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EVALUATION OF METHODS FOR MEASUREMENT OF SNOWFALL AND COLLECTION OF SNOW FOR CHEMICAL ANALYSIS

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EVALUATION OF METHODS FOR MEASUREMENT OF SNOWFALL AND COLLECTION OF SNOW FOR CHEMICAL ANALYSIS

ABSTRACT

This study developed and assessed methods for monitoring snowfall and its chemical constituents. Specific objectives were to:
1) Compare measurements of snow (or snow and rain) volume and chemical concentration from several monitoring devices or procedures.
2) Develop and document guidelines for sampling interval, collection, storage, transport, and processing techniques, and equipment selection for point monitoring of snow (or snow and rain) volume and chemical concentration.
3) Evaluate one sampling technique, snowpack sampling, at spatially distributed sites receiving a wide range of snowfall amounts and potentially widely varying snow chemistries.

Snow water equivalent and chemical concentrations were compared between large (32-cm by 122-cm) polyvinyl chloride (PVC) tubes, Belfort precipitation gauges, snowboards, and snowpack samples at an exposed site, near Mammoth Lakes, and in a forest clearing, near Soda Springs, during two recent winters. An Aerochem Metrics collector was also included at the forest site. At the exposed site, the tubes and the Belfort gauges caught 23% less snow water equivalent than the snowboards. In the clearing, the tubes and the Belfort gauges caught 24% more than the snowboards one winter and 20% more the second winter. Except for NO_3^- at the forest site, H^+, NO_3^-, and SO_4^{2-} concentrations of samples from the tubes and the snowboards differed significantly. Although laboratory tests showed no adsorption or desorption of synthetic standard solutions of major ions with the PVC tubes, the differences in concentrations in field samples between the snowboards and the PVC tubes and brittleness of the PVC tubes in cold weather prompt the recommendation that PVC tubes not be used in an operational snow monitoring program. A linear polyethylene (LPE) tube of the same dimensions collected as much snow water equivalent as did the Belfort gauges in the second year of the study. The LPE did not exhibit brittleness during operational field conditions. In areas where forest cover exists and both rain and snow occur, shielded LPE tubes should be used for weekly monitoring of water equivalent and chemistry if they do not contaminate the precipitation samples. At higher elevation sites experiencing moderate-to-high winds and no winter rain, sampling should be weekly by snowboard. The Aerochem Metrics sampler is not suitable for snow collection in areas of moderate-to-high snowfall because of undermeasurement problems, mechanical malfunctions in cold, wet environments, and small bucket capacity. A modified snowboard, with a reservoir for melt or rain water should be designed and evaluated at sites receiving rain and snow.

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DISCLAIMER

CONCLUSIONS AND RECOMMENDATIONS

Although chemical concentrations in snow are low compared to those in rain in the Sierra Nevada, the seasonal loading from snow compared to that from rain mandates the monitoring of snow in the Sierra Nevada.

The snow water equivalent from replicated shielded-Belfort precipitation gauges and experimental polyvinyl chloride (PVC) and linear polyethylene (LPE) collectors was the same at the Central Sierra Snow Laboratory and at Mammoth Mountain, and the weekly snowboard water equivalents and the sum of the daily snowboard water equivalents were the same at the Central Sierra Snow Laboratory. Significant differences were found among the other combinations of the Belfort, tube, and board snow water equivalents.

The PVC tube did not adsorb or desorb ions during tests with synthetic solutions. However, the comparison of weekly field samples showed that the PVC tubes had significantly higher concentrations of most ions than did the snowboards. The reason for this difference is not known, but is worth more research because of its implications in network design. Brittleness of the PVC tubes in cold weather elevated the likelihood of tube breakage.

The Aerochem Metrics sampler used in the California Acid Deposition Monitoring Program and the NADP networks is not suitable for snow collection in areas of moderate-to-high snowfall because of its undermeasurement problems, mechanical malfunction in cold, wet and/or windy environments, and small bucket capacity.

Snowpack sampling, as a "snap-shot" estimate once each year of chemical loading, is a relatively inexpensive alternative to weekly monitoring by tube or snowboard. Difficulties in projecting the specific time of maximum snow accumulation add considerable variability to the precision of loading estimates from this technique.

Although the highest snowpack solute concentrations were recorded in samples from the San Bernardino Mountains, the relatively low snow water equivalent there resulted in maximum solute loading at sites in the Sierra Nevada.

We make the following recommendations on snow sampling for chemistry monitoring:

1. Because of the importance of snow's contribution to landscape-scale deposition, a high-elevation snow monitoring network is needed and would provide the California Air Resources Board with several important types of information:
   a) Current chemical loading stresses to high-elevation watersheds.
   b) Baseline data relevant to the setting of deposition standards.
   c) Regional data to run regional lake acidification models.

2. At moderate elevations where forest cover exists and rain occurs, the shielded LPE tube for weekly monitoring of SWE and chemical concentration should be used if it can be shown to provide insignificant chemical differences to samples from weekly snowboards.

3. At higher elevation sites experiencing moderate-to-high winds and no winter rain, sampling should be done at weekly intervals using a snowboard. Snowboards have the added advantage over tubes of not needing a tower, a windscreen, and weekly rinsing with deionized water. A disadvantage of the boards is the labor-intensive, detailed procedures that must be followed to obtain accurate depth and density measurements and uncontaminated samples for chemical analysis. This problem might be partially overcome by the use of disposable, sealed sampling kits.

4. A strong quality-assurance and quality-control program must be operational during the chemical analysis period. It should include:
   a) Calibration and precision valuations of all instruments should be performed and recorded.
   b) Interlaboratory evaluations should be performed with independently prepared reference materials to assess the accuracy of laboratory instruments and personnel.
   c) Field audits and blanks are a necessary component of the operational protocol.
   d) All collectors and plasticware must be either acid-cleaned with 10% hydrochloric acid followed by multiple rinses with deionized water or soaked in deionized water. Deionized water should have specific conductance less than 1 uS cm^{-1}.

5. The contribution of organic anions to the anion component of the overall charge balance must be included. Specifically, it is necessary to measure acetate and formate in precipitation samples.

6. Experimental design should include adequate field replicates in order to estimate field precision.

7. Cleanliness and operator conscientiousness are paramount in field operations.

8. Snow should be melted at $4^{\circ}C$, filtered through a 0.4-micron, pre-rinsed, polycarbonate or nylon membrane and maintained at $4^{\circ}C$ for not more than three months before chemical analysis. Organic acids should be preserved with chloroform and analyzed within three months. Ammonium should be assayed immediately.

9. Strict calibration procedures must be adhered to for accurate measurement of pH and specific conductance on very dilute water samples.

We make the following recommendations for further research:

1. The linear-polyethylene experimental collectors should be analyzed as was done in this study for the PVC experimental collectors. The LPE tubes exhibit superior rigidity in cold weather and appear to collect snowfall in volumes equal to traditional weighing precipitation gauges (e.g., Belfort).

2. If the LPE tube is not acceptable chemically, a modified snowboard with a reservoir for melt or rain water should be designed and evaluated.

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1. INTRODUCTION

Fourteen percent of California's land area routinely receives at least 25 cm of snowfall each year (Figure 1.1). Of this 14 percent, the snow zones of the Sierra Nevada and Cascade ranges alone produce one-half of the water used in the State (Anderson et al. 1976). Runoff from the melting of these seasonal snowpacks is of very high quality, with low dissolved and suspended sediment loads. This gives it a value greater than that due to its quantity alone.

The accurate measurement of snow depth and volume is of great importance in California for many reasons. The bulk of the California landscape is arid, receiving 30 cm or less precipitation annually, and in the lower elevations the dominant form of precipitation is rain. Approximately 90 percent of the precipitation that falls above 2130 m elevation falls as snow. About 238 million cubic decameters of water falls annually in California, and about half of this amount results in streamflow (California 1983). Because snowfall and snowmelt play such important roles in the hydrologic cycle in the mountains of California, accurate measurement of snowfall depths and volumes is crucial to any estimates of point chemical loading in the State as a whole as well as in the mountains.

Snowfall in many mountainous areas of California has low concentrations of chemical constituents compared to rain or to precipitation elsewhere in California and the USA (Feth et al. 1964, Melack et al. 1982, Berg 1986, McColl and Bush 1978, McColl 1980), but even in the Sierra Nevada, acid precipitation has been measured. In California's snow zone, the available wet deposition record is of short duration and includes only two sites (Soda Springs and Mammoth Mountain) receiving the massive snowfalls typical of thousands of hectares of high elevation, weakly-buffered alpine and subalpine lands in the State.

Precipitation is common at mountainous sites, occurring on over 43% of winter days at the Central Sierra Snow Laboratory, near Lake Tahoe (US Forest Service 1989), and wet deposition of solutes is probably more significant here than elsewhere in the State. Stations that monitor atmospheric deposition in these high precipitation areas must obtain both elemental concentrations and precipitation volume to estimate total chemical loading. However, because a meter or more of water falls as snow compared to a few centimeters of rain per year, annual chemical loading is dominated by the high volume of low ionic strength snowfall (Table 1.1). Accurate measurement of both volume and chemical concentration of the snow is crucial.

Effective monitoring of snow chemistry and volume in mountainous areas is associated with a special set of problems. The techniques for chemical analysis of snowfall are essentially the same as those for rain, but the collection, storage, and processing of snow samples requires more care and planning.

The accurate measurement of snowfall amount is difficult. Snowfall rates and volumes are the least accurate component of hydrological modeling (Peck 1972), and these difficulties are compounded in mountainous environments where winds are high and terrain is rugged. Snow is irregularly deposited over small areas during windy storms because of snow's low density (densities from 50 to 450 kg m^{-3} have been measured in the Sierra Nevada). A typical snowstorm in the central Sierra can deposit 30-75 cm depth of snow (Smith and Berg 1982). It is difficult to maintain a gauge at a fixed height above the snow surface and to design a collector that is sensitive to but not overwhelmed by single storms

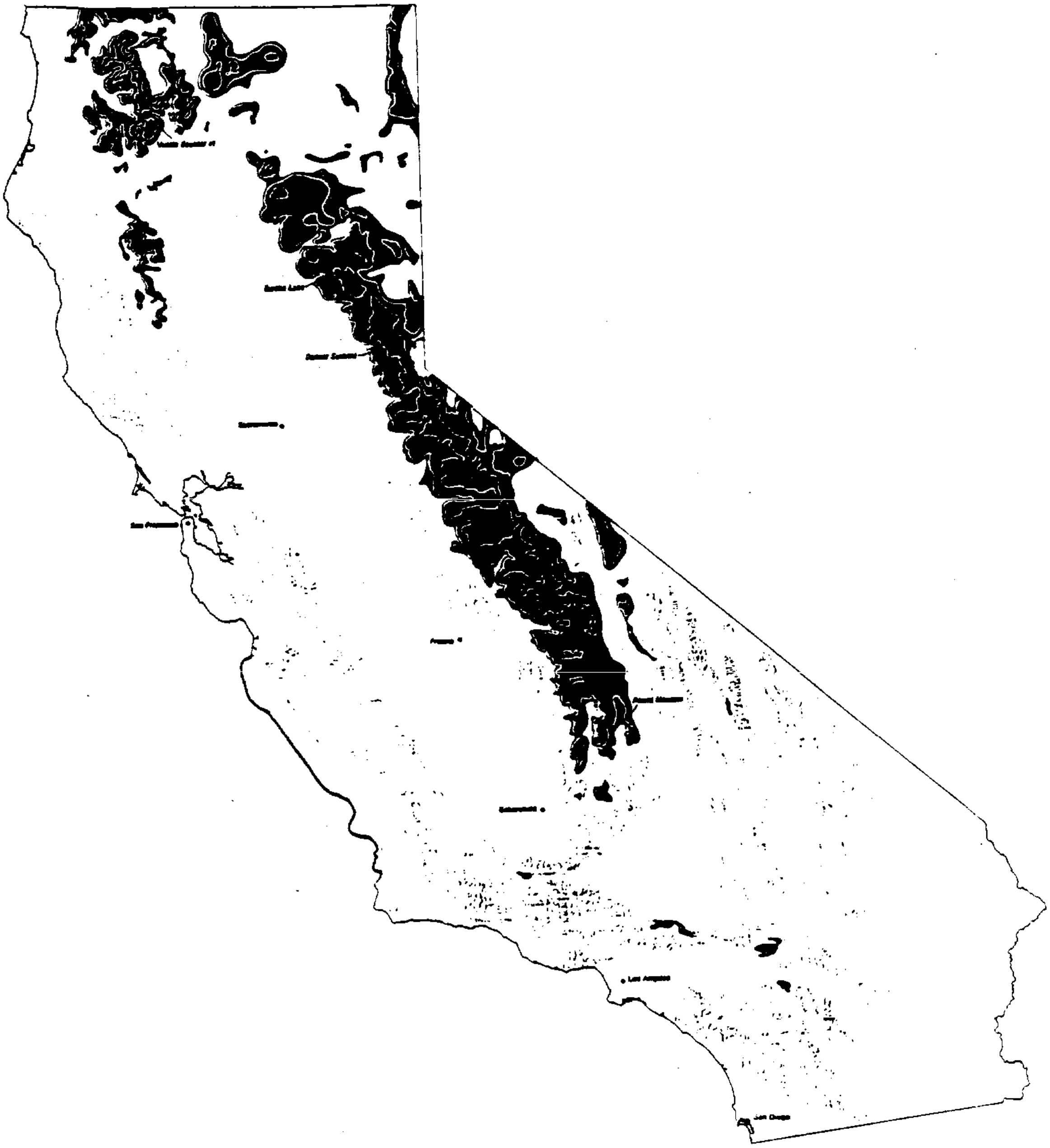

Figure 1.1. Regions in California receiving at least 25 cm snowfall each year (blackened areas) (from California 1979).

that can deposit more than 75 cm of snow. The relatively high surface area-to-mass ratio of falling snow allows it to be readily entrained by wind currents. At even moderate speeds, snow can bypass a gauge orifice. Quantification of this "undercatch" has been the subject of numerous studies (Larson and Peck 1974, Goodison et al. 1981), but a completely efficient and effective gauge is yet to be perfected.

Table 1.1. Loading of hydrogen by rain and snow at the Central Sierra Snow Laboratory, Soda Springs, California, July 1984 - June 1988 (US Forest Service 1989).

Dates	Precipitation Type	Depth (cm H_2O)	pH (Volume-weighted)	Concentration (ueq L^{-1})	Loading (meq m^{-2})/ year
7/84-	Rain	11.5	4.7	18.4	2.1
6/85	Snow	106.0	5.2	6.8	7.3
7/85-	Rain	27.9[1]	5.1	8.2	2.3
6/86	Snow	184.8	5.3	4.7	8.3
7/86-	Rain	7.5	4.6	24.0	1.8
6/87	Snow	97.9	5.1	8.0	7.8
7/87-	Rain	14.5	4.9	13.2	1.9
6/88	Snow	92.9	5.2	6.3	5.9

[1] 56% of all rainfall occurred during January storms each having pH = 5.3. Values of pHs for summer rains were typically below 4.8.

Precipitation type adds a complicating factor to precipitation monitoring in mountainous areas. Although the higher elevations of California's mountains are dominated by snowfall, warm storms with high elevation freezing levels deliver rainfall once or twice annually during winter up to the crest of the central and northern Sierra Nevada (Kattelmann 1987, California 1979, US Army 1956). Monitoring techniques based solely on anticipation of solid precipitation will be inadequate; an effective snow monitoring network may require a range of techniques to obtain accurate information at sites experiencing varying amounts of snowfall, rainfall, and wind.

This study addresses the California Air Resources Board's (CARB) desire to develop a snow monitoring network to augment the current 28-station California Acid Deposition Monitoring Program to:

1) Draw isopleths of acidic wet deposition in California.
2) Determine differences in acid loading among years and regions.
3) Quantify stress to sensitive ecosystems.
4) Generate input data for regional lake acidification models being developed by CARB.

1.1. Study Objectives

This study develops and assesses methods for monitoring snowfall and its chemical constituents. A fundamental problem is that of monitoring precipitation at a point. Research has shown that the technique, sampling interval, and procedure used to monitor precipitation affects the estimate of snow volume and the subsequent calculation of chemical loading (Dawson 1986). Specific objectives of this study are to:

1) Compare measurements of snow (or snow and rain) volume and chemical concentration from several monitoring devices or procedures (e.g., experimental collector, Aerochem Metrics "wet-dry" bucket, snowpack samples) monitored over varying time intervals.
2) Develop and document guidelines for sampling interval, collection, storage, transport, and processing techniques, and equipment selection for point monitoring of snow (or snow and rain) volume and chemical concentration.
3) Evaluate one sampling technique, snowpack sampling, at spatially distributed sites receiving a wide range of snowfall amounts and potentially widely varying snow chemistries.

This study reports the results of observations from two winter's field work at two sites in the Sierra Nevada, as well as extensive laboratory analysis and evaluation of snow chemistry sampling, storage, and transport procedures.

This study does not recommend techniques for monitoring snowmelt chemistry. Several factors complicate the determination of the chemistry of snowmelt runoff in mountainous terrain. Wind affects the distribution of the snow both during and after a storm by creating scour and deposition regions. Snow depths and water contents are therefore highly variable over short distances. The lag time between deposition, melt, and eventual runoff allows the snowpack to undergo significant structural metamorphism that may affect the chemistry of the runoff. The snowpack is subject to losses from evaporation and melt through the winter season. These losses affect the water budget and may increase or decrease the concentration of chemical constituents. These processes vary spatially with wind speed and direction, temperature and humidity, and local terrain and vegetation structure. Attempts have been made to characterize the distribution of snow over an area (e.g., Haston et al 1985, Elder 1988), but the problem is so complex as to be beyond the scope of this study.

2. MEASUREMENT SITES

The field component of this study was designed to test monitoring procedures under two snow regimes representative of conditions in California: forested areas that typically receive rain along with snowfall, and high-elevation alpine and subalpine sites receiving little or no winter rain.

Measurement sites were selected based on the following criteria:

- large volume of annual snowfall
- open, exposed terrain representative of southern Sierra Nevada subalpine and alpine areas
- sheltered, lower elevation sites representative of much of the Sierra Nevada's western slope that receive some winter rainfall
- ease of winter access
- history of snow measurement

Locations with nominal winter snowfall or those dominated by rainfall were eliminated. Ease of access was considered essential to the CARB's goal of establishing a snow monitoring network in the California snow zone. Winter conditions, especially during and immediately after storms, can make backcountry network maintenance both expensive and dangerous. Specially-trained personnel are required to reach remote sites, and costs associated with equipping staff and maintaining sites are high. If short interval or event sampling is deemed necessary, the cost associated with frequent trips into a remote site would be higher yet. Very remote sites would require a resident technician for event sampling. For these reasons, all backcountry or remote sites that were not readily accessible during winter were eliminated due to high cost and logistic difficulties. Proximity to power is an additional important criterion because snow samples must be stored in a freezer while awaiting transport to a laboratory for chemical analysis.

Sites with a history of snow measurement were sought. Measurement over several years or decades ensures a better understanding of site-specific problems associated with sampling. There is also the potential for comparison of data collected during the study to the existing record of past events. Existing records also allow the characterization of a site in terms of average snowfall, snowpack depth, snow density, wind, temperature, and other meteorological parameters, and hence better assure selection of sites representing different snow deposition environments.

Based on the above criteria, the USDA Forest Service's Central Sierra Snow Laboratory (CSSL) (39°19'30" N, 120°22' W) and the University of California at Santa Barbara's Mammoth Mountain research installation (37°28'16" N, 119°01'38" W) were selected (Figure 2.1). CSSL and Mammoth are different in terms of temperature, humidity, wind, precipitation, and terrain, and we believe that they represent different snow environments in California.

