47 ± 0.14	-0.004 ± 0.005	0.73	41		1.04 ± 0.21	0.003 ± 0.005	-0.004 ± 0.016	-0.0009	0.48	29
1992	0.91 ± 0.11	0.005 ± 0.005	0.73	28		0.88 ± 0.12	0.008 ± 0.005	-0.005 ± 0.017	-0.003	0.72	23
Summer 87-92	1.19 ± 0.11	0.004 ± 0.005	0.57	89		0.89 ± 0.07	0.008 ± 0.003	-0.004 ± 0.016	-0.0018	0.67	72
Winter 87-92	1.29 ± 0.06	-0.006 ± 0.003	0.85	85		1.00 ± 0.10	-0.001 ± 0.003	0.000 ± 0.018	0.0018	0.61	61
All years 87-92	0.71 ± 0.05	0.014 ± 0.003	0.49	183		0.46 ± 0.05	0.016 ± 0.002	0.000 ± 0.03	-0.0004	0.42	140
BL versus SR Magnesium concentration (mg/L)											
Year	Slope	Offset	R^2	N		Slope	Offset	SR–BL^T	SR-BL^{50}	R^2	N
1992	1.31 ± 0.04	-0.002 ± 0.002	1.00	3		1.31 ± 0.04	-0.002 ± 0.002	-0.005 ± 0.009	-	1.00	3
1993	1.10 ± 0.11	-0.003 ± 0.003	0.77	31		1.04 ± 0.16	-0.001 ± 0.004	0.0006 ± 0.010	0.0006	0.63	27
1994	1.13 ± 0.24	0.002 ± 0.005	0.48	27		0.94 ± 0.11	0.003 ± 0.002	-0.002 ± 0.007	-0.002	0.75	24
1995	0.80 ± 0.08	0.002 ± 0.002	0.74	35		0.75 ± 0.08	0.002 ± 0.002	0.002 ± 0.007	0.0008	0.73	32
1996	1.30 ± 0.06	-0.01 ± 0.003	0.94	28		0.71 ± 0.08	0.003 ± 0.002	0.003 ± 0.008	0.0016	0.78	24
1997	1.64 ± 0.09	-0.007 ± 0.002	0.89	38		1.00 ± 0.08	0.0007 ± 0.001	-0.001 ± 0.004	-0.0007	0.82	32
Summer 92-97	1.31 ± 0.06	-0.004 ± 0.002	0.87	75		0.97 ± 0.07	0.003 ± 0.002	-0.003 ± 0.007	-0.0013	0.77	63
Winter 92-97	0.73 ± 0.06	0.0008 ± 0.001	0.69	79		0.73 ± 0.06	0.001 ± 0.001	0.002 ± 0.007	0.0012	0.70	73
All years 92-97	1.21 ± 0.04	-0.003 ± 0.001	0.84	162		0.88 ± 0.05	0.0015 ± 0.001	0.0004 ± 0.007	0.0001	0.73	142