CSSL, 1 km east of Soda Springs, California, is a partially forested site on the west slope of the central Sierra Nevada at approximately 2100 m elevation. CSSL receives abundant snowfall that is relatively wet, and rain falls once or twice each winter. Mean annual precipitation over the 89-year recording period is 139 cm and mean annual temperature is 2°C (Smith 1982). The peak snowpack depth is about 3 m of snow that is isothermal near 0°C (McGurk 1983). Measurements were made in a forest clearing approximately 40 m by 50 m

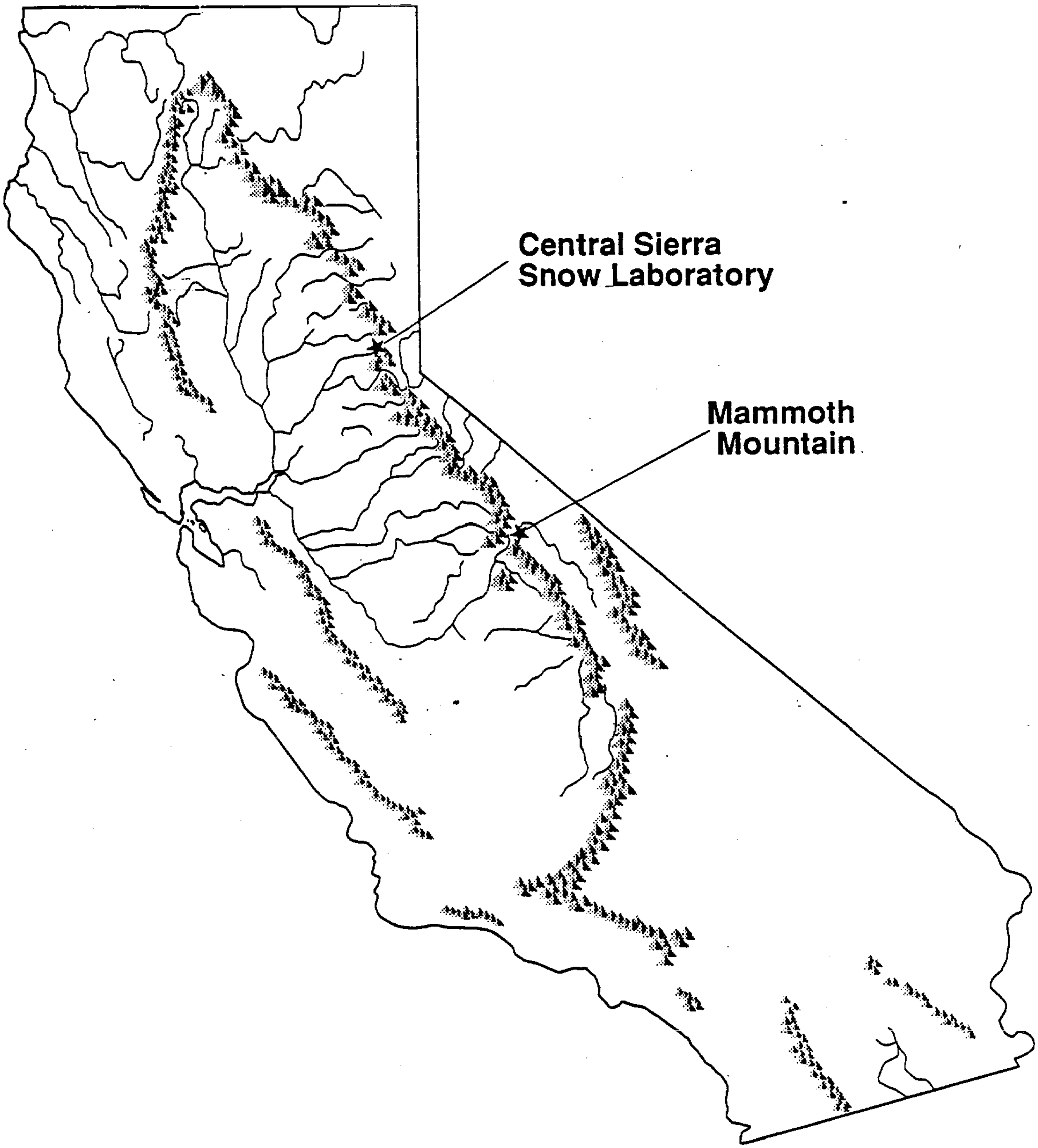

Figure 2.1. Location map of snow study sites at the Central Sierra Snow Laboratory and Mammoth Mountain.

sheltered by 20 m trees. At 11 m above the ground surface, average wind speeds in the clearing are low (ca. 1 m s^{-1}) and atmospheric wet deposition is relatively low (Berg 1986, California Air Resources Board, 1988). CSSL is dominated by a "summer dry" Mediterranean climate with over 90% of the annual precipitation falling during the winter, primarily as snow. Much of the central and northern mountains in the State are similar in these respects to CSSL. A detailed description of this site is presented by Smith and Berg (1982). Field chemistry determinations of sample temperature, pH, and electrical conductivity were made on-site at CSSL.

The Mammoth Mountain site is within the Mammoth Mountain Ski Area on the east slope of the southcentral Sierra at 2940 m near Mammoth Lakes, California. Mean annual precipitation is 142 cm (California Coopertive Snow Survey 1987), and a 3 to 4 m maximum snow depth is common. A snow study plot has been maintained at Mammoth Mountain since 1978. The site is on an open, sloping ridge that is characterized by high winds, dry snow, no mid-winter rain, and the periodic influence of meteorological inputs from the Great Basin. The site is described in more detail by Davis and Marks (1980) and Davis et al. (1984). The Sierra Nevada Aquatic Research Laboratory (SNARL), a facility of the University of California, is 30 km from the Mammoth Mountain study site. Field chemistry determinations of sample temperature, pH and electrical conductivity were made at SNARL.

3. METHODS

The following background section on snow volume measurement puts the primary problem attacked in this study into perspective. Based on this information and field experience at the two sites, the field and laboratory procedures that were used in this study are described.

3.1. Estimating "True" Snow Deposition Volume

The history of snow gauging is a long one that dates at least from a 13th century description of a "snow bin" used in China for estimating snowfall amounts (Peck 1972). Yet the problem of accurate estimation of snowfall amount is far from solved, due in large measure to the lack of an absolute reference or "ground truth" procedure for determination of true snow deposition volume. Even excavation and careful weighing of a large volume of snow (several m^3) has some measurement uncertainty (California Department of Water Resources 1976) and the effort involved makes this approach impractical. The best method of estimating "true" snow deposition volume is to measure the water equivalent of snow (SWE) deposited during a specified interval on the ground or on a snowboard in an area adjacent to the gauge being evaluated. In this approach, SWE is the depth of water that would result if the snow were melted:

$$\mathrm{SWE} = \sum_{i=1}^{n} \rho_s z_l / \rho_w$$

and mean density is defined as

$$\overline{\rho_s} = \rho_w \mathrm{SWE} / z_S$$

where:

n = number of snow layers

ρ_s = density of snow layer (kg m^{-3})

ρ_w = density of water (kg m^{-3})

z_l = snow layer thickness (m)

z_S = total snowpack thickness (m)

With the use of both established and recently developed techniques, SWE measurements at a given location are not difficult to obtain. Methods using precision equipment to measure snow density from excavation and sampling in snowpits are described by Perla and Martinelli (1978). Depth measurement is straightforward at a point. Virtually all techniques require determination of the mass of an extracted sample of known volume from the snowcover, and a variety of methods are available for density determination.

3.2. Measurement of Snowfall Volume

The standard rainfall measurement device is simply an orifice of known cross-sectional area and a vessel that holds the moisture that falls through the orifice. The ideal way to install the gauge is to excavate a pit, mount the orifice at ground level where the wind speed is zero, and allow access into the pit so that the captured rainfall can be volumetrically measured at any desired interval (Alter 1937). When the captured volume is divided by the cross-sectional area of the orifice, an areal depth estimate is the result. With replication of the gauges on level terrain and with no vegetation but grass, the estimate would be expected to be a close approximation of the true rainfall depth. The actual truth would not be known until the entire area of interest was included as part of the gauge.

Because mountainous terrain is rarely flat, and precipitation in the Sierra Nevada is typically wind-driven snow, the pit system is untenable. Above-ground gauges are also often poor estimators of true precipitation depth in snowy environments (Larson and Peck 1974). Accurate estimates of snowfall volume are more difficult to obtain than rainfall amounts (Harris and Carder 1974). Numerous efforts have been made to improve precipitation gauge estimates of actual storm depth and volume. An initial step was to increase the size of the orifice, and gauges designed for alpine use have orifices that are typically 30 cm in diameter rather than 20 cm. Because snow storms are often longer and deposit greater depths than rainstorms at low elevations, gauges in snow country typically have a 750-mm capacity rather than the 300-mm that is standard.

The more important problem associated with the gauging of solid precipitation is caused by wind. Since snow is often one-tenth the density of rain, wind has a greater effect on the trajectory of the falling snow. Compounding the problem is the fact that mountains are typically much windier than low-elevation locations. As the speed of the wind increases, its ability to support snow against the force of gravity increases. Since the orifice of a precipitation gauge depends on gravity to deliver the particles vertically down into it, wind is an obvious threat to accuracy. Further, since air is a fluid, the mere presence of the gauge modifies the wind field, generally increasing air speeds around the body of the gauge to above the mean wind speed of the storm. The typical result at a windy site is undermeasurement of precipitation depth and volume, but quantifying the undermeasurement is quite difficult. Although research studies generally show a near-linear decrease in catch with wind speed increases through 9-10 m s^{-1} (Figure 3.1), both the absolute and the percent undermeasurement typically vary with wind direction (variation in fetch), air temperature, and crystal size and density, so a priori fixed correction factors are likely to be in error.

3.2.1. Windscreens--Meteorologists and hydrologists have tested numerous devices and systems designed to overcome or compensate for the undermeasurement that typically results while measuring solid precipitation at high elevations. Windscreens are common devices that are designed to increase the turbulence and decrease the wind speed around the gauge, and thereby allow the snow particles to fall into the orifice. At moderately low wind speeds of 4 m s^{-1}, shielded gauges collect 70-85% of the "true" amount of snow but unshielded gauges catch only 45-65% (Larson and Peck 1974). At windspeeds between 4.5 and 9 m s^{-1}, catch deficiencies of 20 to 40% of the estimated true catch are reported (Figure 3.1) (Larson and Peck 1974). At speeds in excess of 9 m s^{-1}, even windscreens are unable to compensate for the entrainment effect of the wind, and no combination of gauge and shield will entirely eliminate the adverse effect of wind on gauge catch. Larson and Peck (1974) and other authors have suggested that wind speeds be measured at gauging sites and gauge catches adjusted accordingly.

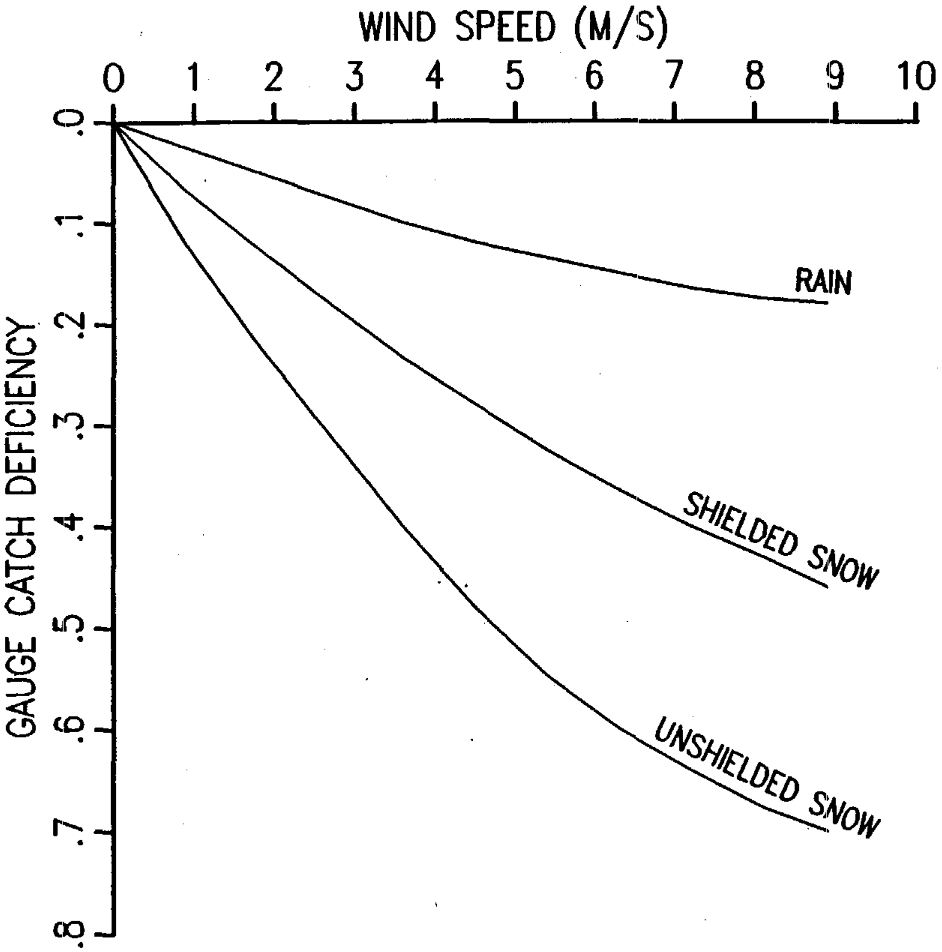

Figure 3.1. Gauge catch ratios versus wind speed for rain, shielded snow, and unshielded snow (after Larson and Peck 1974).

Two types of windscreens in common use in North America are the "Alter" and "Nipher" shields. The Nipher shield is an inverted bell or trumpet-shaped solid shield that is rigidly attached to a hollow cylinder (Nipher 1878). Wind tunnel tests confirm that this design minimizes disturbances in the airflow over the gauge orifice (Potter 1965). As of 1984, a modified version of the Nipher shield was in use at 350 gauging sites in Canada (Goodison and Louie 1986). Goodison (1978) listed favorable features of this shield as having a small surface area exposed to the wind, and a tendency for hard snow particles to bounce off the rim and into the collector. In contrast, a larger version of this type of shield has been criticized for funneling too much hail into the collector (Jarrett and Crow 1988). In Canadian practice, the relatively small (56-cm long, 12.7-cm diameter), non-recording Nipher canister must be monitored manually, usually on a daily basis. During light winds, snow can accumulate on the solid shield, and this problem is aggravated by the wet snow typical on the western slope of the Sierra Nevada. Under wet snow conditions, the collector catches about 15% less than under colder conditions (Goodison 1978). Other disadvantages of the Nipher gauge derive from its non-recording nature. Frequent measurements are labor intensive, and errors accumulate due to water retention on the interior surface of the gauge. Goodison (1978) estimated this undermeasurement to be 0.15 ± 0.02 mm per measurement. Measurements from this gauge may also require correction for trace amounts of snowfall which are not accumulated between observations.

The most common windscreen in the United States is the Alter shield, described as:

> ... shields...made of 20-gauge galvanized sheet iron, cut into wedge-shaped leaves and suspended on an iron frame... . These leaves are freely hinged on the heavy wire ring at the top and held apart by iron washers. They are connected at the bottom with a brass chain somewhat shorter than the supporting ring. The leaves close up when swung inward at an angle of about 45°. The metal leaves are from 7- to 11-inches in length, on the different sized shields (Alter 1937:264).

Modifications of this original design delete the lower chain, allowing the leaves to swing freely thereby reducing the chance of snow accumulation on the leaves. The Alter shield is typically supported independently from recording gauges to avoid vibration problems, but can be affixed directly to storage-type gauges. Compared to the Nipher shield, Alter-shielded gauges are generally less susceptible to mounding of wet snow during low wind-speed conditions.

3.2.2. Dual Gauge Approach--An unshielded gauge catches less solid precipitation than a shielded gauge, and since the catch ratio varies with wind speed, some hydrologists have formulated correction systems based on the catch ratio and some empirical constants. Hamon (1972) compared the catches from shielded and unshielded gauges with the storm precipitation as measured by a snow pillow and determined the following relationship:

$$\ln(U/A) = B \ln(U/S)$$

where U is unshielded catch, S is shielded catch, and A is the actual depth as measured by the pillow. The coefficient B was defined as a function of wind speed and air temperature, and found to be equal to 1.7 for the 20-cm Belfort weighing precipitation gauges used at Reynolds Creek Watershed in southeast Idaho. Hamon suggests that the B value is only applicable for sites similar to Reynolds Creek, but establishes the methodology that would allow determination of

B for any site that has paired gauges and some form of ground truth. In a test of the Hamon methodology, Rechard and Wei (1980) found wide variation in B values between storms at three sites in Wyoming, and the average value across all storms was not 1.7. Results from other studies (e.g., Sturges 1986, Larson 1986, Hanson et al. 1979, Hanson 1988) showed good agreement between catches calculated from the dual gauge system and "true" precipitation. A drawback of this system is the requirement of two gauges, adding appreciable equipment costs and increased maintenance and data reduction expenses over single-gauge systems.

3.2.3. Gauge Siting Criteria--Hydrologists and meteorologists have developed gauge siting criteria that are designed to overcome the effects of wind (Goodison et al. 1981). The ideal gauge site is in the middle-elevation range of a watershed and is on flat or gently sloping ground. The gauge should be mounted so that it is above the maximum snow depth, so in many areas a tower is necessary. Trees provide excellent protection against wind, so a clearing between one and two times the height of the trees is most desirable (Rechard and Wei 1980). Ridges, saddles, and long, treeless slopes should be avoided if possible. In many cases, however, the ideal site does not exist or is too remote for easy access.

3.2.4. Snowboards--A labor-intensive solution to the difficulty of gauging solid precipitation can be achieved through the use of snowboards. Snowboards are typically square plywood surfaces (0.3-0.4 m^2 in area) having a protruding rod to allow location of the board after snow has fallen (Figure 3.2). Snow volume is estimated by measuring depth and by weighing samples from the board with a corer of known cross-sectional area. Snowboards can be measured at any interval, but typical intervals range from twice a day to once a week. The longer the interval, the more likely the snowboard is to be buried and lost. Because the snowboard is at the snow surface and does not create any extra turbulence, snowboard measurements are often accepted as "ground true" values of snowfall (Goodison et al. 1981, McGurk 1986). In windy sites with dry, cold snow, however, both drifting and wind scour can distort the measurements obtained by snowboards (Harris and Carder 1974). At sites receiving rainfall, melt water or rain percolating through the new snow and running off the board will not be monitored. If snowboards are serviced once or more times per day, however, there is less time for melt or wind scour to occur. Snow samples that are to be analyzed for chemical constituents may be taken from snowboards if a thin layer of snow is left behind when the sample is removed and/or if the plywood surface is covered with a chemically inert material.

3.3. Precipitation Measurement in the Sierra Nevada and the Southern California Mountains

Relatively little is known about gauge performance in mountainous environments that experience high winds. Studies by Pagliuca (1934), Garstka (1944), Chadwick (1972), and Hamon (1972) show that problems associated with wind are increased in rugged, high-altitude regions where gauge placement can significantly alter gauge catch. In alpine regions, volume alone will overwhelm most snow collection systems. Reynolds (1972) stated that at high-altitude, high-volume, snowfall sites, gauge capacity must be at least 180 cm of water. The problems of keeping the gauge at a fixed height above the surface or from being buried during large events are not usually addressed. While the 1987 and 1988 snow seasons were relatively light in California, during the 1986 snow season 200-300 cm of water fell as snow in much of the Sierra Nevada, raising

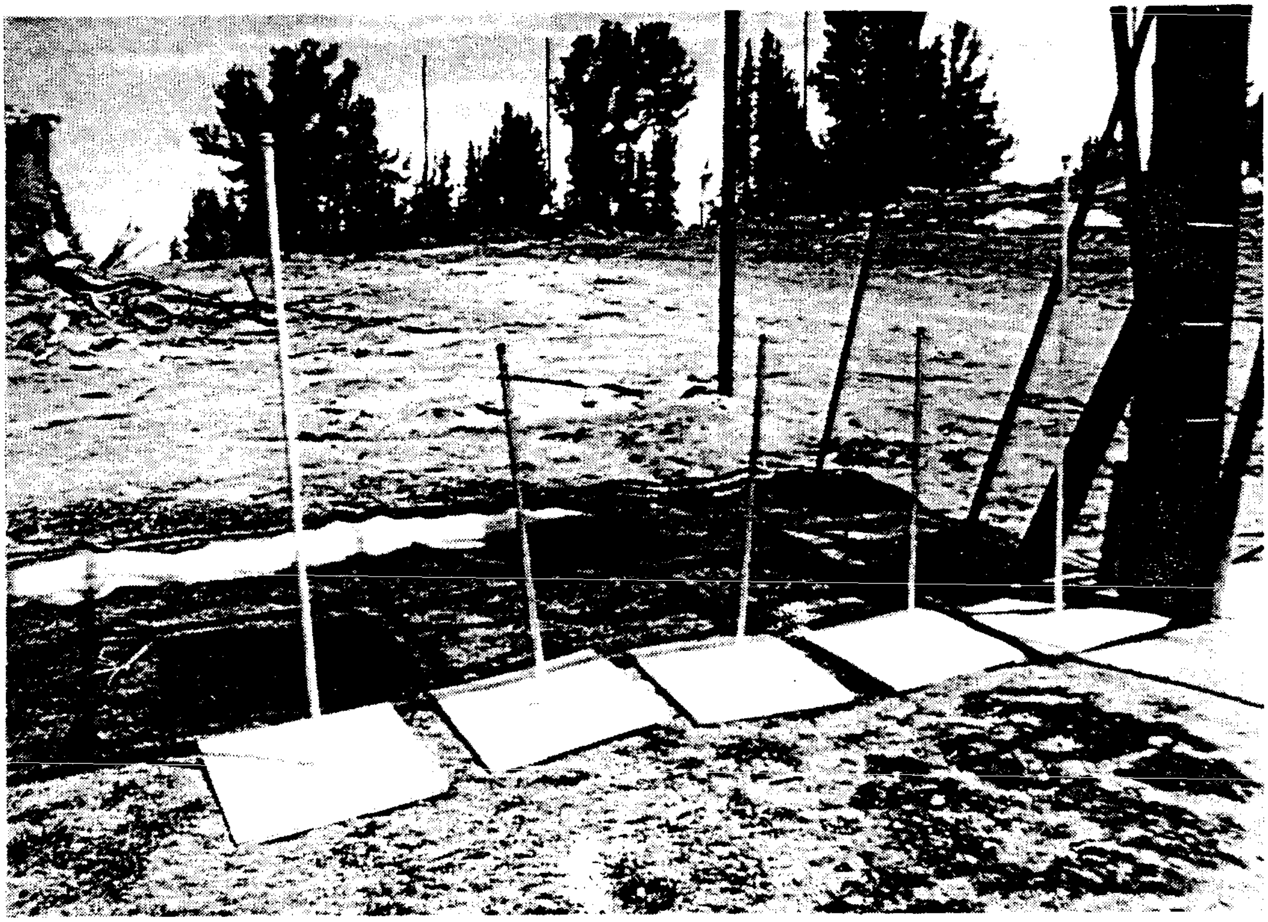

Figure 3.2. Snowboards at Mammoth Mountain site. The longer rods on the end-most boards improve the chance of locating the boards at weekly intervals. The middle boards are turned daily.

serious questions about the efficacy of traditional gauge maintenance and anti-freeze recharge operations, and overall utility of snow-collection gauges.

Snow measurement in the Sierra Nevada is especially difficult due to the wide range of elevations and climatic characteristics. In the central Sierra, abundant snow falls above 1700 m, but the snow is frequently followed or interrupted by rain. As air temperature oscillates around 0°C, snow is very likely to stick to precipitation gauging equipment. Gauges may "cap over" under these circumstances and fail to record the succeeding portions of the storm. Some portion of the cap eventually falls into the gauge, but the storm's catch will be understated.

In the southcentral Sierra, rain still occurs at the 1700 to 2100-m level, but the peaks are much higher (over 3000 m), so large areas do not receive significant winter rain. These areas, however, may be very steep, extremely windy (gusts over 45 $m\ s^{-1}$), and have little vegetation in which to shelter gauge sites. At the southern tip of the Sierra, elevations are not as great, and snow storms are frequently interspersed with rain events. The vegetation is predominantly sagebrush-chaparral, rather than the mixed conifers found in the central Sierra.

Because of climatic differences among the mountains surrounding the Los Angeles basin and the various portions of the Sierra Nevada, monitoring equipment and site criteria that match one portion of California may be inappropriate for other portions. No siting guidelines currently exist, and no estimates of gauge error are available across the range of conditions in the California snow zone. In above-average winters, snow water equivalent (SWE) in the central and southcentral Sierra can be 175 and 250 cm, respectively, so precipitation gauging catch deficiencies of 20 to 50% could seriously understate the volume and chemical loading from both individual storms and the total of the winter's events. While snow-core samples taken late in the winter provide a more convenient way to measure both the chemical concentration and SWE, the results are likely to be in serious error for the lower elevations of the Sierra Nevada, the San Bernardino, and the San Jacinto mountains. Due to the rain and the frequent midwinter melt periods, both mass and chemical constituents will have been transported out of the snowpack and into the soil prior to sampling.

3.4. Sampling Strategies for Monitoring Precipitation Volume and Chemistry

The amount of precipitation volume and chemistry information obtained in a monitoring program is directly related to sampling frequency, but increased information cannot be achieved without increased cost. For determination of the end-of-season total chemical loading at a site, the lowest-cost snow-sampling scheme would call for seasonal snowpack (pit) sampling only. Measurement of snow depths and core samples would be made (with replication so that estimates of variablity could be obtained) near the time of peak accumulation. However, losses of both mass and chemical constituents might have already occurred by the time of the sampling due to snowpack releases generated by midwinter rain and surface melt or evaporation.

Interval sampling provides more information, and monthly intervals would provide more information than seasonal samples. Monthly pit samples from representative locations in the Sierra would, as for seasonal samples, entail taking integrated core samples to the ground. Changes in total loading from month to month could be calculated. Rough concentration profiles could be constructed if samples from the various levels were analyzed separately, but new surface layers would not necessarily contain all the chemicals or mass that fell during the month. If melt or rain had occurred, chemicals would probably have been transported into lower layers within the snowpack.

Short-interval (e.g., weekly) precipitation sampling would provide far more detailed information on SWE and chemical loading than monthly or seasonal pit sampling. Either collection tubes or snowboards could potentially be used for both chemical and volume sampling. Depending on the frequency of storms, the samplers could provide single storm information. At lower elevation or central and southern California sites, weekly servicing of snowboards endangers accuracy due to possible rain or snowmelt and the resultant loss of SWE and chemicals. Redistribution of snow to, or away from, board surfaces by wind after a storm may be a problem at the exposed, high-elevation sites.

Event (daily) sampling provides the greatest amount of information, but has the highest cost. While a storm event is underway, daily samples are collected. The loading associated with each storm can be estimated, and in combination with wind direction data, source areas could potentially be defined. Snowboards are likely to provide higher quality information when sampled and cleared on a daily rather than a weekly basis. Costs increase over weekly sampling due to both the dramatic increase in sample numbers and the staffing requirements.

3.5. Field Data Collection

Snowfall volume and snow-layer density and depth measurements were made during the 1986-1987 and 1987-1988 winters. Snow samples were collected for chemical analyses as snowfall and as deposited snow during one winter at two sites.

3.5.1. Snow Physical Properties--With the exception of the continuing operation of an Aerochem Metrics collector solely at CSSL, identical data collection systems were established at CSSL and Mammoth Mountain. Precipitation, wind speed and direction, and air temperature and humidity were measured during the winters of 1986-1987 and 1987-1988 with the following equipment at each site:

- Two Belfort weighing precipitation gauges, 30-cm orifice, Model 6071PR, windscreen (modified Alter)
- One Belfort weighing precipitation gauge, 30-cm orifice, Model 6071PR, no windscreen
- One Omnidata Easy Logger data collection field unit, Model EL824-GP
- One Vaisala temperature and humdity sensor, Vaisala Model HMP113Y
- One R.M. Young wind vane and 3-cup anemometer, Omnidata Model WSD330P
- One weather-tight box for the Easy Logger
- One Met One vaned radiation shield, Model 071A
- Five painted plywood snowboards, fabricated (0.36 m^2), each covered with a sheet of polyvinyl chloride

In addition to these devices, two experimental snowfall collectors designed for both volume measurement and chemical-sample collection, were installed at each site each year (Dawson 1986). These collectors were designed to mimic the shape of Belfort precipitation gauges and were cylindrical tubes 1.22 m in length, with a nominal inside diameter of 30 cm at the orifice. During the winter Schedule 20 (0.5-cm wall) polyvinyl chloride (PVC) was the tube material. This material proved brittle in cold weather; extremely careful handling of the tubes was required, a necessity not easily rendered during high-elevation field work in a windy, frigid environment. Replacement of the PVC tubes by linear polyethylene (LPE) cylinders at both sites for the 1987-1988 winter obviated the breakage problems and appeared not to foster any other problems. Both the PVC and LPE tubes were shielded by modified Alter windscreens.

Water equivalent measurements were made from the Belfort precipitation gauges, the experimental collectors, the snowboards, the Aerochem Metrics sampler (at CSSL only) and at two-week intervals from snowpack cores. The cores were taken from the walls of snowpits located a few meters from the collectors and gauges.

At Mammoth Mountain all gauges and collectors were mounted atop a metal 2.5-m x 9-m platform, raised 5.6 m off the ground and oriented with its long axis perpendicular to the predominant wind direction (Figure 3.3). At CSSL the shielded Belfort precipitation gauges and PVC/LPE collectors were on two 8-m towers (Figure 3.4); an Aerochem Metrics collector and unshielded Belfort were on a 7-m tower, 15 m away.

Evaluation of snowfall volume and chemistry techniques was the central focus of this study, and extensive sample replication procedures were instituted to ensure statistical credibility of the results. Storm depth as recorded by a precipitation gauge is a point estimate, and without a second depth estimate, no measure of the variablility around that value can be obtained. With the second measurement, the variability is defined and an error band around the mean of the values can be specified. For this reason, duplicate measurements of volume estimates from the PVC/LPE collection tubes, snowboards, and shielded precipitation gauges were made, and two adjacent "profiles" in the snowpits were monitored.

Sampling at the two sites was done to satisfy the multiple objectives of the study. "True" snowfall was defined as the snow water equivalent monitored on snowboards each day during storms. SWE was calculated as the product of the mean of two or more (generally four) snow-depth measurements at the corners of the boards and the mean weight (from a top-loading field balance) of two or more corresponding cores cut from each board with a 10 cm-diameter PVC corer. (Appendix A specifies details of the snow sampling protocols.)

3.5.1.1.--Quality Assurance Procedures--The study design included a program to ensure accuracy and comparability between sites for both volume and chemistry measurements. Identical instruments were used, and adherence to standardized data collection procedures and field analysis protocols was emphasized with the field staff at both sites. The field staffs met as the first season began and were trained as one group. Replication of volume measurements and sample collections allowed estimation of procedural variability and of confidence intervals around mean values.

All Belfort gauges were calibrated across their full range both at the start and the end of the season. Snowboards, snow-density cutters and tubes, and other equipment for both sites were fabricated and calibrated by the manufacturer or our technicians.

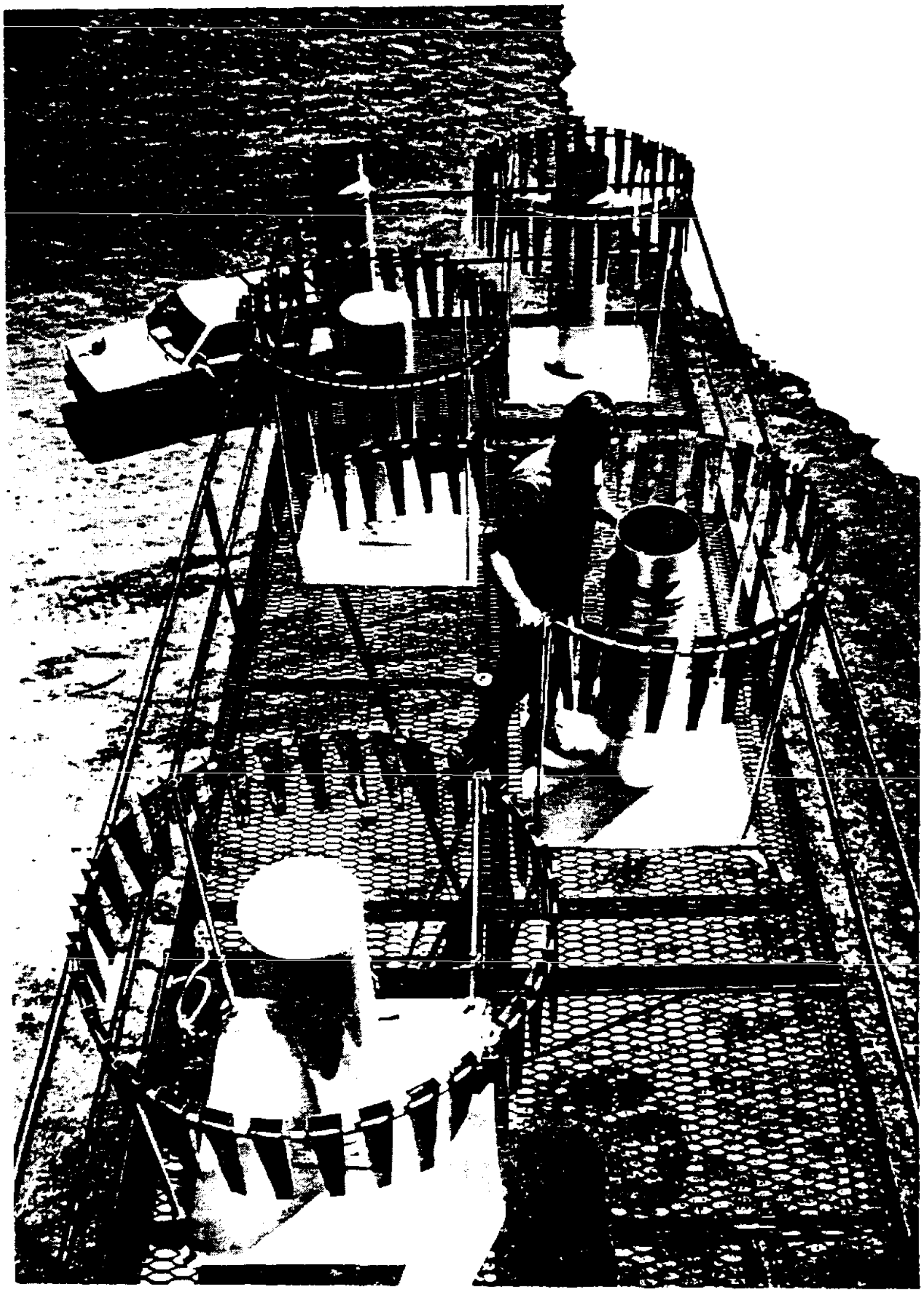

Figure 3.3. Instrument platform at Mammoth Mountain. Gauges on right are shielded Belforts. At left rear is unshielded Belfort precipitation gauge. At near and middle left are shielded PVC collectors.

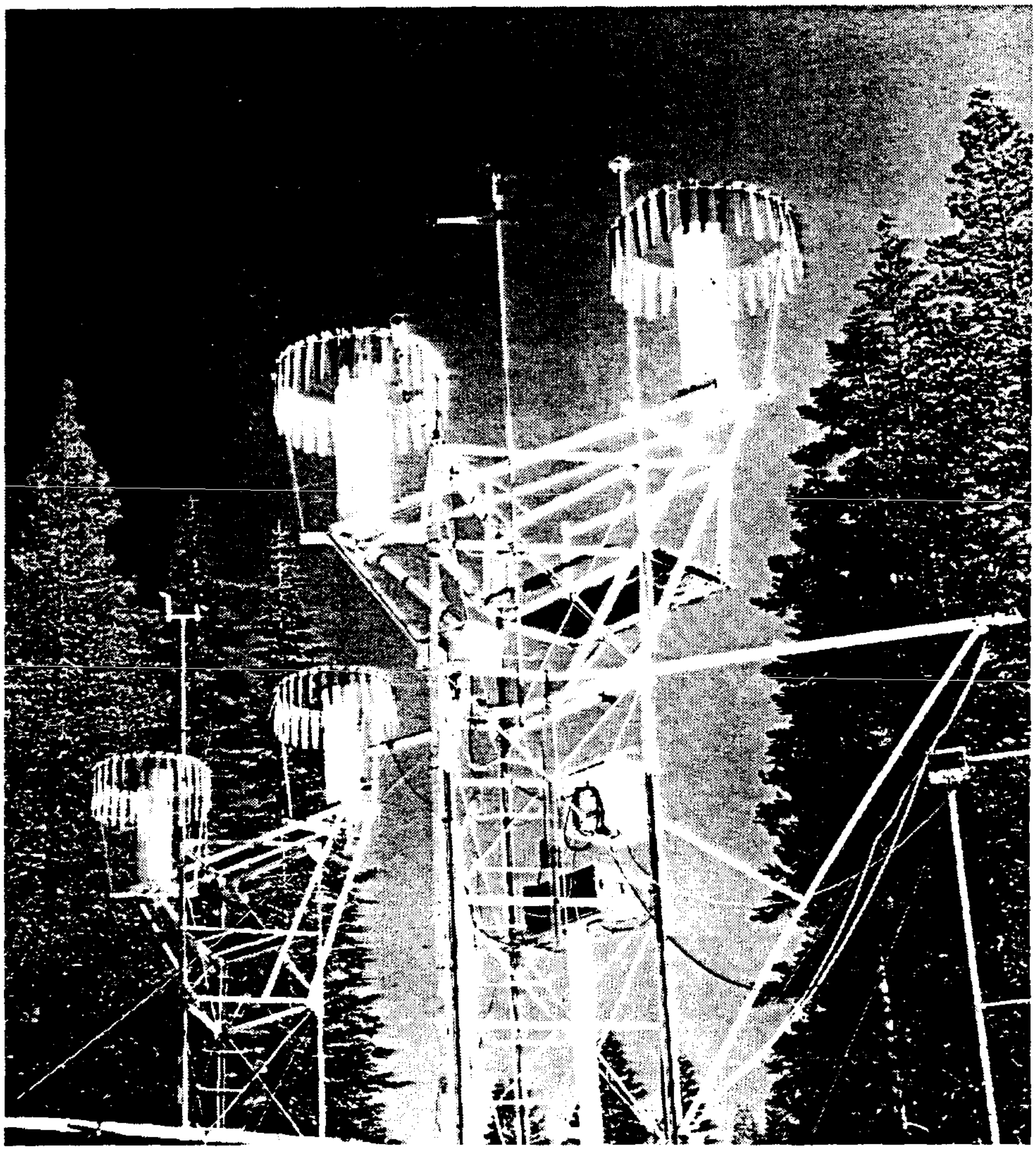

Figure 3.4. Instrument towers at the Central Sierra Snow Laboratory. Shown are shielded Belfort precipitation gauges (left side on each tower), shielded PVC collectors (right side on each tower), propeller anemometers (atop pole at center of right tower), and wind direction vane (atop pole on left tower).

3.5.2. Snow Chemistry: Field Protocols--Field and laboratory chemistry procedures were aimed at developing and assessing methods for determining the solute concentrations of snow samples for the following constituents: H^+, NH_4^+, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, NO_3^-, SO_4^{2-}, and the organic anions formate (HCO_2^-) and acetate ($CH_3CH_2O^-$). Other aspects of snow chemistry determinations anticipated for an operational field monitoring network were also assessed. These included procedures for sample collection, storage, and transportation to a central laboratory. Intensive research was undertaken at the two main field facilities but evaluation of sample collection, storage and transport procedures on an extensive scale from 10 sites spanning a distance of 750 km was also made.

3.5.2.1.--Sample Collection and Processing--Effective monitoring of snow chemistry in mountainous areas is associated with a special set of problems. The techniques for chemical analysis of snowfall are the same as those for rain, but the collection, storage and processing of snow samples requires more care and planning.

Snow samples were collected during the 1986-1987 winter at CSSL and Mammoth Mountain; no samples were collected for chemical analysis in the winter of 1987-1988. At each site, samples were collected in the duplicate PVC cylinders, from four snowboards (two turned daily during precipitation events, and two turned weekly), and from two profiles in each snow pit. The PVC tubes were soaked in 10% HCl overnight and then repeatedly rinsed with deionized water (acid-cleaned) before initial installation. At weekly intervals the PVC tubes were replaced with tubes previously rinsed in deionized water. The tubes were capped during all transits to or from the field labs. Snowboards were sampled with a 4-cm diameter, deionized-water rinsed, polyethylene (PE) tube. The depth integrated sample was placed in acid-cleaned, 2-liter polyethylene bottles. At each twice-monthly sampling of the snowpack at CSSL and Mammoth Mountain, the pit face was dug back 60 cm and the complete depth of the snowpack was sampled with a 4-cm diameter clear plastic corer in two adjacent profiles. Appendix B contains copies of field worksheets.

Snow samples were treated in either of two ways. Snow collected for the state-wide survey of snowpack chemistry (section 3.7) remained frozen until analyzed at the laboratory at the University of California, Santa Barbara (UCSB). The protocol for snow collected on Mammoth Mountain and at CSSL called for the initial melting step (inside SNARL and CSSL, at 15°C) to be performed at the respective field sites. Snowmelt water was refrozen in acid-cleansed PE bottles at the field sites before shipment to UCSB.

Snow samples for the state-wide survey were placed in ziplock bags cleaned at UCSB by soaking and rinsing in Milli-Q water (specific conductance <1 uS cm^{-1}, 25°C). A second ziplock bag enclosed the sample bag during transport. Samples were maintained at -30°C until analysis.

Mammoth Mountain procedures--All labware, 2-liter PE snow sample bottles, and cylinder collectors were washed before initial use with 10% HCl solution then rinsed 5-10 times with dionized water (acid cleaned). Between snow sample analysis sessions or installation in the field, all labware and sample receptacles were stored and capped, with approximately 2 liters of distilled water in them. On the day of installment onto the field platform, this 2 liters of water was discarded and the tube was rinsed with an additional 2 liters from which a field blank was obtained.

All samples from snowboards were placed in 2-liter LPE bottles and were stored frozen, at Mammoth Mountain, until the weekly sampling, at which time all the samples were transported to the lab at SNARL. Samples were allowed to melt, indoors, capped in their original containers and to warm to near room temperature. Melting required approximately 24 hours. The sample volume and water equivalence for the tube sample were determined by weighing the sample and collector on a large triple beam balance, pouring the sample into a clean Aerochem Metrics collector bucket and reweighing the empty sampler. Samples were swirled during melting in order to melt any residual snow. Samples were transferred to clean, labelled 250-ml PE bottles (acid-cleaned at UCSB), rinsed with a small amount of sample when available, and then immediately frozen for storage and transport to UCSB. Snow-pit samples were transferred directly to cleaned ziplock bags.

The temperature and conductivity (non-temperature compensated) of a 10^{-4} M KCl standard solution were measured with a YSI Model 32 Conductance Meter (K = 1.0 cell). Next, the temperature and conductivity of two field audit samples, 34.6 and 10.2 uS cm^{-1}, 25°C (as measured at UCSB), were determined. Sample conductivities were then measured. The cell and thermistor were each rinsed three times with distilled water and with an aliquot of standard or sample between measurements. All data were recorded on the "Chemistry Data Form" (see Appendix B).

Prior to measurement of pH, the meter and electrode (Fisher Acumet 825 MP, with Orion 8103 Ross combination pH electrode) were calibrated with pH 4 and pH 7 buffers, near room temperature, following the manufacturer's instructions. Following calibration, the electrode and thermistor were rinsed for five minutes in a beaker of stirred, distilled water. A clean beaker was rinsed with a small amount of sample which was then discarded. The beaker was filled with sample, the electrode and thermistor immersed and the sample swirled momentarily. After five minutes of equilibration, the sample temperature and pH (corrected to 25°C) were recorded. The electrode and thermistor were rinsed with distilled water. The sample beaker was rinsed twice with distilled water and the above procedure was used on the next sample. Following pH determination of all other samples, the temperatures and pH of a CARB pH reference solution (pH = 4.28) and of a field audit sample (measured at UCSB as pH = 4.74) were determined using the same procedure.

CSSL procedures--All labware, collectors and 2-liter PE bottles were washed and rinsed as per procedures at Mammoth Mountain with the exception that labware and sample receptacles were not stored with distilled water in them. About 90% of the 250-ml PE bottles were acid cleaned and rinsed at UCSB. The remainder were washed with deionized water, then soaked in a solution of 0.06 N HCl for two days while being rotated on their sides five times a day. These bottles were then rinsed three more times with deionized water, capped and stored. Other LPE bottles used for temporary sample storage were washed and rinsed in this manner also.