NF versus SR Magnesium deposition (kg/Ha)											
	Valid dataset					Reduced dataset					
Year	Slope	Offset	R^2	N		Slope	Offset	SR–NF^T	SR-NF^{50}	R^2	N
1987	0.15 ± 0.07	0.002 ± 0.0006	0.13	31		0.13 ± 0.08	0.003 ± 0.0007	0.002 ± 0.007	0.0008	0.11	24
1988	0.23 ± 0.10	0.002 ± 0.0009	0.21	22		0.26 ± 0.11	0.002 ± 0.001	0.004 ± 0.006	0.003	0.26	17
1989	0.26 ± 0.04	0.001 ± 0.0006	0.51	34		0.26 ± 0.05	0.002 ± 0.0007	0.006 ± 0.009	0.003	0.56	25
1990	0.40 ± 0.08	0.0006 ± 0.001	0.52	27		0.41 ± 0.09	0.0003 ± 0.001	0.005 ± 0.007	0.003	0.51	22
1991	0.23 ± 0.08	0.002 ± 0.0006	0.19	41		0.24 ± 0.08	0.002 ± 0.0008	0.003 ± 0.006	0.001	0.23	29
1992	0.27 ± 0.10	0.001 ± 0.0005	0.24	28		0.26 ± 0.10	0.002 ± 0.0006	0.002 ± 0.003	0.001	0.26	23
Summer 87-92	0.53 ± 0.05	0.001 ± 0.0003	0.60	89		0.54 ± 0.05	0.001 ± 0.0004	0.001 ± 0.003	0.0006	0.65	72
Winter 87-92	0.22 ± 0.03	0.001 ± 0.0004	0.33	85		0.23 ± 0.04	0.001 ± 0.0005	0.006 ± 0.008	0.004	0.37	61
All years 87-92	0.26 ± 0.03	0.01 ± 0.0003	0.34	183		0.27 ± 0.03	0.002 ± 0.0003	0.004 ± 0.007	0.002	0.37	140
BL versus SR Magnesium deposition (kg/Ha)											
Year	Slope	Offset	R^2	N		Slope	Offset	SR–BL^T	SR-BL^{50}	R^2	N
1992	1.43 ± 0.02	-0.0003 ± 0.00	1.00	3		1.43 ± 0.02	-0.0003 ± 0.00	0.0001 ± 0.002	-	1.00	3
1993	0.65 ± 0.19	0.001 ± 0.001	0.30	31		0.73 ± 0.12	0.0004 ± 0.001	0.0009 ± 0.002	0.0004	0.59	27
1994	0.60 ± 0.11	0.001 ± 0.0003	0.55	27		0.58 ± 0.12	0.001 ± 0.0004	0.0003 ± 0.002	0.000	0.51	24
1995	0.81 ± 0.08	0.000 ± 0.001	0.74	35		0.83 ± 0.09	0.000 ± 0.0005	0.0008 ± 0.002	0.000	0.73	32
1996	0.57 ± 0.05	0.001 ± 0.0004	0.82	28		0.56 ± 0.06	0.001 ± 0.0005	0.002 ± 0.003	0.0006	0.81	24
1997	0.74 ± 0.04	0.000 ± 0.000	0.89	38		0.77 ± 0.05	0.000 ± 0.000	0.0007 ± 0.001	0.0008	0.91	32
Summer 92-97	0.75 ± 0.07	0.001 ± 0.0004	0.62	75		0.72 ± 0.05	0.001 ± 0.0003	0.000 ± 0.001	0.000	0.79	63
Winter 92-97	0.57 ± 0.04	0.000 ± 0.000	0.71	79		0.58 ± 0.04	0.000 ± 0.000	0.001 ± 0.002	0.001	0.71	73
All years 92-97	0.66 ± 0.04	0.001 ± 0.0002	0.63	162		0.67 ± 0.03	0.001 ± 0.0002	0.0008 ± 0.002	0.0004	0.73	142

Appendix B. (Cont'd.)