At CSSL, snowboard and pit samples were placed in capped, 2-liter LPE bottles and allowed to warm to near room temperature. PVC cylinder samples were allowed to warm to near room temperature in the original (capped) cylinders. Melted samples were poured into a thoroughly-rinsed, Nalgene graduated cylinder and weighed. Samples were transferred to clean, labelled 250-ml PE bottles which were first rinsed with a small amount of sample when available, and immediately frozen for storage and transport to UCSB.

A Cole Palmer model 1052 conductivity meter (temperature-compensated, Cole Palmer cell N-5800-20) was calibrated against a 0.0005 N KCl solution at the beginning of each sample analysis session. The cell was rinsed thoroughly with deionized water ($\leq$ 1 uS cm^{-1}, 25°C), after calibration and at least three times between each sample measurement.

The pH electrode and thermistor were the same at both field sites. At CSSL the meter (Fisher Acumet 805 MP) was calibrated with pH 4 and pH 7 buffers at the beginning of each sample analysis session. The pH probe was then rinsed with copious amounts of deionized water. Between measurements, the sample beaker was rinsed three times with deionized water. Samples equilibrated about one-half minute before measurement. Field audits and recording of sample pH and conductivity were performed as at Mammoth Mountain.

3.5.2.2.--Quality Integrity--Performance at both field sites was assessed by means of field blanks and field audit samples. Field blanks were of three kinds. The acrylic snow sampler blank and the PVC cylinder blank were obtained by rinsing each, respectively, with deionized water three times; a final rinse with 250-ml of deionized water was collected into acid-cleaned PE bottles and sent to UCSB along with a sample of the deionized water (DIW blank) used for that day.

Field audit samples were prepared and bottled individually at UCSB and shipped to each field laboratory at the beginning of the study period. There were two kinds of field audits, one for pH and one for specific conductance; the latter was at two levels, 34.6 and 10.2 uS cm^{-1}, at 25°C, respectively. Each field audit sample was used one time and then discarded. Field audit measurements for pH and for conductance were performed throughout the study period.

3.5.3. Sampling Schedule and Procedures--Seven-day periods were the primary temporal units of comparison. Since the Belfort precipitation gauges provide continuous measurement, their information could be subdivided into daily, weekly, monthly, and seasonal precipitation depths (Table 3.1). A pair of snowboards was monitored once every 24 hours during events for both SWE and solute content. One core from each of two boards was collected for chemical analysis. The same set of procedures was followed for an additional pair of snowboards except that they were measured at weekly intervals if precipitation occurred during the preceding week.

The data collection system allowed the estimation of relative collection rates of the different devices and the influence of meteorological factors. By having identical instrumentation at both sites, the effects of wind, elevation, and other physical characteristics could be assessed.

Table 3.1. Summary and schedule of routine sampling/measurement procedures.

Parameter	Sampling Frequency
Precipitation Volume and Chemistry	
Snowboards	daily (0800) during storm events weekly (0800) on separate boards
Precipitation gauges[1]	continuously[2]
PVC/LPE collectors	changed weekly (0800)
Meteorological	
Wind speed and direction	scanned at 5-min intervals, 15-min means recorded
Air temperature	" " "
Humidity	" " "
Snowpack (surface-to-ground pits) Snow Water Equivalent and Chemistry	
Cores at CSSL and Mammoth	every two weeks
Cores for spatial distribution of snow chemistry (10 sites)	once, at time of maximum snowpack

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[1] No chemistry samples collected from the Belfort precipitation gauges.

[2] Monitored continuously with automated data acquisition system. Data were reduced to hourly means or totals. Functioning of instrumentation and data recording system was checked twice weekly at Mammoth Mountain and daily at CSSL.

Collection by PVC/LPE Tubes--At each site, the two PVC/LPE tubes were mounted so that the orifice was at the same height as the modified Alter windscreen. Samples were not collected at daily intervals from the PVC cylinders for ionic analysis since the snowboards were sampled daily during storms. If overtopping appeared imminent during major storms, empty tubes could be installed. On a weekly basis, both PVC/LPE tubes were capped and lowered from the tower. After the tube's contents were melted and weighed or measured volumetrically, the tubes were drained, rinsed, capped, and stored for re-use. Samples were not collected at monthly intervals from the tubes due to the probable loss of snow from overflowing, wind scour, or evaporation.

Event vs. Weekly Volume and Chemistry Comparison--A major concern for this study was whether a weekly collection schedule would produce the same results as daily sampling for events that occur during a week. The weekly total catches from the PVC/LPE tubes were compared statistically and graphically with the weekly SWE catches from the two shielded Belforts, the weekly catches of the two weekly snowboards, and the weekly sums of the catches from the "daily" snowboards. At CSSL, weekly data from the Aerochem Metrics collector were included in the "weekly" comparisons. Similar comparisons could be made for chemical concentrations in samples collected by the various techniques at both the daily and weekly intervals.

The statistical analyses attempted to identify statistically significant differences between techniques by testing for overlap of confidence intervals around the mean SWEs and concentrations from each technique. For instance, the differences between the PVC/LPE tube SWEs were compared to the weekly snowboard SWEs and the weekly Belfort increases. The average SWE of the two PVC/LPE tubes was subtracted from both the average SWE of the Belforts and the snowboards for each week during the snow season. The variability around the differences between these means was estimated, and if the range included zero, no significant difference between the mean SWEs measured by the three devices was identified.

Twice-monthly Integrated Snow Core Samples--While the snowboards and PVC tubes measure the volume and chemical inputs to the snowpack, direct measurement of the entire snowpack is also of interest. At both sites, a pit was dug to the ground. A pair of samples was collected at two-week intervals, and the depth of the pit was recorded. The surface-to-ground cores were collected from the pit face using a 5 x 50-cm, acid-washed plastic corer. Each core's contents was emptied into acid-washed bags, weighed, and stored in a freezer until it was transported to the chemical lab at UCSB. Only one of the cores was analyzed, but when aberrant values appeared, the replicate core section was analyzed to determine if the initial sample was accidentally contaminated during collection. Total snowpack SWE was calculated from two snow density profiles using coring techniques described in detail in Appendix A.

The pits were located as near each instrument tower as was practical, and in successive two-week periods the pits were extended across the slope if the pits were still open. The pits were marked with snow stakes and flagging to mark the hazard. Pits were not located closer than 20 m to trees to avoid potential contamination due to throughfall.

3.6. Laboratory Protocols at UCSB

3.6.1. Sample Preparation--Frozen snow samples were transferred from ziplock bags into 6-liter polyethylene buckets having closable lids. The buckets were kept at room temperature for a few hours to initiate melting and then placed in a cold room (4°C) overnight. The following day the samples were allowed to come to room temperature and swirled prior to pH and specific conductance determinations and filtration. The filtered sample (60-100 ml) was returned to cold storage (4°C) until analysis.

Filtered water (Gelman A/E, binder-free, glass fiber filters or Nuclepore membrane) was used for ammonium, and major cation and anion determinations. Filters were rinsed with ca. 300 ml deionized water before use and ca. 20 ml of sample was passed through the filter and discarded before the sample was collected into a 10% HCl cleaned, deionized water rinsed polyethylene bottle. Filter blanks of deionized water, stored in PE bottles cleaned as above at a three percent frequency, were processed and analyzed for dissolved ions.

3.6.2. Quality Assurance--To assure the credibility and integrity of data, the quality control program at UCSB incorporates the following features:

1) A standard protocol is followed for storage, melting, filtration and analyses. Only deionized water having a specific conductance of 0.2 - 0.5 uS cm^{-1} is used for analytical work (i.e. Milli-Q water).
2) All chemicals are analytical reagent grade conforming to specifications of the Committee on Analytical Reagents of The American Chemical Society.
3) Chemicals for primary standards are traceable to The National Bureau of Standards.
4) Freshly-prepared calibration standards that bracket the samples' concentration and reagent blanks are used in every assay.
5) Calibration standard controls are distributed at 5% frequency throughout an analytical run as a check on calibration drift; if variation from the expected value is more than ±10% the new calibration value is used.

To determine if analytical bias exists during the analysis of cations and anions, a synthetic charge balance control (CBC) consisting of six ions only was prepared from standard solutions of $CaCl_2$, $MgSO_4$, and $NaNO_3$. The CBC is included in each analytical run. Any persistent deviation in ion balance ([sum of positive charge]/[sum of negative charge]) over the study period would suggest a bias. A value of one implies no bias for the chemical methods that were employed.

To assess the effectiveness of filtration followed by storage at 4°C as a means of preservation of chemical species, known additions of NH_4^+, Ca^{2+}, Mg^{2+}, Na^+, Cl^-, NO_3^-, SO_4^{2-}, HCO_2^- and $CH_3CH_2O^-$ were made to subportions of two filtered snow melt samples and also to Milli-Q water. Samples for organic anion analysis were preserved with chloroform. These spiked samples were stored three months at 4°C before analysis.

Accuracy was assessed in each run by comparison with two certified controls (NBS and EPA) and by recovery after known addition of synthetic standards to 5% of the actual samples. Precision was estimated by analyzing 5% of the samples in a run in duplicate. In addition, UCSB is a continuing participant in interlaboratory comparison studies. In 1986 and 1988, UCSB's average ratings were 3 and 4, respectively, in overall laboratory performance for values of cations and anions submitted to the U.S. Geological Survey's Analytical Evaluation Program-Standard Reference Water Samples. Rating 3 was 0.51 to 1.00 standard deviation; the highest rating was 4 with 0.00 to 0.50 standard deviation. The standard deviations are of the value averaged over all the submitted values from individual laboratories. About 35 laboratories participated with various chemical species.

In order to validate data sets, UCSB adhered to the following acceptance criteria (Drouse et al. 1985). Charge balance was evaluated as an ion balance ratio (the sum of positive ions/sum of negative ions) and as the absolute value of the sum of positive ions minus the sum of negative ions. Theoretical specific conductance was calculated from measured ion concentrations and compared with measured specific conductance as the conductance deficit (measured conductance minus calculated conductance).

3.6.3. Analytical Methodology--Ammonium was determined by the phenol-hypochlorite method (Koroleff 1969). The major cations: calcium, magnesium, sodium and potassium, were analyzed with a Varian-AA6 atomic absorption spectrophotometer. An air-acetylene flame was used; addition of lanthanum chloride suppressed chemical and ionization interferences during calcium and magnesium determinations. The inorganic anions: chloride, nitrate, and sulfate and organic anions: acetate and formate, were measured by ion chromatography with a Dionex Model 2010i employing chemical ion suppression and conductivity detection.

The pH measurements were made with a Ross 8104 combination pH electrode on a Fisher Acumet 805 MP pH meter. For each trial the electrode was calibrated with pH 7.00 and pH 4.00 NBS-traceable reference buffer solutions. After thorough rinsing with deionized water, a calibration measurement with a freshly prepared 10^{-4} M HCl solution was performed (Galloway et al. 1979); if the pH was greater than ±0.05 pH units of theoretical (pH 4.00), a recalibration was performed. After copious rinsing with deionized water, the electrode was rinsed with an aliquot of sample. The temperature-compensated pH determination was made on a fresh, quiescent sample after 5 minutes as streaming potential effects on pH measurements have been documented (Koch and Marinenko 1983). Other precautions in the protocol included equilibrating samples and buffers to ambient temperature and thorough rinsing of the electrode with deionized water between readings. Occasionally, pH measurement was repeated on subportions of a single sample as a check on precision.

3.7. Statewide Survey of Snowpack Water Equivalent and Chemistry

As an integrated measurement of the entire winter precipitation, estimation of chemical loading from snowpit cores is an attractive procedure. A single measurement, taken at the time of maximum snowpack accumulation, could be relatively inexpensive and allow a greater areal coverage of snowpack chemistry than more frequent monitoring of precipitation. At lower elevation sites receiving rain, information would be lost due to water leaving the snowpack during and immediately after rainfall, or melt. To assess the effectiveness of snowpack coring under various climatic situations, and to provide a first approximation of snowpack chemistry at selected sites across California, snowpits at 10 sites were sampled between March 18 and March 30, 1987 (Figure 3.5).

Duplicate surface-to-ground snow cores (approximately 1 m apart) were collected at the 10 sites listed below. The coring and sampling procedure used for the twice-monthly pits was employed at these sites as well. All samples were collected on flat, open terrain. Samples were kept frozen and transported to Santa Barbara as soon as possible after collection.

The following sites were selected based on anticipated variations in wet deposition influx, precipitation amount, precipitation type, accessibility, and proximity to California Department of Water Resources (DWR) snow survey sites. Selection of snow survey sites would allow comparison between the 1987 data and the long-term, DWR, snow-water equivalent data base.

- Central Sierra Snow Laboratory
  2100 m elevation, central Sierra Nevada west slope, west of Truckee, 85 cm mean, long-term, April 1 SWE, red fir/lodgepole pine
- Alpine Meadows ski area
  2200 m base elevation, central Sierra Nevada east slope, south of Truckee, 70 cm mean, long-term SWE, subalpine
- Mammoth Mountain ski area

2900 m elevation, south central Sierra Nevada, east slope, near Mammoth Lakes, nearby snow survey course has 100-cm, April 1, mean long term SWE, subalpine
- Snow Summit
  2150 m elevation, northeastern San Bernardino Mountains, 4 km south of Big Bear Lake, 47-cm, May 1, short-term SWE, intermittently surveyed as part of DWR network, subalpine
- Lower Big Draw
  2900 m elevation, eastern San Bernardino Mountains, north slope, southwest of Big Bear Lake, 56-cm, May 1, long-term SWE, snow-survey site in Wilderness area, subalpine
- Kirkwood ski area
  2450 m elevation, central Sierra Nevada, west slope, south of Lake Tahoe, nearby snow survey course has 99-cm, long-term, April 1 SWE, subalpine
- Heavenly Valley ski area
  2950 m elevation, south end of Lake Tahoe, nearby snow survey course has 75-cm, long-term, April 1 SWE, subalpine
- Eastern Brook Lake
  3150 m elevation, southern Sierra Nevada, east slope, 17.5 km south of Crowley Lake, nearby snow survey course has 41-cm, long-term, SWE, subalpine
- Emerald Lake
  2900 m elevation, southern Sierra Nevada, west slope, Kings Canyon/Sequoia Nat'l Parks, 145-cm, 1985-1986 mean, April SWE, subalpine cirque
- Mount Dyer
  2165 m elevation, northern Sierra Nevada, west slope near Lake Almanor, 65-cm, April-1, long-term SWE, DWR snow survey site, red fir/lodgepole pine

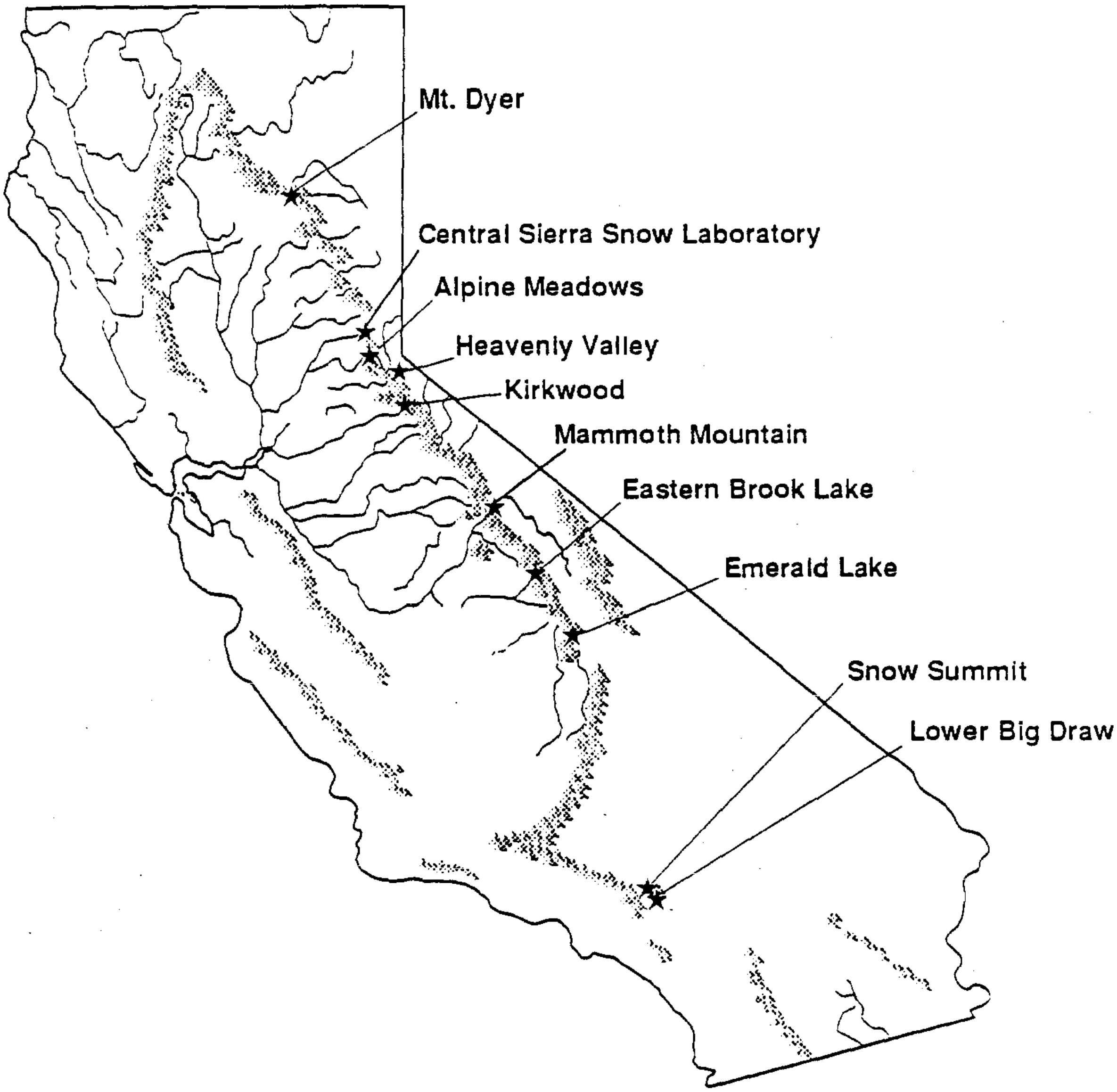


Figure 3.5. Location of sites in the Sierra Nevada and San Bernardino Mountains monitored in late March, 1987 for snowpack water equivalent and chemistry.

4. RESULTS

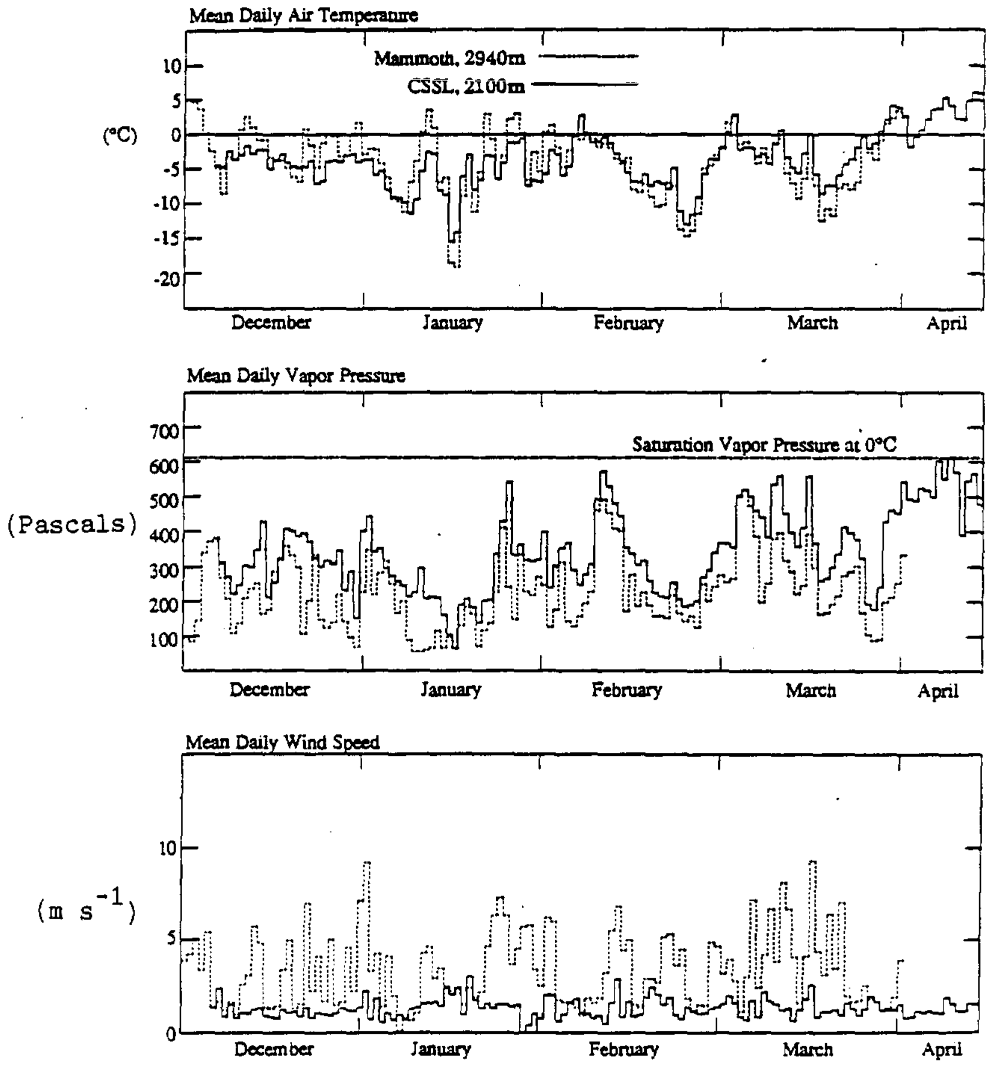
4.1. Climate at CSSL and Mammoth Mountain

Mean daily air temperature, vapor pressure, and wind speed for the 1986-1987 winter illustrate the differences between the two snow study sites (Figure 4.1). At Mammoth Mountain there was a strong vapor gradient away from the snow surface which, when coupled with high winds, would drive sublimation leading to snowcover cooling and mass loss. Beaty (1975) observed that this occurred at high-elevation sites, and Stewart (1982) showed that sublimation could cause up to 25% of the snowcover mass to be lost each year at Mammoth Mountain. The Mammoth Mountain site was appreciably less humid and windier than the CSSL site, and the frequent, near-saturation, daily averages at CSSL indicate that nighttime saturation and surface condensation were routine there. Mammoth Mountain was warmer than CSSL during December and January, and then only slightly cooler during the rest of the snow season. This relative similarity in air temperatures is surprising due to the elevational difference between the two sites. The pattern of the air temperature and vapor pressure traces suggested that large frontal systems affected both sites similarly. Similar data for the 1987-1988 winter (Figure 4.2), available for CSSL only, show similar order-of-magnitude values for wind speed, air temperature, and vapor pressure.

Monthly climatic averages for the 1986-1987 winter further illustrate the differences between the two sites (Table 4.1). Monthly averages have little physical significance, but they allow evaluation of a parameter which is subject to much stochastic short-term variation. Comparison with long-term, monthly, temperature averages reported by Smith and Berg (1982) indicate that it was about 2°C colder than average at CSSL during the 1986-1987 winter. Air temperatures were more moderate at CSSL during the 1988 snow season; humidities, on the average, were higher also, while wind speeds were nearly identical to those of the previous year (Table 4.2).

4.2. Precipitation Volume

During the 1986-1987 snow season, nearly 70% more precipitation was recorded by the high-capacity Belfort gauges at CSSL than was measured at Mammoth Mountain (Figure 4.3, Tables 4.3 and 4.4). For a comparable recording period during the following year, however, the CSSL gauges averaged only 5% more than the Belfort gauge at Mammoth Mountain (Tables 4.5 and 4.6). This seasonal difference is due to the difference in the spatial intensities of major frontal storms, not gauging procedures. Although the unshielded gauge caught less than the shielded gauges at Mammoth Mountain in 1986-1987 and at CSSL during both years, the end-of-season differences were not statistically significant (at $p<0.05$) (Figures 4.3 and 4.4). Gauge placement may have caused microclimatic variation at each gauge, confounding the effects of the presence or absence of shields. CSSL's two shielded Belforts were approximately 10 m and 17 m from the northwest edge of the forest clearing. The unshielded Belfort was near the center of the 50-m clearing. At Mammoth Mountain, space limitations on the platform resulted in the shielded Belforts being 2-3 m downwind from the shielded PVC/LPE tubes. The proximity of the devices may have further modified wind conditions.



Mean Daily Air Temperature

Mean Daily Vapor Pressure

Mean Daily Wind Speed

Figure 4.1. Mean daily air temperature, vapor pressure, and wind speed at the Central Sierra Snow Laboratory and Mammoth Mountain study sites, winter 1986-1987.

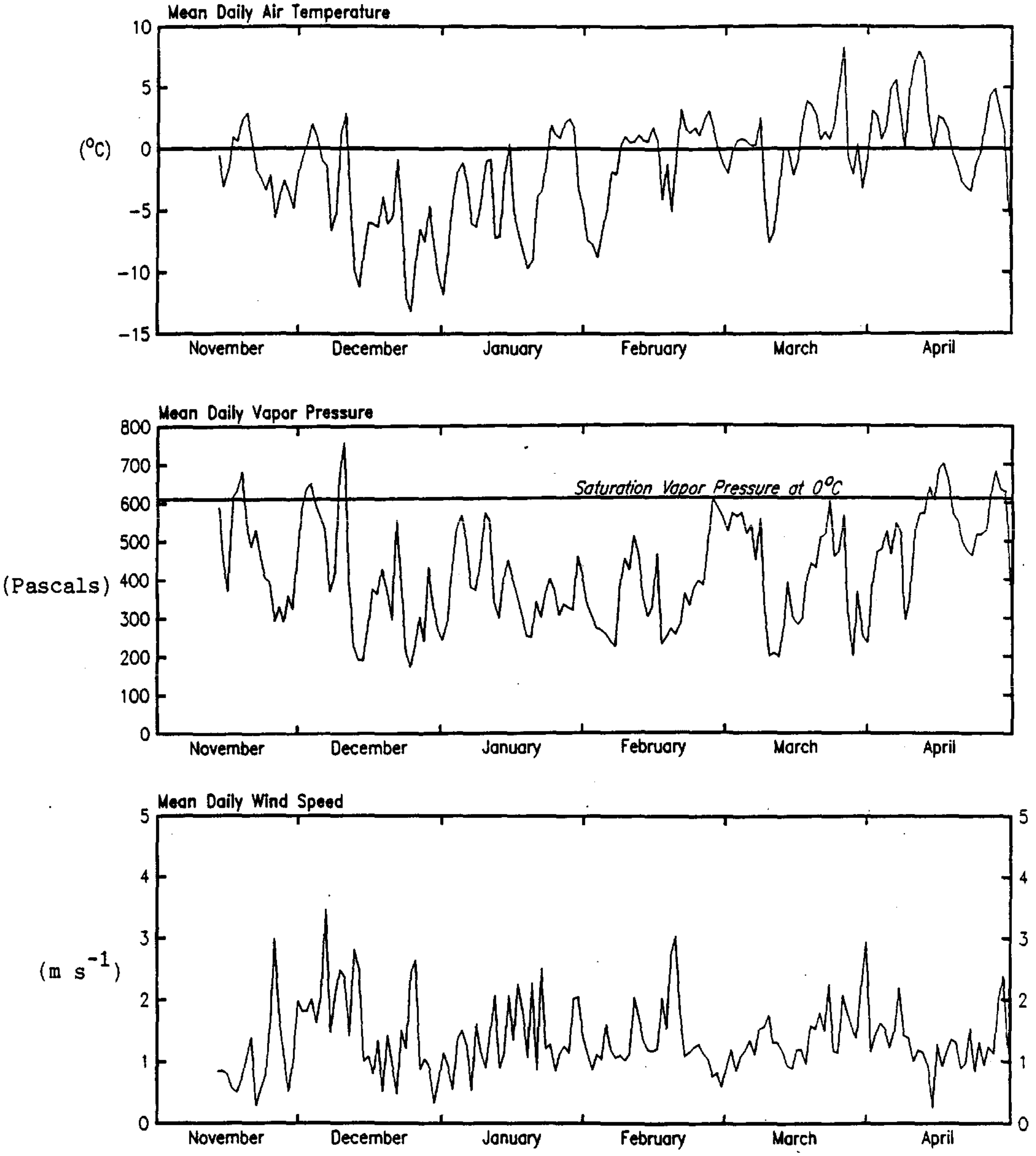


Figure 4.2. Mean daily air temperature, vapor pressure, and wind speed at the Central Sierra Snow Laboratory, winter 1987-1988.

Table 4.1. Climate summary for the Central Sierra Snow Laboratory and Mammoth Mountain snow study sites, 1986-1987 winter.

Air Temperature Summary, Monthly Averages (^{o}C)

	CSSL			Mammoth Mountain		
Month	Mean	Max[1]	Min[1]	Mean	Max[1]	Min[1]
Dec	-3.9	2.1	-8.5	-1.6	1.3	-4.2
Jan	-6.4	-1.0	-11.0	-4.7	-1.3	-8.3
Feb	-4.9	0.2	-9.4	-5.6	-2.0	-8.7
Mar	-2.5	2.1	-6.8	-3.9	-0.7	-7.0
Apr	3.0	9.9	-3.0	3.0	6.5	-1.2
Seasonal Mean	-2.9	2.7	-7.8	-2.6	0.8	-5.9

Humidity Summary, Monthly Averages (Pascals)

	CSSL			Mammoth Mountain		
Month	Mean	Max[1]	Min[1]	Mean	Max[1]	Min[1]
Dec	316	409	227	212	292	131
Jan	271	372	187	181	264	104
Feb	312	400	230	231	317	150
Mar	389	479	299	271	350	192
Apr	523	676	389	294	448	219
Seasonal Mean	362	467	266	238	344	159

Wind Speed Summary, Monthly Averages ($m\ s^{-1}$)

	CSSL			Mammoth Mountain		
Month	Mean	Max[1]	Min[1]	Mean	Max[1]	Min[1]
Dec	1.14	2.14	0.23	3.15	6.33	1.03
Jan	1.38	2.64	0.38	3.47	7.40	1.20
Feb	1.38	2.52	0.41	3.07	6.47	0.94
Mar	1.38	2.74	0.34	3.89	7.71	1.35
Apr	1.24	2.41	0.29	2.90	6.45	0.78
Seasonal Mean	1.30	2.49	0.33	3.30	6.83	1.06

[1] Monthly means computed from daily maximum and minimum values.

Although only 60% of the 30-year mean annual precipitation was deposited in water year 1987, precipitation was recorded during 15 weeks of the 16-week monitoring period. During only 5 weeks at Mammoth Mountain and 6 weeks at CSSL did precipitation SWE exceed 4 cm (Figure 4.5). Also, during 5 weeks at Mammoth Mountain and 6 weeks at CSSL, minor amounts of precipitation were detected in the tubes but not on snowboards. At Mammoth Mountain in 1986-1987, the tower-mounted collectors caught significantly less SWE than did the snowboards during both large storms and for the seasonal total (Table 4.4). The monthly and seasonal wind speeds at Mammoth Mountain were approximately three times the CSSL values (Tables 4.1 and 4.2), and this difference may be the cause of the 25% undermeasure by Mammoth Mountain's Belforts and PVC tubes as compared to the snowboards. No rain was reported at Mammoth Mountain during either season. Based on the 1987 seasonal average wind speed of $3.3\ m\ s^{-1}$, a collector catch deficiency of approximately 23% might be expected (Figure 3.1). Although a seasonal average wind speed is not directly related to wind speeds during storms, there is close correspondence between the actual and the projected deficiency. At Mammoth Mountain also, catch deficiencies by the Belforts and PVC tubes were larger during large storms; the weekly storm totals that were less than 3 cm showed no clear difference among methods (Figure 4.5B).

Table 4.2. Climate summary for the Central Sierra Snow Laboratory, 1987-1988 winter.

Air Temperature Summary, Monthly Averages (°C)

Month	Mean	Max[1]	Min[1]
Nov	-1.7	3.6	-5.6
Dec	-5.2	-1.6	-8.9
Jan	-3.4	1.3	-7.5
Feb	-0.7	6.5	-6.1
Mar	0.0	6.3	-5.3
Apr	1.8	7.1	-2.9
Seasonal Mean	-1.5	3.8	-6.0

Humidity Summary, Monthly Averages (Pascals)

Month	Mean	Max[1]	Min[1]
Nov	452	570	365
Dec	398	483	307
Jan	385	476	292
Feb	366	469	275
Mar	400	535	289
Apr	535	662	410
Seasonal Mean	422	586	323

Wind Speed Summary, Monthly Averages ($m\ s^{-1}$)

Month	Mean	Max[1]	Min[1]
Nov	1.06	2.28	0.22
Dec	1.57	2.89	0.43
Jan	1.38	2.82	0.29
Feb	1.34	2.35	0.35
Mar	1.43	2.82	0.30
Apr	1.27	2.56	0.25
Seasonal Mean	1.34	2.62	0.31

[1] Monthly means of daily maximum and minimum values.

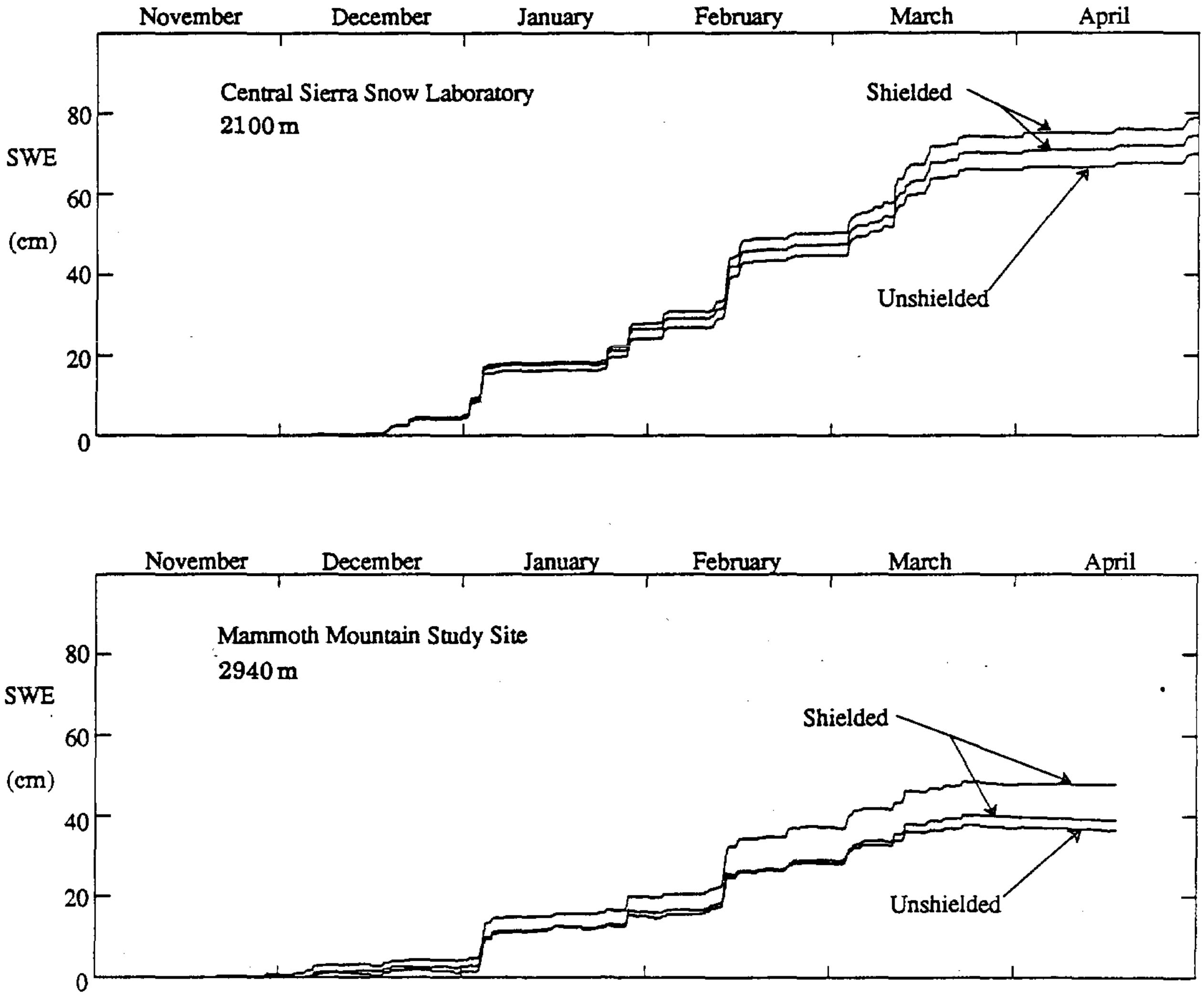


Figure 4.3. Cumulative precipitation for the 1986-1987 winter as measured by shielded and unshielded Belfort high-capacity gauges at the Central Sierra Snow Laboratory and Mammoth Mountain study sites.

Table 4.3. Precipitation depths (cm) between weeks ending 23 December 1986 and 24 April 1987 at the Central Sierra Snow Laboratory.

Interval Ending	Belfort gauges 1	2	Mean	PVC tubes 1	2	Mean	24-h boards 1	2	Mean	Weekly boards 1	2	Mean	Aerochem Metrics[1]
861223	3.8	3.8	3.8	3.9	3.8	3.9	2.3	2.1	2.2	3.8	3.8	3.8	3.1
861231	0.3	0.5	0.4	0	0	0	0	0	0	0.6	0.6	0.6	0
870106	12.8	12.7	12.8	12.8	12.9	12.8	11.6	11.8	11.7	15.1	15.6	15.3	5.6
870113	0.2	0.3	0.3	0.2	0.2	0.2	0	0	0	0	0	0	0.9
870127[2]	3.6	4.1	3.8	3.8	3.8	3.8	3.0	3.0	3.0	2.5	3.0	2.8	2.9
870203	7.9	8.5	8.2	8.0	7.8	7.9	8.9	8.3	8.6	7.7	8.3	8.0	5.0
870210	0.4	0.3	0.4	0.3	0.4	0.3	0	0	0	0	0	0	0.3
870217	16.3	17.7	17.0	17.8	15.6	16.7	13.2	15.3	14.2	12.0	14.1	13.0	14.0
870224	1.3	1.3	1.3	1.2	1.2	1.2	1.3	1.4	1.4	1.1	1.0	1.0	1.0
870303	0.2	0.1	0.1	0.2	0.1	0.1	0.3	0.3	0.3	0	0	0	0.2
870310	5.8	6.3	6.1	6.1	6.2	6.2	3.8	3.9	3.8	1.7	1.8	1.7	6.0
870317	10.1	10.7	10.4	9.7	10.3	10.0	8.9	9.4	9.2	8.8	8.8	8.8	7.8
870324	6.8	7.0	6.9	6.4	6.7	6.6	5.5	6.7	6.1	5.8	5.9	5.9	5.0
870408	0.7	0.8	0.7	0.6	0.7	0.6	0.8	0.7	0.8	0	0	0	0.8
870424	1.0	1.0	1.0	0.8	0.8	0.8	0	0	0	0	0	0	0.7
Mean Totals			73.2			71.1			61.3[3]			60.9[3]	53.3

[1] Aerochem Metrics sampler was not replicated.
[2] No precipitation recorded for the weeks ending 20 January and 1 April, 1988.
[3] Underestimated due to rain.

Cumulative average weekly totals from the Belforts, the PVC tubes, the Aerochem Metrics sampler, and the daily and weekly snowboards showed other differences as well during the 1986-1987 snow season (Tables 4.3 and 4.4). At CSSL, the tower-mounted collectors caught significantly more SWE than the snowboards ($p<0.01$). The ca. 10-cm difference is about halved once the 4.3 cm of rain that occurred during two early 1987 storms is added to the board depths. Rain during the weeks of 17 February, 10 March, and both April weeks contributed to the comparatively low weekly and daily board SWE depths (Figure 4.5A). Analysis of variance of the weekly results from the Belforts and PVC tubes yielded no significant differences in SWE between those collectors at either site. At CSSL, the daily and weekly board SWE values also did not differ significantly during the 1986-1987 season. The other combinations of Belforts, tubes, and boards had significantly different weekly SWE volumes ($p<0.01$). Analysis of the replicates showed that the 95% confidence intervals around the mean weekly differences for the Belforts, tubes, and weekly and daily boards averaged ±0.4 cm and ranged from ±0.2 cm to ±0.6 cm.

Table 4.4. Precipitation depths (cm) between weeks ending 23 December 1986 and 31 March 1987 at Mammoth Mountain.

Interval	Belfort gauges			PVC tubes			24-h boards			Weekly boards		
Ending	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean
861223	0.7	1.2	1.0	1.2	---	1.2	1.1	0.9	1.0	0.9	1.4	1.2
870106[1]	10.0	10.4	10.2	9.7	---	9.7	14.9	14.9	14.9	14.6	13.7	14.2
870113	0.4	0.4	0.4	0.1	0.2	0.2	0	0	0	0	0	0
870120	0.6	0.7	0.6	0.7	0.8	0.8	1.1	0.9	1.0	0.6	0.6	0.6
870127	0.8	1.0	0.9	1.1	1.3	1.2	0.8	0.8	0.8	1.0	1.3	1.2
870203	3.3	3.9	3.6	3.9	3.5	3.7	4.6	4.8	4.7	8.4	6.3	7.4
870210	1.0	0.9	1.0	1.1	1.1	1.1	1.1	1.2	1.1	1.3	1.4	1.4
870217	9.0	13.0	11.0	10.2	9.8	10.0	14.6	14.3	14.5	15.0	14.4	14.7
870224	1.7	2.5	2.1	3.0	3.2	3.1	2.3	2.1	2.2	2.6	2.7	2.7
870303	0.8	0.2	0.5	0.5	0.4	0.4	0.6	0.5	0.6	0	0	0
870310	5.1	4.7	4.9	5.5	5.5	5.5	7.0	6.9	6.9	5.3	5.1	5.2
870317	4.4	4.4	4.4	4.3	---	4.3	2.6	2.7	2.6	4.4	6.6	6.0
870324	2.4	2.6	2.5	3.7	---	3.7	2.4	2.1	2.3	4.1	3.8	4.0
870331	0	0	0	0.3	---	0.3	2.3	2.4	2.3	0	0	0
Mean Totals			43.1			45.2			54.9			58.6

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[1] No precipitation recorded for the week ending 31 December 1987.

The 1988 water year was also dry, but although only 55% of the 30-year mean precipitation was deposited, precipitation was recorded during 18 weeks of the 22-week monitoring period at CSSL. Precipitation SWE exceeded 4 cm, however, for only 7 of the 26 weeks of record at Mammoth Mountain and 9 weeks at CSSL (Tables 4.5 and 4.6). Also, at CSSL when both boards and LPE tubes were in operation, precipitation was detected during 3 of the 18 weeks in the tubes but not on the weekly snowboards. The weekly precipitation pattern at CSSL during the 1987-1988 winter did not differ appreciably from the previous winter's (Figure 4.6A). As in 1986-1987, the Belforts and tubes generally collected more SWE than the boards.