NF versus SR Ammonium concentration (mg/L)											
	Complete valid weekly dataset					Precip-filtered weekly dataset					
Year	Slope	Offset	R^2	N		Slope	Offset	$SR–NF^{T}$	$SR\text{-}NF^{50}$	R^2	N
1987	1.10 ± 0.16	0.004 ± 0.02	0.62	31		1.19 ± 0.25	-0.004 ± 0.03	-0.018 ± 0.083	-0.01	0.50	24
1988	0.52 ± 0.19	0.06 ± 0.03	0.28	22		0.36 ± 0.09	0.04 ± 0.01	0.008 ± 0.082	-0.003	0.50	17
1989	0.68 ± 0.25	0.05 ± 0.05	0.19	34		0.80 ± 0.23	0.03 ± 0.04	-0.008 ± 0.124	-0.002	0.35	25
1990	0.88 ± 0.26	0.08 ± 0.06	0.31	27		0.38 ± 0.20	0.09 ± 0.04	-0.001 ± 0.13	-0.022	0.16	22
1991	0.46 ± 0.14	0.08 ± 0.02	0.22	41		0.57 ± 0.16	0.06 ± 0.02	-0.019 ± 0.102	-0.023	0.31	29
1992	0.58 ± 0.11	0.09 ± 0.03	0.52	28		0.58 ± 0.12	0.09 ± 0.03	0.000 ± 0.13	0.000	0.54	23
Summer 87-92	0.90 ± 0.10	0.06 ± 0.02	0.48	89		0.73 ± 0.08	0.07 ± 0.02	0.004 ± 0.12	-0.026	0.54	72
Winter 87-92	0.18 ± 0.10	0.09 ± 0.02	0.04	85		0.22 ± 0.10	0.07 ± 0.01	-0.023 ± 0.11	-0.004	0.07	61
All years 87-92	0.70 ± 0.07	0.06 ± 0.01	0.34	183		0.64 ± 0.07	0.06 ± 0.01	-0.008 ± 0.108	-0.012	0.45	140
BL versus SR Ammonium concentration (mg/L)											
Year	Slope	Offset	R^2	N		Slope	Offset	$SR–BL^{T}$	$SR\text{-}BL^{50}$	R^2	N
1992	-0.68 ± 3.5	0.12 ± 0.19	0.04	3		-0.68 ± 3.5	0.12 ± 0.19	-0.037 ± 0.097	-	0.04	3
1993	0.76 ± 0.17	0.02 ± 0.03	0.41	31		0.73 ± 0.18	0.02 ± 0.03	0.018 ± 0.091	-0.003	0.40	27
1994	0.55 ± 0.19	0.07 ± 0.04	0.25	27		0.54 ± 0.14	0.06 ± 0.03	0.005 ± 0.094	-0.008	0.41	24
1995	0.65 ± 0.09	0.03 ± 0.01	0.62	35		0.62 ± 0.10	0.03 ± 0.01	0.018 ± 0.051	0.011	0.58	32
1996	0.57 ± 0.10	0.02 ± 0.02	0.55	28		0.62 ± 0.11	0.02 ± 0.02	0.046 ± 0.072	0.048	0.61	24
1997	1.29 ± 0.13	-0.03 ± 0.02	0.73	38		0.76 ± 0.12	0.02 ± 0.02	0.007 ± 0.054	-0.002	0.59	32
Summer 92-97	0.85 ± 0.11	0.03 ± 0.02	0.47	75		0.78 ± 0.08	0.03 ± 0.02	0.000 ± 0.07	-0.005	0.59	63
Winter 92-97	0.33 ± 0.06	0.05 ± 0.008	0.30	79		0.33 ± 0.06	0.05 ± 0.008	0.03 ± 0.07	0.021	0.31	73
All years 92-97	0.72 ± 0.06	0.03 ± 0.01	0.45	162		0.63 ± 0.06	0.03 ± 0.009	0.017 ± 0.074	0.008	0.47	142