At CSSL in the 1987-1988 winter, the tower-mounted collectors caught significantly more SWE than the snowboards ($p<0.001$). Rainfall equalling 10.2 cm SWE could account for much of the 11.8-cm difference between the 24-h board and Belfort gauge totals, two-thirds of which occurred during the weeks ending 8 December and 15 December when the weekly board catch was low or absent (Figure 4.6A).

Table 4.5. Precipitation depths (cm) between weeks ending 24 November 1987 and 26 April 1988 at the Central Sierra Snow Laboratory.

Interval	Belfort gauges			LPE tubes			24-h boards			Weekly boards			Aerochem
Ending	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean	Metrics[1]
871124	2.1	2.8	2.4	---	---	---	1.1	1.1	1.1	1.2	1.5	1.3	1.2
871201	1.3	2.0	1.7	---	---	---	2.0	2.3	2.1	2.4	2.1	2.3	1.5
871208[2]	18.3	13.7	16.0	---	---	---	12.2	12.2	12.2	9.8	9.7	9.7	11.5
871215	4.7	3.8	4.2	---	---	---	2.0	1.9	2.0	0	0	0[2]	3.3
871222[2]	5.7	5.4	5.6	5.7	5.8	5.7	5.2	5.1	5.2	5.0	5.2	5.1	4.8
871229[3]	---	---	5.4	5.1	5.7	5.4	7.8	8.6	8.2	8.5	9.5	9.0	4.1
880105	7.1	8.1	7.6	9.1	8.0	8.6	7.4	7.2	7.3	8.7	8.2	8.5	4.8
880111	7.7	6.7	7.2	7.1	7.0	7.1	8.5	7.6	8.1	7.3	6.7	7.0	4.8
880119	7.7	8.3	8.0	7.8	7.8	7.8	7.5	8.0	7.8	8.8	8.2	8.5	2.8
880202[4]	3.2	3.4	3.3	3.2	3.2	3.2	3.4	3.0	3.2	2.8	2.9	2.8	2.5
880301[2]	1.6	1.6	1.6	2.7	2.7	2.7	2.4	2.4	2.4	2.2	2.4	2.3	2.5
880308[2]	2.3	2.2	2.2	0.9	0.9	0.9	0	0	0	0	0	0	0.9
880315	0.2	0.3	0.2	0	0	0	0	0	0	0	0	0	0.2
880322[2]	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0
880329[2]	0.4	0.3	0.4	0	0	0	0	0	0	0	0	0	0.4
880405[2]	0.7	0.7	0.7	0.7	0.7	0.7	0	0	0	0	0	0	0.7
880419[2]	5.2	5.1	5.1	4.4	4.4	4.4	2.5	2.8	2.7	2.3	2.1	2.2	4.1
880426	5.1	5.1	5.1	5.7	5.8	5.7	2.8	2.8	2.8	0	0	0	4.7
Mean Totals			76.8 52.5[6]			--- 56.1			65.1[5] 47.7			58.7[5] 45.3	58.0 40.5

---

[1] Aerochem Metrics sampler was not replicated.

[2] Rainfall during period.

[3] Belfort gauges froze and were inoperable. Value listed is mean SWE from the two PVC collectors.

[4] No precipitation recorded for the weeks ending 26 January and 9, 16 and 23 February, 1988.

[5] Underestimated due to rain.

[6] LPE tubes in operation between 16 December 1987 and 26 April 1988. Second line lists precipitation for this period.

Analysis of variance of the 1987-1988 weekly results showed no significant differences in SWE between the Belforts and tubes at CSSL. All other combinations of Belfort, tube, and boards had significantly different weekly volumes ($p<0.001$). Analysis of the replicates showed that the 95% confidence intervals around the mean weekly differences for the Belforts, tubes, and weekly and 24-h boards averaged ±0.3 cm and ranged from ±0.2 cm to ±0.7 cm.

The limited data set available from Mammoth Mountain for the 1987-1988 winter showed nearly equal precipitation totals for the Belfort gauges and the LPE tubes (Table 4.6 and Figure 4.6B), and there was no significant statistical difference between the two methods ($p<0.001$). Cumulative precipitation between weeks ending 10 December 1987 and 23 April 1988 was 67.9 cm (mean of the two LPE tubes) as compared to 69.2 cm from the single Belfort gauge.

Table 4.6. Precipitation depths (cm) between weeks ending 10 December 1987 and 23 April 1988 at Mammoth Mountain.

Interval Ending	Belfort	LPE Tubes 1	LPE Tubes 2	LPE Tubes Mean	Cumulative Belfort	Cumulative LPE Tubes
871210[1]	14.5	14.5	---	14.5	14.5	14.5
871217	3.1	3.2	3.2	3.2	17.6	17.7
871225	7.3	4.3	4.1	4.2	24.9	21.9
871231	5.9	5.9	---	5.9	30.8	27.8
880106	12.2	12.3	---	12.3	43.0	40.1
880120	9.1	8.8	9.1	8.9	52.1	49.0
880131	0.9	1.2	1.1	1.1	53.0	50.1
880303	4.8	5.8	5.4	5.6	57.8	55.7
880405	0.3	0.5	0.5	0.5	58.1	56.2
880416	3.5	3.6	3.7	3.6	61.6	59.8
880423	7.6	8.6	7.7	8.1	69.2	67.9

[1] The LPE tubes were not in place before December 10. Volume estimates prior to December 10 are based on the shielded Belfort data, and are included to allow comparison of seasonal totals between the gauging systems.

[2] No precipitation recorded for the weeks ending 14 and 27 January, 6, 13, 20, and 27 February, 10, 17, 23, and 30 March, 1988.

At CSSL, the Belfort gauges and the tubes caught 35% more precipitation than did the Aerochem Metrics sampler in 1986-1987 and 40% more in 1987-1988 (Tables 4.3 and 4.5) during the interval when all devices were in service. The undermeasurement by the Aerochem Metrics sampler appeared most pronounced--with the exception of measurements made for weeks ending 17 February 1987 and 8 December 1987--when precipitation was great or had a large fraction of rain as in the December 1987 storm (Figures 4.4 and 4.5A). A windscreen cannot be fitted to this sampler, and the screen's absence may account for part of this difference. An Aerochem Metrics was used for several years at the windy Mammoth Mountain site with little success (Dawson 1986). At CSSL, considerable maintenance was required to free the collector's movable arm when it froze in place and to empty the shallow (40 cm) bucket during large snow deposition events. During large storms at CSSL, the presence of an on-site technician allowed replacement of the bucket as often as needed. In an average winter at both Mammoth Mountain and CSSL, weekly Aerochem Metrics bucket changes might seriously underestimate SWE between three and six times during the winter.

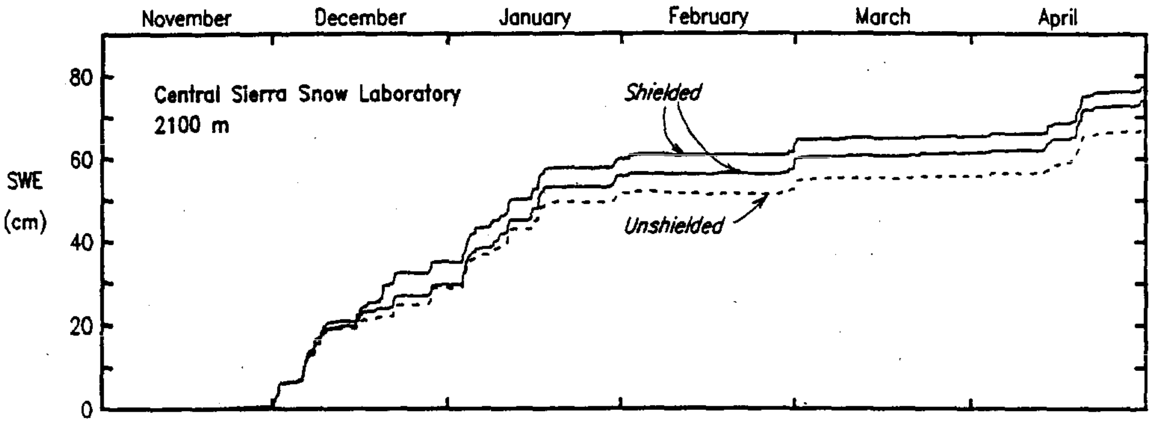

Figure 4.4. Cumulative precipitation for the 1987-1988 winter as measured by shielded and unshielded Belfort high-capacity gauges at the Central Sierra Snow Laboratory.

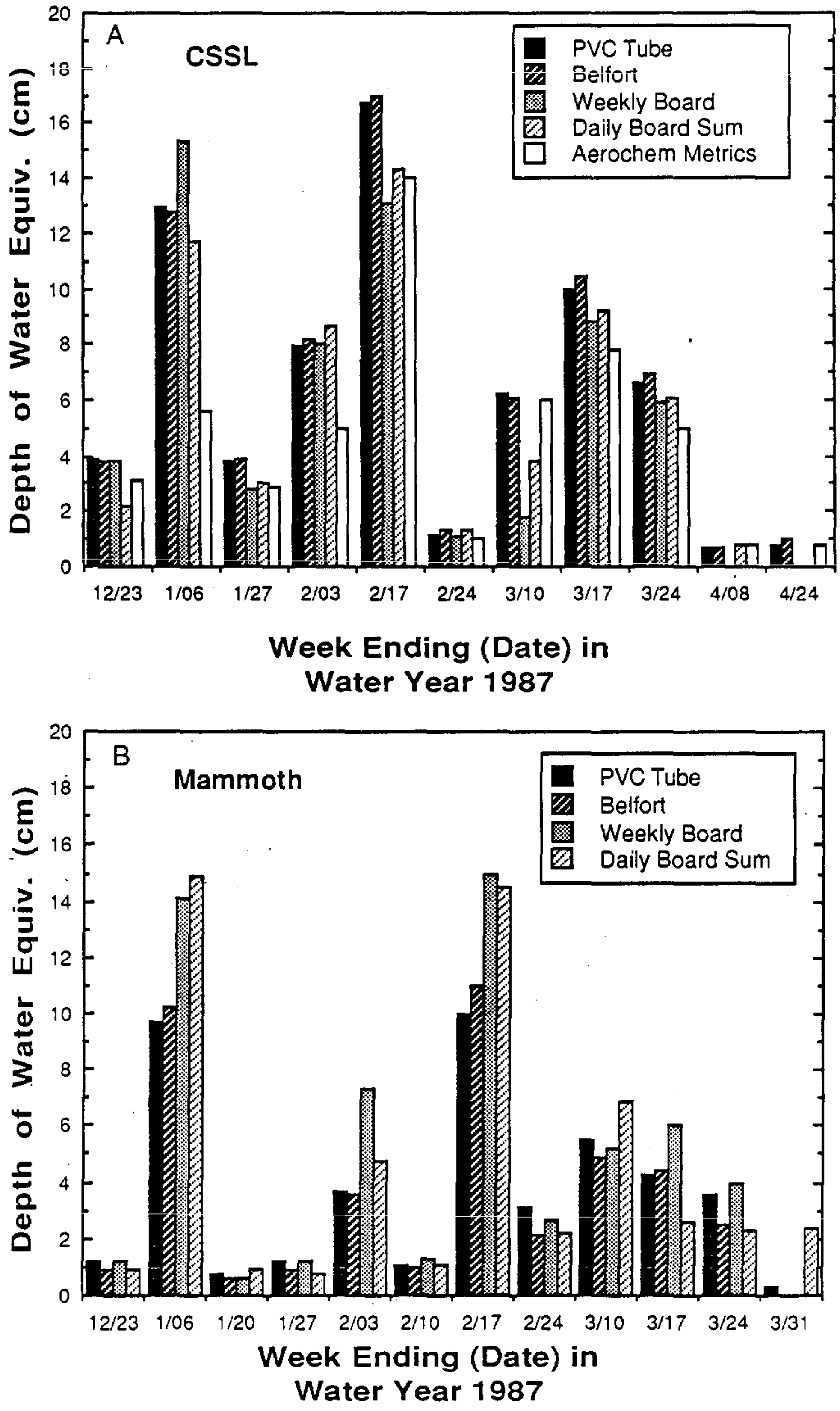

Figure 4.5. Mean weekly precipitation (≥ 0.5 cm water equivalent) measured by several methods during the 1986-1987 winter at the Central Sierra Snow Laboratory (A) and Mammoth Mountain (B).

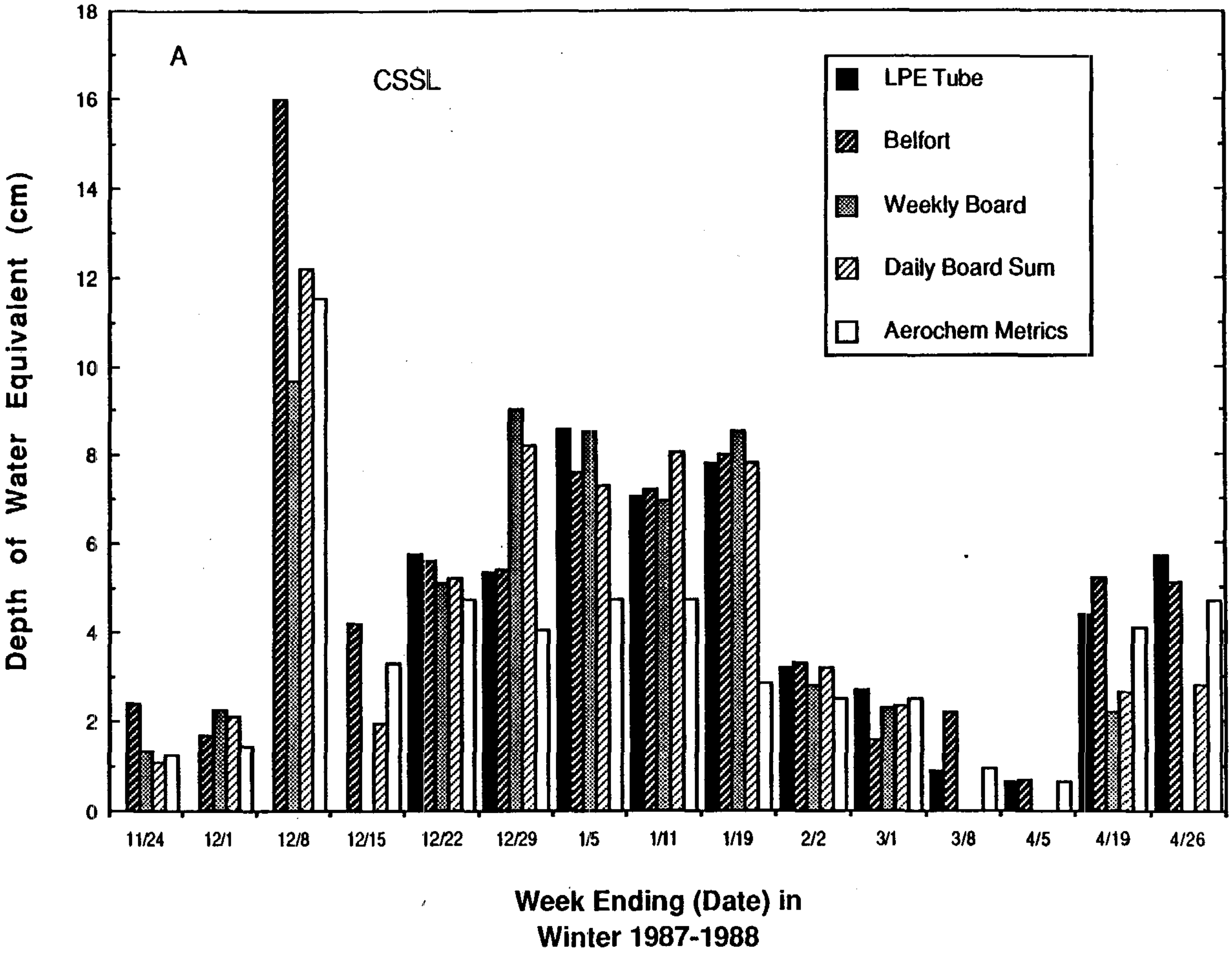

Figure 4.6. Mean weekly precipitation (>0.5 cm water equivalent) measured by several methods during the 1987-1988 winter at the Central Sierra Snow Laboratory (A) and Mammoth Mtn. (B).

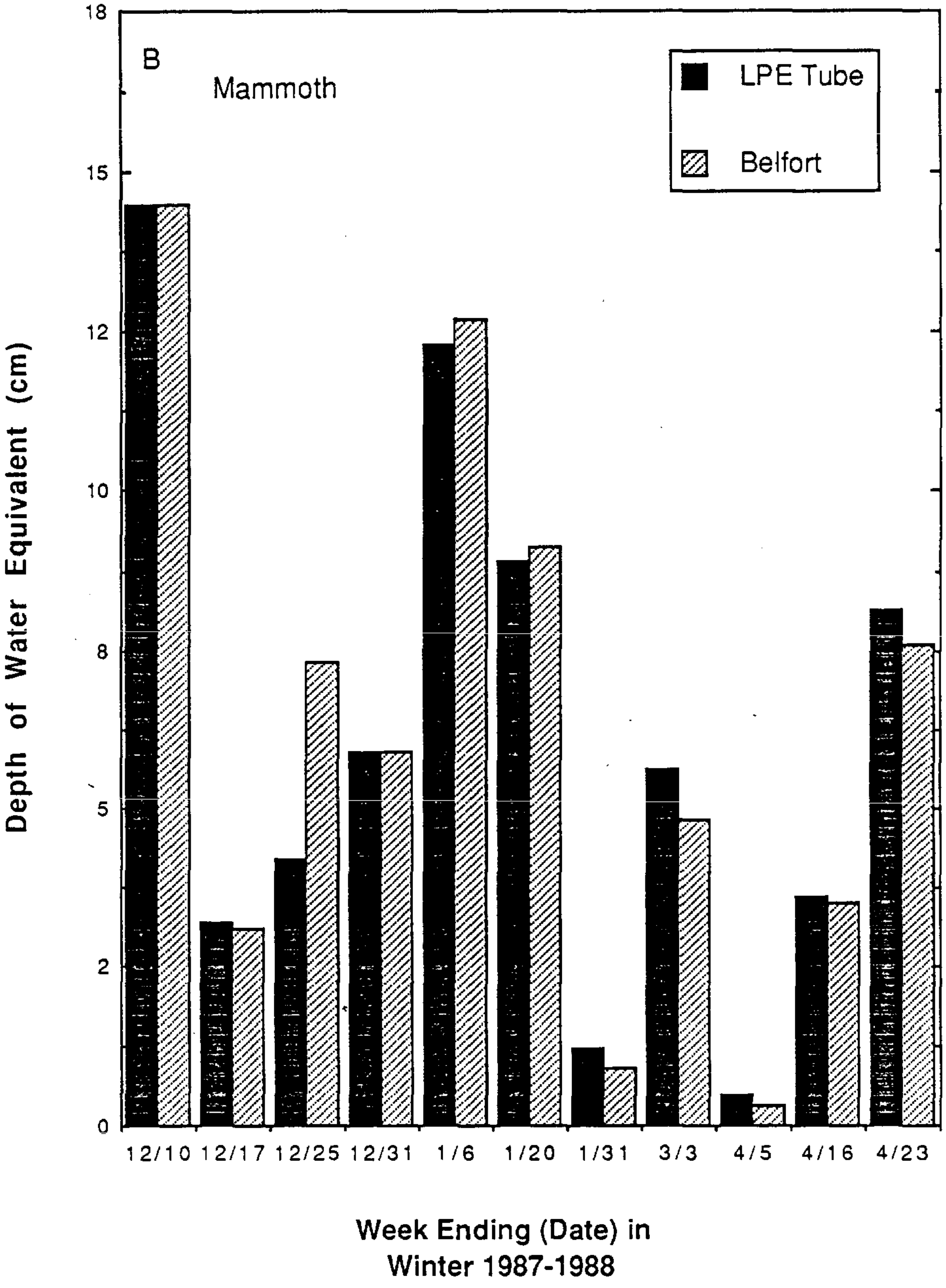

Figure 4.6. (continued)

Other observations on the comparative behavior of the techniques are:

1) the weekly boards are inadequate at the end of the season; they retain little or no SWE because snow melts off the board (Figure 4.5A, week ending 4/24/87).
2) Snow falling on the weekly board at the beginning of a 7-day sampling interval may melt prior to measurement (Figure 4.6A, week ending 12/15/87).
3) Typically the LPE or PVC collectors and the Belfort gauges caught effectively equal amounts of precipitation, and in 18 weeks out of 33 over the two years of observations at CSSL either of these devices caught more precipitation than any other device or technique.
4) Both the PVC and LPE experimental collectors captured precipitation at rates equal to that of the high-capacity Belfort gauge. In cold weather conditions, the LPE tube is preferred since it does not readily shatter.

4.3. Precipitation Chemistry

Primary aims of this study were to compare the chemistry of samples collected in the field by a variety of techniques and to develop and document procedures for snow-sample collection, storage, transportation and laboratory analysis. Table 4.7 lists all the chemical analyses of precipitation and the snowpack from CSSL, Mammoth Mountain, and the survey sites for the 1986-1987 snow season. The data are grouped by site, collector and date, and include depth intervals sampled and associated SWE. Table 4.7B lists the subset of samples for which organic anions (formate and acetate) were analyzed. Concentrations of these anions range from undetectable to several ueq L^{-1}.

The 1986-1987 field precipitation monitoring methods are compared first, followed by assessment of the field sample integrity tests, the laboratory procedures, and chemical charge balances.

4.3.1. Methods Comparison--Combination of the SWE's and chemical analyses for each collection method permitted calculation of volume-weighted mean concentrations and areal loadings (Table 4.8). Storms that deposited less than 1.5 cm of SWE had higher concentrations of solutes than storms that deposited at least 1.5 cm of SWE (Tables 4.9 and 4.10). This disparity was greater at CSSL than at Mammoth Mountain.