NF versus SR Ammonium deposition (kg/Ha)											
	Valid dataset					Reduced dataset					
Year	Slope	Offset	R^2	N		Slope	Offset	$SR–NF^{T}$	$SR\text{-}NF^{50}$	R^2	N
1987	0.65 ± 0.11	0.001 ± 0.003	0.53	31		0.65 ± 0.14	0.001 ± 0.005	0.008 ± 0.018	0.005	0.49	24
1988	0.12 ± 0.08	0.008 ± 0.003	0.09	22		0.14 ± 0.05	0.006 ± 0.002	0.012 ± 0.033	0.003	0.33	17
1989	0.12 ± 0.06	0.011 ± 0.005	0.10	34		0.11 ± 0.07	0.015 ± 0.007	0.032 ± 0.073	0.011	0.09	25
1990	0.10 ± 0.07	0.018 ± 0.005	0.08	27		0.10 ± 0.07	0.018 ± 0.006	0.026 ± 0.060	0.006	0.09	22
1991	0.24 ± 0.11	0.010 ± 0.005	0.11	41		0.27 ± 0.13	0.010 ± 0.006	0.015 ± 0.037	0.007	0.15	29
1992	0.43 ± 0.10	0.007 ± 0.005	0.43	28		0.41 ± 0.10	0.007 ± 0.006	0.018 ± 0.030	0.011	0.44	23
Summer 87-92	0.53 ± 0.07	0.009 ± 0.003	0.44	89		0.54 ± 0.07	0.008 ± 0.003	0.008 ± 0.026	0.004	0.47	72
Winter 87-92	0.07 ± 0.02	0.007 ± 0.002	0.10	85		0.07 ± 0.02	0.009 ± 0.002	0.017 ± 0.029	0.011	0.12	61
All years 87-92	0.19 ± 0.03	0.011 ± 0.002	0.15	183		0.19 ± 0.04	0.012 ± 0.002	0.019 ± 0.046	0.007	0.16	140
BL versus SR Ammonium deposition (kg/Ha)											
Year	Slope	Offset	R^2	N		Slope	Offset	$SR–BL^{T}$	$SR\text{-}BL^{50}$	R^2	N
1992	-1.25 ± 1.7	0.013 ± 0.010	0.37	3		-1.25 ± 1.7	0.013 ± 0.010	-0.003 ± 0.009	-	0.37	3
1993	0.31 ± 0.11	0.014 ± 0.005	0.20	31		0.32 ± 0.11	0.012 ± 0.005	0.010 ± 0.028	0.003	0.24	27
1994	0.25 ± 0.04	0.011 ± 0.002	0.62	27		0.24 ± 0.04	0.012 ± 0.002	0.008 ± 0.031	0.000	0.61	24
1995	0.66 ± 0.10	0.007 ± 0.005	0.55	35		0.69 ±0.11	0.005 ± 0.005	0.007 ± 0.019	0.005	0.57	32
1996	0.59 ± 0.08	0.002 ± 0.004	0.69	28		0.57 ± 0.09	0.004 ± 0.005	0.015 ± 0.021	0.012	0.65	24
1997	0.44 ± 0.06	0.008 ± 0.003	0.59	38		0.45 ± 0.07	0.008 ± 0.004	0.013 ± 0.024	0.006	0.61	32
Summer 92-97	0.76 ± 0.06	0.005 ± 0.002	0.70	75		0.75 ± 0.06	0.005 ± 0.003	0.001 ± 0.011	0.000	0.71	63
Winter 92-97	0.33 ± 0.04	0.010 ± 0.002	0.44	79		0.34 ± 0.04	0.008 ± 0.002	0.031 ± 0.062	0.011	0.48	73
All years 92-97	0.45 ± 0.04	0.010 ± 0.002	0.48	162		0.45 ± 0.04	0.009 ± 0.002	0.01± 0.024	0.004	0.49	142

Appendix C. NADP weekly concentration and weekly deposition and total annual deposition for SO_4^{2-}, NO_3^-, Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, and NH_4^+

Sulfate concentration (mg/L) and deposition (kg/Ha) reported by NADP							
	Concentration weekly averages			Deposition annual totals		Deposition weekly averages	
Year	SR	NF		SR	NF	SR	NF
1987	0.60	0.68		5.24	3.73	0.10	0.07
1988	0.72	0.77		8.65	4.28	0.17	0.08
1989	0.77	0.80		9.72	4.00	0.19	0.08
1990	0.49	0.56		6.39	3.35	0.12	0.06
1991	0.51	0.58		6.40	3.40	0.12	0.07
1992	0.63	0.72		6.79	2.62	0.13	0.07
average	**0.62**	**0.69**		**7.20**	**3.56**	**0.14**	**0.07**
Year	**SR**	**BL**		**SR**	**BL**	**SR**	**BL**
1992	0.63	0.40		6.79	1.20	0.13	0.09
1993	0.59	0.53		8.41	6.77	0.16	0.13
1994	0.55	0.47		4.58	3.50	0.09	0.07
1995	0.46	0.41		6.53	5.82	0.13	0.11
1996	0.52	0.35		6.83	4.91	0.13	0.09
1997	0.53	0.43		6.34	5.16	0.12	0.10
average	**0.55**	**0.43**		**6.58**	**4.56**	**0.13**	**0.10**

Nitrate concentration (mg/L) and deposition (kg/Ha) reported by NADP							
	Concentration weekly averages			Deposition annual totals		Deposition weekly averages	
Year	SR	NF		SR	NF	SR	NF
1987	0.63	0.79		5.48	4.28	0.11	0.12
1988	0.51	0.59		6.08	3.25	0.12	0.06
1989	0.77	0.89		9.73	4.48	0.19	0.09
1990	0.76	0.82		9.95	4.90	0.19	0.09
1991	0.67	0.79		8.38	4.57	0.16	0.09
1992	0.87	0.91		9.43	3.30	0.18	0.06
average	**0.70**	**0.80**		**8.18**	**4.13**	**0.16**	**0.08**
Year	**SR**	**NF**		**SR**	**NF**	**SR**	**NF**
1992	0.87	0.67		9.43	2.04	0.18	0.15
1993	0.59	0.63		8.44	8.02	0.16	0.15
1994	0.71	0.68		5.94	5.06	0.11	0.10
1995	0.63	0.56		8.95	8.05	0.17	0.15
1996	0.80	0.54		10.65	7.67	0.20	0.15
1997	0.76	0.67		9.20	8.06	0.18	0.16
average	**0.73**	**0.63**		**8.77**	**6.48**	**0.17**	**0.12**

Appendix C. (Cont'd.)