For the PVC tubes and the weekly boards, analysis of variance for H^+, SO_4^{2-}, and NO_3^- concentrations identified statistically significant differences ($p<0.05$) in volume-weighted concentration at both sites for each constituent except for NO_3^- at CSSL. For many weekly comparisons, solute concentrations of samples from the tubes were appreciably larger than concurrently collected samples from the weekly and daily boards (Figures 4.7 and 4.8). This trend was more pronounced for CSSL than Mammoth Mountain.

Table 4.7A. Chemical concentrations (ueq L^{-1}) and charge balances of all samples.

The sample codes in the table are as follows: CBD--Event Snow Board, CSSL; CBW--Weekly Snow Board, CSSL; CP--Weekly Snow Pit, CSSL; CT--PVC Tube, CSSL; MBD--Event Snow Board, Mammoth; MBW--Weekly Snow Board, Mammoth; MPW--Weekly Snow Pit, Mammoth; MTW--PVC Tube, Mammoth; APS--Survey Pit, Alpine Meadows; CPS--Survey Pit, CSSL; HPS--Survey Pit, Heavenly Valley; DPS--Survey Pit, Mt. Dyer; BPS--Survey Pit, Eastern Brook Lake; MPS--Survey Pit, Mammoth; KPS--Survey Pit, Kirkwood; SPS--Survey Pit, Snow Summit; LPS--Survey Pit, Lower Big Draw; LBD--Survey Pit, Lower Big Draw, unknown date.

u = below limit of detection

Date/Profile	Sample	Zt	Zb	SWE	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}	Σ+	Σ−	(Σ+) − (Σ−)	Σ+/Σ−
861223a	CBD003	19	0	2.3	8.3	0.8	4.7	1.2	4.5	1.8	4.7	3.5	4.5	21.3	12.7	8.6	1.7
861223b	CBD004	18	0	2.1	8.7	0.3	3.0	1.8	4.5	u	4.2	3.1	3.7	18.3	11.0	7.3	1.7
861231a	CBD005	4	0	0.4	12.0	1.3	5.3	1.5	9.7	0.8	7.4	7.2	6.8	30.6	21.4	9.2	1.4
861231b	CBD006	4	0	0.4	12.0	2.2	3.4	1.3	10.0	1.1	8.0	6.5	8.0	30.0	22.5	7.5	1.3
870101a	CBD007	14	0	0.8	6.7	0.6	2.5	0.4	2.8	0.3	2.0	3.0	4.4	13.3	9.4	3.9	1.4
870101b	CBD008	15	0	0.9	5.8	0.8	3.0	1.5	3.3	u	2.6	2.7	4.3	14.4	9.6	4.8	1.5
870102a	CBD009	15	0	2.4	3.6	0.4	2.5	1.2	5.1	u	2.4	1.2	1.6	12.8	5.2	7.6	2.5
870102b	CBD010	16	0	2.6	3.4	0.4	1.4	0.7	2.8	u	3.3	1.5	1.7	8.7	6.5	2.2	1.3
870103a	CBD011	20	0	2.4	12.0	2.7	3.0	1.1	3.4	u	2.9	9.7	4.4	22.2	17.0	5.2	1.3
870103b	CBD012	23	0	2.5	12.0	2.8	2.5	0.4	2.7	0.6	7.6	9.9	4.5	21.0	22.0	-1.0	1.0
870104a	CBD013	48	24	2.6	3.4	u	2.0	0.5	1.2	u	1.8	6.3	0.2	7.1	8.3	-1.2	0.9
870104a	CBD014	24	0	2.6	3.1	u	2.5	0.4	1.1	u	0.7	4.0	0.4	7.1	5.1	2.0	1.4
870104b	CBD015	47	24	2.5	2.9	0.3	3.0	u	1.0	u	1.3	4.0	0.1	7.2	5.4	1.8	1.3
870104b	CBD016	24	0	2.6	2.0	0.5	2.2	1.1	2.6	u	1.5	7.0	0.4	8.4	8.9	-0.5	0.9
870106a	CBD017	5	0	0.4	17.0	6.4	5.9	3.6	9.0	0.8	6.1	16.	9.5	42.7	31.6	11.1	1.4
870106b	CBD018	5	0	0.3	18.0	6.4	2.8	2.0	8.6	0.5	7.0	14.	8.5	38.3	29.5	8.8	1.3
870123a	CBD019	3	0	0.5	8.9	2.6	2.5	0.5	8.0	0.7	10.9	7.2	6.0	23.2	24.1	-0.9	1.0
870123b	CBD020	4	0	0.5	7.8	3.1	1.9	0.6	7.9	0.7	9.9	8.0	5.8	22.0	23.7	-1.7	0.9
870124a	CBD021	25	0	1.7	2.6	u	1.3	u	2.2	u	1.5	0.5	0.8	6.1	2.8	3.3	2.2
870124b	CBD022	26	0	1.8	2.4	u	1.9	0.1	2.9	0.7	2.8	0.9	1.0	8.0	4.7	3.3	1.7
870125a	CBD023	6	0	0.8	3.8	u	2.5	0.5	5.8	0.8	7.2	1.9	2.4	13.4	11.5	1.9	1.2
870125b	CBD024	5	0	0.7	3.2	1.3	1.9	0.3	2.9	u	3.1	0.6	1.2	9.6	4.9	4.7	2.0
870128a	CBD025	63	30	3.3	7.1	2.3	1.3	0.4	3.7	u	2.7	6.2	3.3	14.8	12.2	2.6	1.2
870128a	CBD026	30	0	3.0	7.6	1.6	2.5	0.3	1.9	0.7	2.1	6.0	3.7	14.6	11.8	2.8	1.2
870128b	CBD027	50	25	3.0	4.5	1.6	1.9	0.4	2.1	0.6	2.8	2.4	1.2	11.1	6.4	4.7	1.7
870128b	CBD028	25	0	2.7	7.1	2.3	1.3	0.4	3.7	u	2.7	6.2	3.3	14.8	12.2	2.6	1.2
870203a	CBD029	24	0	2.6	4.3	1.1	1.3	0.6	2.5	0.6	2.7	1.3	1.5	10.4	5.5	4.9	1.9
870203b	CBD030	24	0	2.6	3.7	1.1	3.7	0.7	5.0	0.9	2.8	1.5	1.7	15.1	6.0	9.1	2.5
870211a	CBD031	9	0	1.3	4.9	1.1	1.9	0.1	1.3	0.7	0.9	2.2	0.6	10.0	3.7	6.3	2.7
870211b	CBD032	9	0	1.3	4.3	1.7	1.9	u	1.5	u	0.7	2.4	0.6	9.4	3.7	5.7	2.5
870213a	CBD033	32	0	6.7	3.7	0.3	1.0	0.1	0.9	u	0.6	0.6	0.5	6.0	1.7	4.3	3.5
870213b	CBD034	31	0	7.8	2.3	0.3	1.3	u	1.2	u	0.5	0.2	0.4	5.1	1.1	4.0	4.6
870214a	CBD035	5	0	0.8	6.8	4.3	3.1	7.2	29.5	0.9	50.1	3.0	9.2	51.8	62.3	-10.5	0.8
870214b	CBD036	8	0	1.4	8.3	3.9	2.5	7.9	31.2	1.0	60.1	3.5	10.2	54.8	73.8	-19.0	0.7
870215a	CBD037	33	0	3.3	3.8	0.9	1.3	0.6	3.7	0.7	2.9	0.5	1.1	11.0	4.5	6.5	2.4
870215b	CBD038	37	0	3.7	2.8	1.5	1.3	0.1	2.4	0.6	2.5	0.7	0.9	8.7	4.1	4.6	2.1
870217a	CBD039	6	0	1.1	5.0	3.2	3.1	1.0	12.4	0.8	20.3	2.5	2.0	25.5	24.8	0.7	1.0
870217b	CBD040	6	0	1.1	5.6	3.9	5.0	2.0	15.5	0.8	18.4	2.5	3.2	32.8	24.1	8.7	1.4
870223a	CBD041	9	0	0.7	28.8	21.5	4.4	2.0	12.1	1.9	13.0	34.0	16.0	70.7	63.0	7.7	1.1
870223b	CBD042	10	0	0.8	26.9	20.4	4.4	1.7	13.6	1.3	16.5	38.7	15.9	68.3	71.1	-2.8	1.0
870224a	CBD043	7	0	0.6	5.0	3.1	3.1	0.8	19.2	0.7	28.5	4.2	5.3	31.9	38.0	-6.1	0.8
870224b	CBD044	7	0	0.6	5.0	3.1	2.5	0.4	19.9	0.7	28.0	3.5	4.0	31.6	35.5	-3.9	0.9
870225a	CBD045	4	0	0.3	7.1	4.1	3.1	0.5	32.4	0.7	53.5	7.6	4.8	47.9	65.9	-18.0	0.7
870225b	CBD046	4	0	0.3	9.1	4.1	1.9	0.9	37.5	1.0	56.9	7.3	5.1	54.5	69.3	-14.8	0.8
870305a	CBD047	4	0	1.3	5.1	4.0	2.5	0.6	2.2	0.6	1.4	6.2	5.3	15.0	12.9	2.1	1.2
870305b	CBD048	4	0	1.4	6.6	3.7	1.3	0.5	5.1	0.8	4.5	5.9	5.1	18.0	15.5	2.5	1.2
870306a	CBD049	5	0	1.4	4.1	0.6	1.3	0.1	1.3	0.9	u	1.9	0.5	8.3	2.4	5.9	3.5
870306b	CBD050	4	0	1.4	3.7	0.3	u	0.2	0.8	u	u	1.8	0.3	5.0	2.1	2.9	2.4
870309a	CBD051	5	0	1.1	6.0	1.7	0.7	0.3	2.4	0.5	2.2	2.6	1.7	11.6	6.5	5.1	1.8
870309b	CBD052	5	0	1.1	6.5	2.9	1.9	0.2	3.8	0.6	2.6	3.2	2.4	15.9	8.2	7.7	1.9
870311a	CBD053	7	0	1.1	4.8	11.2	1.3	0.7	5.1	0.5	3.5	9.7	5.3	23.6	18.5	5.1	1.3
870311b	CBD054	6	0	1.0	7.2	11.3	1.3	0.5	4.2	0.5	4.1	9.9	5.3	25.0	19.3	5.7	1.3
870313a	CBD055	37	0	5.1	3.5	1.1	u	0.2	2.0	1.0	2.1	1.6	1.0	7.8	4.7	3.1	1.7
870313b	CBD056	39	0	5.4	3.5	1.1	0.7	0.1	1.0	u	1.2	1.4	1.0	6.4	3.6	2.8	1.8

Table 4.7A. (continued)

u = below limit of detection

Date/Profile	Sample	Zt	Zb	SWE	H$^+$	NH$_4^+$	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	Cl$^-$	NO$_3^-$	SO$_4^{2-}$	Σ+	Σ−	(Σ+) − (Σ−)	Σ+/Σ−
870314a	CBD057	13	0	1.0	7.8	1.2	0.7	0.5	2.7	0.8	3.0	5.9	2.2	13.7	11.1	2.6	1.2
870314b	CBD058	15	0	1.2	8.5	1.6	2.2	0.5	2.9	0.4	2.8	6.0	2.2	16.1	11.0	5.1	1.5
870315a	CBD059	17	0	1.7	4.6	2.3	1.9	0.8	4.9	0.8	7.3	3.2	4.3	15.3	14.8	0.5	1.0
870315b	CBD060	18	0	1.8	5.4	2.4	3.1	0.9	4.8	u	6.0	3.1	4.2	16.6	13.3	3.3	1.2
870318a	CBD061	12	0	1.9	7.1	9.1	1.9	1.1	4.2	0.8	4.0	7.8	8.5	24.2	20.3	3.9	1.2
870318b	CBD062	18	0	2.8	7.9	10.2	0.7	0.9	3.7	0.9	5.7	9.0	9.1	24.3	23.8	0.5	1.0
870319a	CBD063	16	0	2.1	5.3	4.9	0.7	1.0	5.0	0.7	7.9	4.0	3.7	17.6	15.6	2.0	1.1
870319b	CBD064	16	0	2.1	5.8	5.0	0.7	1.1	6.0	0.6	9.0	4.1	4.0	19.2	17.1	2.1	1.1
870322a	CBD065	6	0	0.4	7.9	3.2	1.3	0.6	10.9	1.6	12.5	6.0	3.0	25.5	21.5	4.0	1.2
870322b	CBD066	7	0	0.5	8.1	2.8	1.9	0.5	9.6	1.0	13.3	6.2	3.4	23.9	22.9	1.0	1.0
870323a	CBD067	16	0	1.1	4.5	1.0	u	0.3	3.9	1.5	5.7	2.5	0.9	11.2	9.1	2.1	1.2
870323b	CBD068	17	0	1.3	4.9	1.1	0.7	0.2	3.0	0.5	3.6	1.8	0.6	10.4	6.0	4.4	1.7
870403a	CBD069	7	0	0.8	8.3	11.9	4.6	1.0	17.0	0.9	18.7	14.6	8.7	43.7	42.0	1.7	1.0
870403b	CBD070	7	0	0.7	8.9	11.6	5.0	1.2	20.0	1.2	24.9	14.8	10.0	47.9	49.7	-1.8	1.0
861223a	CBW001	27	0	3.8	15.0	3.1	4.7	1.2	8.7	1.1	5.0	6.1	8.5	33.8	19.6	14.2	1.7
861223b	CBW002	26	0	3.8	12.0	4.1	3.0	1.2	3.9	0.6	3.6	5.5	7.4	24.8	16.5	8.3	1.5
861231a	CBW003	5	0	0.6	12.0	1.5	5.7	1.3	13.	0.6	9.0	7.4	7.5	34.1	23.9	10.2	1.4
861231b	CBW004	5	0	0.7	13.0	1.5	4.6	1.5	17.	1.1	19.	8.0	7.5	38.7	34.5	4.2	1.1
870106a	CBW005	78	49	4.6	4.2	0.5	3.0	u	1.3	u	2.0	2.1	1.2	9.0	5.3	3.7	1.7
870106a	CBW006	49	25	4.7	6.3	1.3	2.8	1.1	2.2	0.5	1.6	5.7	2.3	14.2	9.6	4.6	1.5
870106a	CBW007	25	0	5.8	4.9	0.5	2.5	0.8	2.4	0.5	1.2	3.2	3.1	11.6	7.5	4.1	1.5
870106b	CBW008	79	49	5.3	4.2	0.6	2.0	0.7	1.5	u	0.5	1.9	0.9	9.0	3.3	5.7	2.7
870106b	CBW009	49	25	4.3	7.9	1.4	2.8	1.0	1.6	u	1.3	4.9	1.8	14.7	8.0	6.7	1.8
870106b	CBW010	25	0	6.0	7.1	0.7	3.6	0.4	3.0	u	3.1	4.0	3.3	14.8	10.4	4.4	1.4
870127a	CBW011	18	0	2.5	3.2	1.0	2.5	0.1	2.5	u	3.1	1.2	1.4	9.3	5.7	3.6	1.6
870127b	CBW012	16	0	3.0	3.0	1.0	3.7	0.3	3.1	0.7	3.6	1.2	1.5	11.8	6.3	5.5	1.9
870203a	CBW013	47	20	3.6	4.1	1.0	2.5	0.4	3.3	0.8	3.5	1.4	1.6	12.1	6.5	5.6	1.9
870203a	CBW014	20	0	4.1	7.2	1.7	1.3	0.2	1.7	u	0.8	5.2	2.6	12.1	8.6	3.5	1.4
870203b	CBW015	48	20	3.8	3.5	1.0	3.1	0.1	2.1	u	2.8	1.3	1.3	9.8	5.4	4.4	1.8
870203b	CBW016	20	0	4.5	9.6	2.1	1.3	0.6	2.5	0.6	2.9	5.8	3.3	16.7	12.0	4.7	1.4
870217a	CBW017	59	30	5.1	5.1	1.0	1.9	1.0	6.0	0.6	11.7	1.4	2.1	15.6	15.2	0.4	1.0
870217a	CBW018	30	0	6.9	5.4	u	1.9	0.7	2.9	0.6	0.4	0.6	0.5	11.5	1.5	10.0	7.7
870217b	CBW019	63	30	5.8	3.7	1.9	1.3	1.3	7.7	u	13.5	1.0	1.7	15.9	16.2	-0.3	1.0
870217b	CBW020	30	0	8.3	3.7	0.7	2.5	u	1.2	u	1.4	0.5	0.6	8.1	2.5	5.6	3.2
870224a	CBW021	11	0	1.1	18.6	15.0	2.5	1.3	12.1	0.7	14.0	26.0	11.5	50.2	51.5	-1.3	1.0
870224b	CBW022	10	0	1.0	19.9	11.0	4.4	1.5	13.7	0.7	15.8	24.2	11.0	51.2	51.0	0.2	1.0
870310a	CBW023	5	0	1.7	5.0	1.6	0.7	0.3	2.0	0.6	1.5	2.3	1.6	10.2	5.4	4.8	1.9
870310b	CBW024	5	0	1.8	5.0	1.5	0.7	0.1	1.7	u	3.1	1.3	1.6	9.0	6.0	3.0	1.5
870317a	CBW025	42	20	4.3	6.2	1.8	1.9	1.2	5.9	0.6	5.5	4.0	3.6	17.6	13.1	4.5	1.3
870317a	CBW026	20	0	4.5	3.7	1.0	0.7	0.1	1.0	u	0.4	1.3	0.9	6.5	2.6	3.9	2.5
870317b	CBW027	40	20	4.3	5.0	1.9	3.7	1.5	4.5	0.5	3.9	3.4	2.8	17.1	10.1	7.0	1.7
870317b	CBW028	20	0	4.5	4.1	1.0	u	0.2	1.2	u	0.6	1.3	0.9	6.5	2.8	3.7	2.3
870324a	CBW029	32	0	5.8	7.6	4.2	1.3	0.8	6.0	0.8	7.1	4.7	3.9	20.7	15.7	5.0	1.3
870324b	CBW030	31	0	5.9	6.5	4.6	u	0.5	5.4	u	10.7	4.8	4.1	17.0	19.6	-2.6	0.9
870113a	CP0001	93	73	3.6	4.3	0.7	3.0	1.1	3.8	u	2.5	2.4	1.2	12.9	6.1	6.8	2.1
870113a	CP0002	73	45	6.7	8.9	0.9	5.7	0.5	2.5	0.8	1.4	6.0	2.7	19.3	10.1	9.2	1.9
870113a	CP0003	45	23	6.4	6.9	0.7	4.0	1.5	3.5	0.4	2.9	2.9	3.6	17.0	9.4	7.6	1.8
870113a	CP0004	23	0	6.3	9.1	7.5	5.9	2.2	6.5	1.6	4.8	13.5	8.6	32.8	26.9	5.9	1.2
870113b	CP0005	93	73	3.7	5.1	0.6	2.0	0.7	2.8	u	1.7	2.8	1.6	11.2	6.1	5.1	1.8
870113b	CP0006	73	45	6.7	8.9	1.5	3.0	0.8	2.5	u	1.0	5.9	2.7	16.7	9.6	7.1	1.7
870113b	CP0007	45	23	6.1	6.3	0.7	3.3	1.2	3.5	0.3	3.0	3.2	3.6	15.3	9.8	5.5	1.6
870113b	CP0008	23	0	7.3	12.0	7.8	5.7	2.3	7.9	1.6	6.0	14.5	9.1	37.3	29.6	7.7	1.3
870131a	CP0009	119	90	3.8	5.6	2.5	1.9	0.3	2.2	u	2.4	3.4	2.3	12.5	8.1	4.4	1.5
870131a	CP0010	90	60	6.5	6.2	1.5	2.5	0.2	3.2	u	3.5	3.2	2.2	13.6	8.9	4.7	1.5
870131a	CP0011	60	30	8.7	6.9	1.5	1.3	u	1.8	u	1.2	3.6	1.6	11.5	6.4	5.1	1.8
870131a	CP0012	30	0	9.1	11.7	5.3	3.1	1.8	3.7	0.8	4.1	10.0	7.3	26.4	21.4	5.0	1.2
870131b	CP0013	119	90	3.8	6.6	2.0	1.9	0.7	1.8	0.7	2.0	3.4	2.4	13.7	7.8	5.9	1.8
870131b	CP0014	90	60	6.5	5.0	1.8	1.3	0.1	3.5	0.7	4.1	3.4	2.7	12.4	10.2	2.2	1.2
870131b	CP0015	60	30	8.7	6.6	1.1	1.3	u	2.1	u	0.2	3.7	1.7	11.1	5.6	5.5	2.0
870131b	CP0016	30	0	9.1	11.0	4.9	2.5	1.0	3.4	0.8	4.4	10.1	7.2	23.6	21.7	1.9	1.1
870214a	CP0017	133	105	6.5	3.8	1.0	1.3	1.1	5.6	0.7	9.3	0.8	2.4	13.5	12.5	1.0	1.1
870214a	CP0018	105	70	11.3	4.2	1.1	1.3	u	1.5	0.6	0.9	2.1	1.2	8.7	4.2	4.5	2.1
870214a	CP0019	70	35	12.4	4.7	1.4	1.3	0.1	2.5	0.6	2.8	3.3	1.9	10.6	8.0	2.6	1.3