Chlorine concentration (mg/L) and deposition (kg/Ha) reported by NADP						
	Concentration weekly averages		Deposition annual totals		Deposition weekly averages	
Year	**SR**	**NF**	**SR**	**NF**	**SR**	**NF**
1987	0.13	0.08	1.17	0.41	0.023	0.011
1988	0.11	0.10	1.33	0.55	0.026	0.011
1989	0.16	0.11	1.98	0.57	0.038	0.011
1990	0.13	0.11	1.73	0.67	0.033	0.013
1991	0.10	0.08	1.31	0.48	0.025	0.009
1992	0.12	0.09	1.28	0.31	0.025	0.006
average	**0.13**	**0.10**	**1.47**	**0.50**	**0.028**	**0.010**
Year	**SR**	**NF**	**SR**	**NF**	**SR**	**NF**
1992	0.12	0.06	1.28	0.19	0.025	0.014
1993	0.10	0.07	1.39	0.93	0.027	0.018
1994	0.07	0.06	0.60	0.42	0.012	0.008
1995	0.06	0.06	0.93	0.89	0.018	0.017
1996	0.11	0.07	1.46	1.03	0.028	0.020
1997	0.07	0.06	0.85	0.76	0.016	0.015
average	**0.09**	**0.06**	**1.09**	**0.70**	**0.021**	**0.013**

Sodium concentration (mg/L) and deposition (kg/Ha) reported by NADP						
	Concentration weekly averages		Deposition annual totals		Deposition weekly averages	
Year	**SR**	**NF**	**SR**	**NF**	**SR**	**NF**
1987	0.15	0.07	1.30	0.39	0.025	0.011
1988	0.12	0.12	1.39	0.64	0.027	0.012
1989	0.21	0.11	2.61	0.57	0.050	0.011
1990	0.09	0.06	1.16	0.36	0.022	0.007
1991	0.09	0.06	1.11	0.34	0.021	0.007
1992	0.10	0.07	1.08	0.24	0.021	0.005
average	**0.12**	**0.08**	**1.44**	**0.42**	**0.028**	**0.008**
Year	**SR**	**NF**	**SR**	**NF**	**SR**	**NF**
1992	0.10	0.06	1.08	0.18	0.021	0.013
1993	0.08	0.07	1.07	0.95	0.021	0.018
1994	0.05	0.04	0.43	0.30	0.008	0.006
1995	0.06	0.05	0.87	0.75	0.017	0.014
1996	0.10	0.06	1.30	0.83	0.025	0.016
1997	0.06	0.05	0.68	0.62	0.013	0.012
average	**0.07**	**0.06**	**0.90**	**0.60**	**0.017**	**0.012**

Potassium concentration (mg/L) and deposition (kg/Ha) reported by NADP						
	Concentration weekly averages		Deposition annual totals		Deposition weekly averages	
Year	**SR**	**NF**	**SR**	**NF**	**SR**	**NF**
1987	0.02	0.02	0.17	0.10	0.003	0.003
1988	0.02	0.01	0.22	0.08	0.004	0.002
1989	0.01	0.02	0.17	0.08	0.003	0.002
1990	0.01	0.03	0.18	0.16	0.003	0.003
1991	0.01	0.02	0.18	0.09	0.003	0.002
1992	0.02	0.02	0.21	0.07	0.004	0.001
average	**0.02**	**0.02**	**0.18**	**0.10**	**0.003**	**0.002**
Year	**SR**	**NF**	**SR**	**NF**	**SR**	**NF**
1992	0.02	0.01	0.21	0.04	0.004	0.003
1993	0.01	0.01	0.14	0.14	0.003	0.003
1994	0.01	0.02	0.12	0.11	0.002	0.002
1995	0.01	0.01	0.14	0.19	0.003	0.004
1996	0.02	0.01	0.31	0.20	0.006	0.004
1997	0.01	0.01	0.17	0.14	0.003	0.003
average	**0.02**	**0.01**	**0.18**	**0.14**	**0.003**	**0.003**

Appendix C. (Cont'd.)

Calcium concentration (mg/L) and deposition (kg/Ha) reported by NADP							
	Concentration weekly averages			Deposition annual totals		Deposition weekly averages	
Year	**SR**	**NF**		**SR**	**NF**	**SR**	**NF**
1987	0.20	0.17		1.74	0.93	0.03	0.03
1988	0.19	0.20		2.23	1.11	0.04	0.02
1989	0.19	0.26		2.46	1.28	0.05	0.02
1990	0.19	0.18		2.44	1.07	0.05	0.02
1991	0.14	0.18		1.75	1.06	0.03	0.02
1992	0.17	0.18		1.81	0.64	0.03	0.01
average	**0.18**	**0.20**		**2.07**	**1.02**	**0.04**	**0.02**
Year	**SR**	**NF**		**SR**	**NF**	**SR**	**NF**
1992	0.17	0.09		1.81	0.27	0.03	0.02
1993	0.11	0.13		1.61	1.68	0.03	0.03
1994	0.12	0.11		0.98	0.81	0.02	0.02
1995	0.11	0.10		1.52	1.48	0.03	0.03
1996	0.19	0.11		2.47	1.61	0.05	0.03
1997	0.11	0.11		1.35	1.27	0.03	0.02
average	**0.14**	**0.11**		**1.62**	**1.19**	**0.03**	**0.02**

Magnesium concentration (mg/L) and deposition (kg/Ha) reported by NADP							
	Concentration weekly averages			Deposition annual totals		Deposition weekly averages	
Year	**SR**	**NF**		**SR**	**NF**	**SR**	**NF**
1987	0.03	0.02		0.25	0.13	0.005	0.004
1988	0.03	0.03		0.30	0.14	0.006	0.003
1989	0.03	0.03		0.36	0.17	0.007	0.003
1990	0.03	0.02		0.35	0.14	0.007	0.003
1991	0.02	0.02		0.23	0.13	0.004	0.003
1992	0.02	0.02		0.24	0.08	0.005	0.002
average	**0.02**	**0.02**		**0.29**	**0.13**	**0.006**	**0.003**
Year	**SR**	**NF**		**SR**	**NF**	**SR**	**NF**
1992	0.02	0.01		0.24	0.03	0.005	0.002
1993	0.02	0.02		0.23	0.22	0.004	0.004
1994	0.01	0.01		0.11	0.09	0.002	0.002
1995	0.01	0.01		0.19	0.19	0.004	0.004
1996	0.02	0.01		0.32	0.20	0.006	0.004
1997	0.01	0.01		0.16	0.15	0.003	0.003
average	**0.02**	**0.01**		**0.21**	**0.15**	**0.004**	**0.003**

Ammonium concentration (mg/L) and deposition (kg/Ha) reported by NADP							
	Concentration weekly averages			Deposition annual totals		Deposition weekly averages	
Year	**SR**	**NF**		**SR**	**NF**	**SR**	**NF**
1987	0.09	0.12		0.78	0.65	0.015	0.018
1988	0.05	0.06		0.57	0.36	0.011	0.007
1989	0.15	0.14		1.93	0.73	0.037	0.014
1990	0.12	0.15		1.56	0.90	0.030	0.017
1991	0.09	0.13		1.14	0.74	0.022	0.014
1992	0.16	0.20		1.69	0.71	0.033	0.014
average	**0.11**	**0.13**		**1.28**	**0.68**	**0.025**	**0.013**
Year	**SR**	**NF**		**SR**	**NF**	**SR**	**NF**
1992	0.16	0.04		1.69	0.13	0.033	0.009
1993	0.10	0.09		1.48	1.18	0.028	0.023
1994	0.14	0.10		1.14	0.77	0.022	0.015
1995	0.11	0.10		1.59	1.42	0.031	0.027
1996	0.15	0.08		2.04	1.10	0.039	0.021

Appendix D. NADP annual statistics for SO_4^{2-}, NO_3^-, Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, and NH_4^+

Deposition (kg/Ha): comparison of annual totals as reported by NADP							
	NF versus SR 1987 – 1992*				BL versus SR 1993 - 1997		
Species	**Slope**	**Offset**	**R^2**		**Slope**	**Offset**	**R^2**
Ca	0.30 ± 0.12	0.43 ± 0.26	0.60		0.48 ± 0.24	0.62 ± 0.40	0.56
Mg	0.24 ± 0.09	0.07 ± 0.03	0.64		0.49 ± 0.23	0.07 ± 0.05	0.60
K	-0.09 ± 0.69	0.12 ± 0.13	0.00		0.33 ± 0.20	0.10 ± 0.04	0.49
Na	0.12 ± 0.08	0.28 ± 0.13	0.34		0.66 ± 0.19	0.12 ± 0.18	0.79
NH4	0.27 ± 0.11	0.35 ± 0.15	0.60		0.34 ± 0.37	0.58 ± 0.58	0.22
NO3	0.26 ± 0.12	2.32 ± 1.04	0.53		0.62 ± 0.25	2.01 ± 2.20	0.67
Cl	0.21 ± 0.09	0.23 ± 0.14	0.55		0.57 ± 0.17	0.21 ± 0.19	0.78
SO4	0.15 ± 0.08	2.70 ± 0.57	0.47		0.83 ± 0.18	-0.19 ± 1.17	0.88

* The 1992 NF deposition value is the sum of the measurements made at NF (37 weeks) and BL (14 weeks).

Appendix E. Recommendation: Use of IMPROVE Data to Assess Air Pollution and Deposition

As demonstrated in this report, the initial evaluation of Snowy Range, WY, module A (IMPROVE) concentrations compare reasonably well with concentrations from EPA's National Dry Deposition Network (NDDN) site. Each program however, has a different protocol, each designed for a different purpose. Although comparisons may be reasonable, several factors should be addressed when using IMPROVE data to either estimate concentrations directly or calculate deposition amounts:

1. **Physical site characteristics:** Location and emission frequency of upwind sources may preclude an accurate estimate of site concentration and deposition. For example, because IMPROVE protocol allows for 24-hr samples only on Wednesdays and Saturdays, an operation that emits pollution only on Fridays would be missed.

2. **Sample intake, orientation, and filter chemistry:** The physical dimensions and placement of the air sample collection head and flow rate will determine aerosol (particulate) size cutoff. The type of filter(s) used, pore size, and pre-treatment for specific gaseous species collection also vary and must be considered. IMPROVE modules A, B, & C are designed to collect aerosols equal to and less than 2.5 micrometers in diameter only. Assuming the presence of aerosols larger than 2.5µm, concentrations and deposition derived from IMPROVE would be biased on the low side. The exact amount of bias would be site, season, and species specific.

3. **Support data for deposition estimates:** While wet deposition can be measured directly, dry deposition is estimated from programs like NDDN (and potentially IMPROVE) by multiplying measured concentrations by modeled deposition velocities or by choosing a "best guess" single deposition velocity value for a specific site. For modeled deposition velocity, detailed site meteorology, canopy characteristics, and leaf-area-index (LAI) are required. To choose a single value, canopy characteristics and LAI are needed. To select or compute a deposition velocity, either review the literature to justify a selection or solicit the recommendation of an expert. As an example Zeller et al. (1997a) chose the value 0.4 cm s^{-1} to apply to aerosols in the Rila mountain area of Bulgaria (pine, spruce, and fir forest) based on matching site characteristics with available literature at the time: Bytnerowicz et al. (1987) and the general information on deposition velocities given by Sehmel (1984). Calculations made for the Brdy Mountains, Czech Republic (Zeller et al. 1996 & 1997b), used an approach similar to Appendix A.

   Based on this report, given a new average annual Brooklyn IMPROVE SO_4 concentration of 0.7 µg m^{-3} and given an average aerosol deposition velocity of 0.2 cm s^{-1} selected for the estimate:

   (1) Convert 0.7 to an equivalent NDDN value by either using the Figure 9c regression equation ($y = 0.63\,x + 0.11$) where y (IMPROVE) = 0.7 and solve for x (NDDN) = 0.94 µg m^{-3}, or

   (2) Convert 0.7 to an equivalent NDDN value by using the 22% overall average difference cited in the dry deposition results discussion: 0.7 + 0.22 (0.7) = 0.85 µg m^{-3}. Manager's choice.

   (3) Use equation 3, $F_c = (\bar{c}_z - \bar{c}_o)\,V_d$, to calculate deposition (vertical flux): $F_c = (0.94 - 0.0)\ 0.2$ (µg m^{-3} cm s^{-1}) = 0.002 µg m^{-2} s^{-1} = 0.6 kg ha^{-1} yr^{-1}.

4. **Site location and averaging periods:** Based on this study of Snowy Range, WY, NADP wet deposition data analyses with adjacent sites, site comparisons improve with longer averaging periods (yearly concentration averages, and total annual deposition compare better than seasonal and weekly) and closer sites, as one would expect. If sites are in the same general geographical area, one might use the same approach climatologists use for applying rain gage data to areas within 25 kilometers (i.e., use annual values as spatially representative and seasonal or shorter period values only to understand potential variability).

In general, the use of IMPROVE data for estimating sulfate concentration and deposition is defendable. The same anion and cation aerosols are measured by both IMPROVE and NDDN but diameter size for IMPROVE is limited to 2.5µm, hence results will be biased toward lower than actual. Results will also be dependent on both the site and the specific species of interest. Module A does not measure nitrate so it wasn't evaluated; however, there are additional gas to aerosol phase changes for nitrate that affect filter collection systems that would have to be taken into account.

References

Bytnerowicz, A., Miller, P, & Olyzyk, D., 1987. Dry deposition of nitrate, ammonium and sulfate to a *Ceanothus crassifolius* canopy and surrogate surfaces, Atm. Envir. 21:8 1749-1757.

ESE, Inc. No. 86612-0212-3170, 1990a. National dry deposition network: Laboratory operations manual, EPA Contract No. 68-02-4451, EPA/AREAL, RTP, NC 27791, August 1990.

ESE, Inc. No. 86612-0108-2110, 1990b. National dry deposition network: Field operations manual, EPA Contract No. 68-02-4451, EPA/AREAL, RTP, NC 27791, July 1990.

Sisler, J.F., 1996. Spatial and seasonal patterns and long term variability of the composition of the haze in the U.S.: An analysis of data from the IMPROVE network, CIRA, CSU, Ft. Collins, CO. July, ISSN: 0737-5352-32.

Schmel, G. 1984. Chapter 12: Deposition and resuspension, In: D. Randerson ed., *Atmospheric_Science and Power Production*, DOE/TIC-27601 (DE84005177) pp 533-583.

Zeller, K., Cerny, M., Smith, L. et al. 1996. Weekly dry deposition of and at Brdy Mountain, Czech Republic. Proceedings of NATO-Advanced Research Workshop: Atmospheric Deposition and Forest Management. 23-26 April, 1996. Spindleruv Mlyn, Krkonose Mtn., Czech Republic.

Zeller, K., Cerny, M., Bytnerowicz, A., Smith, L., Sestak, M., Michalec, M., Pernegr, V. & Kucera, J., 1997b. Air pollution status of a representative site in the Czech Republic Brdy mountains. *Environmental Pollution,* 98 (3), 291-297.

Zeller, K., Donev, E., Bojinov, H., Nikolov, N., 1997a. Air pollution status of the Bulgarian Govedartsi Ecosystem. *Environmental Pollution,* 98 (3), 281-289.

Zeller. K. 1993. BLM IWAES filter pack monitoring: what does it really do? USDA FS RMFRES IAG K910-A1-0008 T01. project report. March.

RMRS
ROCKY MOUNTAIN RESEARCH STATION

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of forests and rangelands. Research is designed to meet the needs of National Forest managers, federal and state agencies, public and private organizations, academic institutions, industry, and individuals.

Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications can be found worldwide.

Research Locations

Flagstaff, Arizona
Fort Collins, Colorado*
Boise, Idaho
Moscow, Idaho
Bozeman, Montana
Missoula, Montana
Lincoln, Nebraska
Reno, Nevada
Albuquerque, New Mexico
Rapid City, South Dakota
Logan, Utah
Ogden, Utah
Provo, Utah
Laramie, Wyoming

* Station Headquarters, 2150 Centre Avenue, Building A, Fort Collins, CO 80526