Table 4.7A. (continued

u = below limit of detection

Date/Profile	Sample	Zt	Zb	SWE	H$^+$	NH$_4^+$	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	Cl$^-$	NO$_3^-$	SO$_4^{2-}$	Σ+	Σ−	(Σ+) − (Σ−)	Σ+/Σ−
870214a	CP0020	35	0	14.8	6.0	3.5	3.1	0.7	2.5	0.8	3.5	5.2	3.6	16.6	12.3	4.3	1.3
870214b	CP0021	136	100	8.8	3.8	0.8	1.3	0.3	1.7	0.7	1.8	0.4	0.6	8.6	2.8	5.8	3.1
870214b	CP0022	100	70	10.6	4.5	2.0	1.9	0.3	1.8	0.7	2.1	2.4	1.5	11.2	6.0	5.2	1.9
870214b	CP0023	70	35	13.5	3.2	1.1	1.3	u	2.1	u	2.5	1.9	1.2	7.7	5.6	2.1	1.4
870214b	CP0024	35	0	14.0	4.5	1.7	1.9	0.2	2.6	1.0	2.9	4.1	3.5	11.9	10.5	1.4	1.1
870228a	CP0025	141	120	4.0	6.8	4.6	1.3	1.9	6.0	0.9	10.0	5.0	4.0	21.5	19.0	2.5	1.1
870228a	CP0026	120	90	9.7	3.1	1.0	1.3	0.4	2.1	0.9	1.4	0.5	0.4	8.8	2.3	6.5	3.8
870228a	CP0027	90	60	11.1	4.5	1.1	1.3	0.5	3.8	0.6	2.7	3.1	2.2	11.8	8.0	3.8	1.5
870228a	CP0028	60	30	10.9	6.5	1.1	1.3	u	2.2	0.6	2.0	3.7	2.0	11.7	7.7	4.0	1.5
870228a	CP0029	30	0	10.3	7.9	1.7	2.5	0.6	3.7	0.7	3.3	6.5	4.0	17.1	13.8	3.3	1.2
870228b	CP0030	141	120	4.1	7.1	4.2	1.9	0.6	6.6	0.6	9.8	6.2	3.9	21.0	19.9	1.1	1.1
870228b	CP0031	120	90	8.5	4.7	0.7	1.3	0.8	3.9	u	6.1	0.9	1.8	11.4	8.8	2.6	1.3
870228b	CP0032	90	60	10.5	4.9	1.8	1.9	0.3	2.7	0.6	1.7	2.0	1.3	12.2	5.0	7.2	2.4
870228b	CP0033	60	30	11.0	7.4	2.3	1.3	0.1	1.8	0.8	2.0	4.0	2.0	13.7	8.0	5.7	1.7
870228b	CP0034	30	0	10.6	7.8	3.7	3.1	0.5	3.6	0.7	4.1	4.2	6.0	19.4	14.3	5.1	1.4
870314c	CP0035	180	150	3.5	6.3	1.6	0.7	0.7	3.1	0.6	4.2	4.1	2.9	13.0	11.2	1.8	1.2
870314c	CP0036	150	120	6.5	3.3	1.7	1.3	0.3	1.0	u	0.5	1.6	1.0	7.6	3.1	4.5	2.5
870314c	CP0037	120	80	14.5	4.1	1.2	u	0.5	3.5	0.5	4.9	1.6	1.8	9.8	8.3	1.5	1.2
870314c	CP0038	80	40	15.8	3.9	1.2	0.7	0.3	2.1	u	1.8	2.0	1.3	8.2	5.1	3.1	1.6
870314c	CP0039	40	0	16.4	5.1	1.1	0.7	0.3	1.8	u	1.6	1.9	2.0	9.0	5.5	3.5	1.6
870411a	CP0040	110	70	16.0	4.5	1.5	1.3	0.4	1.7	1.5	3.1	1.8	1.3	10.9	6.2	4.7	1.8
870411a	CP0041	70	30	16.1	3.4	1.0	u	0.2	1.6	0.6	0.9	1.6	1.0	6.8	3.5	3.3	1.9
870411a	CP0042	30	0	13.9	2.8	1.8	1.9	0.2	2.3	u	1.9	3.0	2.6	9.0	7.5	1.5	1.2
870411b	CP0043	114	74	17.7	2.9	0.8	u	0.2	2.5	1.2	2.7	0.8	0.5	7.6	4.0	3.6	1.9
870411b	CP0044	74	34	16.6	3.6	0.6	0.7	0.5	3.2	0.5	6.1	1.2	0.7	9.1	8.0	1.1	1.1
870411b	CP0045	34	0	15.9	2.0	1.0	3.1	0.7	2.8	0.9	1.8	1.7	1.3	10.5	4.8	5.7	2.2
870424a	CP0046	66	36	10.9	3.4	1.0	1.9	0.3	1.5	1.0	1.2	1.7	1.0	9.1	3.9	5.2	2.3
870424a	CP0047	36	0	16.6	1.8	0.9	0.7	0.4	3.0	0.9	1.4	1.4	1.2	7.7	4.0	3.7	1.9
870424b	CP0048	62	32	12.0	3.1	0.7	1.9	0.6	1.5	0.9	0.9	1.5	0.9	8.7	3.3	5.4	2.6
870424b	CP0049	32	0	15.1	3.5	0.9	u	0.2	1.8	u	4.3	0.8	1.3	6.4	6.4	0.0	1.0
861223a	CT0001	2770	(ml)	3.9	13.0	4.3	9.6	1.3	4.9	0.6	4.8	7.4	11.	33.7	23.2	10.5	1.5
861223b	CT0002	2720	(ml)	3.8	13.0	4.0	8.3	1.1	5.0	0.6	6.7	6.1	12.	32.0	24.8	7.2	1.3
870106a	CT0005	9165	(ml)	12.8	6.5	0.4	5.1	u	3.3	u	2.2	3.9	3.7	15.3	9.8	5.5	1.6
870106b	CT0006	9257	(ml)	12.9	6.0	0.9	5.3	1.9	4.7	0.3	4.9	4.0	2.9	19.1	11.8	7.3	1.6
870113a	CT0007	130	(ml)	0.2	7.2	3.3	40.0	10.	78.	3.6	100.0	22.	30.	142.1	152.0	-9.9	0.9
870113b	CT0008	137	(ml)	0.2	5.4	4.2	40.	10.	79.	3.8	103.	21.5	30.0	142.4	154.5	-12.1	0.9
870127a	CT0011	2690	(ml)	3.8	5.8	u	4.4	0.6	5.0	0.6	6.5	1.5	3.1	16.4	11.1	5.3	1.5
870127b	CT0012	2728	(ml)	3.8	3.2	0.5	3.7	0.5	3.9	u	4.4	2.1	3.1	11.8	9.6	2.2	1.2
870203a	CT0013	5740	(ml)	8.0	7.2	1.5	2.5	0.3	2.9	0.6	3.7	4.0	3.5	15.0	11.2	3.8	1.3
870203b	CT0014	5560	(ml)	7.8	6.3	2.1	4.4	0.7	3.1	0.7	5.1	4.1	3.5	17.3	12.7	4.6	1.4
870210a	CT0015	250	(ml)	0.3	7.1	17.	48.9	4.4	56.	3.1	101.	26.5	37.	136.5	164.5	-28.0	0.8
870210b	CT0016	272	(ml)	0.4	7.6	22.4	60.0	7.8	60.0	3.0	100.0	34.0	71.7	160.8	205.7	-44.9	0.8
870217a	CT0017	12752	(ml)	17.8	5.6	1.1	1.9	0.8	4.2	0.6	5.6	1.7	2.2	14.2	9.5	4.7	1.5
870217b	CT0018	11199	(ml)	15.6	4.4	1.3	3.1	0.7	3.8	u	4.9	1.7	2.1	13.3	8.7	4.6	1.5
870224a	CT0019	845	(ml)	1.2	19.5	16.0	12.4	2.3	23.6	1.0	30.3	29.3	16.	74.8	75.6	-0.8	1.0
870224b	CT0020	860	(ml)	1.2	24.0	16.9	11.2	2.3	26.6	1.3	42.7	18.0	17.0	82.3	77.7	4.6	1.1
870303a	CT0021	137	(ml)	0.2	16.6	17.7	19.2	5.9	177.0	7.3	100.0	33.2	20.9	243.7	154.1	89.6	1.6
870303b	CT0022	100	(ml)	0.1	14.8	11.1	16.0	5.1	184.0	4.0	81.0	24.1	18.1	235.0	123.2	111.8	1.9
870310a	CT0023	4365	(ml)	6.1	6.8	3.4	3.7	0.5	1.8	0.6	1.8	6.4	5.6	16.8	13.8	3.0	1.2
870310b	CT0024	4428	(ml)	6.2	5.5	3.5	4.4	0.4	1.7	0.9	3.1	6.5	5.1	16.4	14.7	1.7	1.1
870317a	CT0025	6940	(ml)	9.7	8.7	2.8	3.1	0.7	3.5	2.0	4.7	3.9	3.2	20.8	11.8	9.0	1.8
870317b	CT0026	7370	(ml)	10.3	6.5	3.0	1.9	1.2	3.8	3.6	3.6	3.8	2.8	20.0	10.2	9.8	2.0
870407a	CT0031	415	(ml)	0.6	10.2	13.6	12.4	2.0	13.2	2.3	18.4	21.7	15.7	53.7	55.8	-2.1	1.0
870407b	CT0032	470	(ml)	0.7	10.5	13.4	12.4	1.9	12.0	1.2	23.8	19.7	16.0	51.4	59.5	-8.1	0.9
870421a	CT0035	580	(ml)	0.8	7.4	12.5	11.1	3.9	12.2	3.9	7.0	14.0	13.0	51.0	34.0	17.0	1.5
870421b	CT0036	580	(ml)	0.8	6.6	6.6	9.9	2.8	13.1	3.2	7.3	13.5	13.4	42.2	34.2	8.0	1.2
870505a	CT0039	1540	(ml)	2.1	10.2	16.9	11.8	2.3	5.6	1.6	9.7	19.8	19.4	48.4	48.9	-0.5	1.0
870505b	CT0040	1680	(ml)	2.4	10.7	16.8	8.7	2.4	5.3	1.6	5.8	21.3	21.0	45.5	48.1	-2.6	0.9
861223a	MBD001	3	0	1.1	1.1	u	17.	2.1	3.2	3.3	2.6	7.0	13.	26.7	22.6	4.1	1.2
861223b	MBD002	5	0	0.7	3.2	1.8	25.	3.0	5.0	1.8	4.4	11.	15.	39.8	30.4	9.4	1.3
870116a	MBD003	6	0	1.0	5.6	2.0	2.9	1.0	6.6	0.6	3.0	6.7	3.9	18.7	13.6	5.1	1.4
870116b	MBD004	5	0	0.7	4.3	1.2	1.7	1.0	3.5	0.4	1.7	7.3	3.3	12.1	12.3	-0.2	1.0
870127c	MBD005	3	0	0.8	1.6	u	6.2	1.0	3.3	0.8	3.1	3.1	3.9	12.9	10.1	2.8	1.3

Table 4.7A. (continued)

u = below limit of detection

Date/Profile	Sample	Zt	Zb	SWE	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}	Σ+	Σ−	(Σ+) − (Σ−)	Σ+/Σ−
870128a	MBD006	25	0	4.0	4.1	7.3	6.0	1.0	2.6	1.1	2.1	11.8	7.2	22.1	21.1	1.0	1.0
870128b	MBD007	24	0	3.9	6.0	5.0	5.6	0.3	2.1	0.7	0.7	11.0	6.6	19.7	18.3	1.4	1.1
870203a	MBD008	6	0	0.6	0.9	0.6	6.0	0.8	2.1	0.9	1.4	7.5	0.9	11.3	9.8	1.5	1.2
870203b	MBD009	5	0	0.8	3.4	0.2	5.8	0.5	1.2	0.3	0.5	7.2	0.5	11.4	8.2	3.2	1.4
870210a	MBD011	11	0	1.1	6.2	6.3	5.8	0.5	1.6	0.6	1.2	5.2	8.4	21.0	14.8	6.2	1.4
870210b	MBD012	11	0	1.1	6.8	6.8	4.6	0.5	1.4	0.6	0.9	5.2	8.7	20.7	14.8	5.9	1.4
870211a	MBD013	7	0	0.8	2.4	4.1	1.3	0.2	2.1	0.9	1.0	6.4	3.7	11.0	11.1	-0.1	1.0
870211b	MBD014	7	0	0.9	2.6	3.7	3.7	0.5	2.0	0.6	0.8	6.0	3.4	13.1	10.2	2.9	1.3
870213a	MBD015	76	40	4.9	1.2	0.5	u	0.1	u	u	u	0.4	0.2	1.8	0.6	1.2	3.0
870213a	MBD016	40	0	7.0	1.2	2.0	1.0	0.3	u	0.6	u	1.0	0.3	5.1	1.3	3.8	3.9
870213b	MBD017	76	40	5.1	1.4	0.2	u	0.6	u	1.0	1.8	1.2	0.5	3.2	3.5	-0.3	0.9
870213b	MBD018	40	0	7.1	1.2	0.1	1.3	u	u	u	u	0.4	0.2	2.6	0.6	2.0	4.3
870215a	MBD019	13	0	1.6	2.4	0.9	1.9	0.1	u	u	1.0	1.1	2.2	5.3	4.3	1.0	1.2
870215b	MBD020	13	0	1.6	1.9	1.4	0.7	0.1	u	u	0.9	1.1	2.2	4.1	4.2	-0.1	1.0
870224a	MBD021	23	0	2.3	1.9	4.9	2.5	0.4	1.2	0.6	1.2	5.7	3.1	11.5	10.0	1.5	1.1
870224b	MBD022	22	0	2.1	3.5	5.4	u	0.5	0.8	u	0.8	5.0	2.6	10.2	8.4	1.8	1.2
870225a	MBD023	6	0	0.6	4.4	2.8	2.5	0.3	1.0	0.6	1.9	9.3	2.8	11.6	14.0	-2.4	0.8
870225b	MBD024	6	0	0.5	2.1	2.2	6.8	0.3	1.0	0.6	1.0	10.5	2.6	13.0	14.1	-1.1	0.9
870305a	MBD025	19	0	2.4	1.5	1.8	0.7	0.1	0.7	u	u	1.3	4.4	4.8	5.7	-0.9	0.8
870305b	MBD026	20	0	2.4	1.8	1.3	0.7	u	u	0.6	u	1.2	3.9	4.4	5.1	-0.7	0.9
870306a	MBD027	19	0	2.5	1.6	0.5	0.7	0.1	1.5	0.6	0.9	1.5	0.5	5.0	2.9	2.1	1.7
870306b	MBD028	19	0	2.6	2.6	0.5	1.9	0.2	u	0.6	u	1.5	0.3	5.8	1.8	4.0	3.2
870310a	MBD029	9	0	2.0	2.8	4.7	1.3	0.5	2.1	0.5	1.2	3.4	4.7	11.9	9.3	2.6	1.3
870310b	MBD030	11	0	1.8	2.3	4.9	0.7	0.4	1.6	0.5	0.9	3.6	3.2	10.4	7.7	2.7	1.4
870315a	MBD031	23	0	2.6	1.3	1.8	3.7	0.5	1.0	1.0	1.0	2.7	2.5	9.3	6.2	3.1	1.5
870315b	MBD032	24	0	2.7	1.4	1.1	1.9	1.2	1.5	1.3	1.2	0.9	2.2	8.4	4.3	4.1	2.0
870319a	MBD033	5	0	0.8	19.1	5.7	1.3	1.5	5.6	0.8	6.1	21.4	7.1	34.0	34.6	-0.6	1.0
870319b	MBD034	4	0	0.4	15.5	5.6	1.9	2.1	5.9	0.6	7.8	21.0	8.9	31.6	37.7	-6.1	0.8
870321a	MBD035	24	0	1.6	5.8	2.4	3.1	0.9	1.8	0.6	2.1	7.8	3.9	14.6	13.8	0.8	1.1
870321b	MBD036	26	0	1.7	8.3	2.8	0.7	0.4	1.3	u	1.5	8.5	2.0	13.5	12.0	1.5	1.1
870326a	MBD037	17	0	2.3	1.9	1.8	2.5	0.6	2.2	0.8	0.8	4.0	1.7	9.8	6.5	3.3	1.5
870326b	MBD038	18	0	2.4	2.0	1.5	1.9	0.5	1.5	0.8	u	2.6	1.6	8.2	4.2	4.0	2.0
870403a	MBD039	6	0	0.9	3.0	4.4	3.1	0.8	1.6	0.7	1.1	5.5	2.7	13.6	9.3	4.3	1.5
870403b	MBD040	6	0	0.9	2.6	4.4	1.9	0.3	1.1	u	2.1	5.2	2.6	10.3	9.9	0.4	1.0
861209a	MBW001	12	0	2.0	1.8	0.8	3.4	0.9	1.6	u	0.8	2.2	5.8	8.5	8.8	-0.3	1.0
861209b	MBW002	13	0	1.9	1.8	0.8	2.5	0.6	1.2	u	0.8	2.1	3.0	6.9	5.9	1.0	1.2
861223a	MBW003	5	0	0.9	4.0	5.1	15.	1.9	3.5	1.3	4.2	13.	19.	30.8	36.2	-5.4	0.9
861223b	MBW004	7	0	1.4	4.2	3.9	11.	1.8	6.8	1.0	3.1	9.5	15.	28.7	27.6	1.1	1.0
870106a	MBW005	82	0	14.6	2.2	1.0	7.1	1.0	2.1	0.6	1.2	5.1	3.0	14.0	9.3	4.7	1.5
870106b	MBW006	81	0	13.7	2.2	2.1	6.8	1.0	1.8	0.3	1.0	4.7	2.6	14.2	8.3	5.9	1.7
870127a	MBW007	8	0	2.0	1.4	1.1	7.5	0.6	3.0	0.7	2.8	4.9	3.9	14.3	11.6	2.7	1.2
870127b	MBW008	5	0	1.3	1.6	2.5	6.8	1.0	2.9	0.7	2.2	3.6	3.6	15.5	9.4	6.1	1.6
870203a	MBW009	28	0	6.3	1.5	4.8	5.2	0.7	2.1	0.7	2.2	6.8	4.0	15.0	13.0	2.0	1.2
870203b	MBW010	35	0	8.3	3.4	2.5	4.4	1.2	3.3	0.7	1.6	9.6	5.7	15.5	16.9	-1.4	0.9
870210a	MBW011	12	0	1.2	4.9	5.6	6.2	0.8	4.6	0.8	2.2	5.8	9.5	22.9	17.5	5.4	1.3
870210b	MBW012	12	0	1.4	4.2	5.6	6.6	0.2	1.7	0.6	1.3	5.4	9.0	18.9	15.7	3.2	1.2
870217c	MBW013	75	40	6.3	1.7	0.7	3.7	0.1	u	0.8	0.4	1.7	1.1	7.0	3.2	3.8	2.2
870217c	MBW014	40	0	8.7	0.5	0.7	3.7	0.6	0.7	1.9	0.4	5.9	0.9	8.1	7.2	0.9	1.1
870224a	MBW015	26	0	2.7	3.3	1.0	2.5	0.5	1.2	1.2	1.2	7.3	4.0	9.7	12.5	-2.8	0.8
870224b	MBW016	26	0	2.6	3.8	0.8	2.0	0.1	u	0.8	1.3	6.6	3.8	7.5	11.7	-4.2	0.6
870310a	MBW017	22	0	5.1	2.5	1.3	2.5	0.1	1.0	1.2	u	2.8	2.5	8.6	5.3	3.3	1.6
870310b	MBW018	25	0	5.3	2.3	1.6	1.3	0.1	u	u	2.1	2.5	2.5	5.3	7.1	-1.8	0.7
870317a	MBW019	27	0	5.4	2.0	1.6	1.3	0.3	1.9	u	0.2	2.0	1.7	7.1	3.9	3.2	1.8
870317b	MBW020	30	0	6.6	0.7	1.7	1.0	0.4	1.3	0.8	4.7	3.2	2.2	5.9	10.1	-4.2	0.6
870326a	MBW021	28	0	4.1	0.7	1.2	1.3	0.1	1.5	0.6	0.8	5.8	1.6	5.4	8.2	-2.8	0.7
870326b	MBW022	26	0	3.8	1.7	1.0	2.5	0.2	3.0	u	0.8	5.9	1.6	8.4	8.3	0.1	1.0
870117a	MPW002	74	35	8.6	1.6	u	2.9	0.7	0.9	0.3	1.3	2.9	1.3	6.4	5.5	0.9	1.2
870117a	MPW003	35	0	9.0	3.6	3.1	4.4	1.2	1.5	0.6	3.8	7.9	6.8	14.4	18.5	-4.1	0.8
870117b	MPW004	75	35	9.7	1.4	u	2.1	1.0	1.1	0.2	1.1	2.3	1.4	5.8	4.8	1.0	1.2
870117b	MPW005	35	0	9.9	2.8	4.6	4.8	1.0	2.0	0.7	3.0	7.4	6.4	15.9	16.8	-0.9	0.9
870131a	MPW006	52	25	6.0	5.0	5.5	4.6	0.7	2.1	0.6	1.3	9.7	5.6	18.5	16.6	1.9	1.1
870131b	MPW007	52	25	6.0	3.7	3.7	3.1	0.4	1.5	0.6	1.1	8.9	5.1	13.0	15.1	-2.1	0.9
870131a	MPW008	25	0	7.8	2.0	2.4	5.0	0.6	1.8	0.6	0.3	5.2	3.6	12.4	9.1	3.3	1.4

Table 4.7A. (continued)

u = below limit of detection

Date/Profile	Sample	Zt	Zb	SWE	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}	Σ+	Σ−	(Σ+) − (Σ−)	Σ+/Σ−
870131b	MPW009	25	0	7.4	2.4	2.4	2.5	0.5	1.7	0.6	0.3	5.2	3.2	10.1	8.7	1.4	1.2
870214c	MPW010	133	95	8.3	2.8	0.1	1.3	0.1	1.0	u	0.9	0.8	0.5	5.3	2.2	3.1	2.4
870214c	MPW012	95	60	7.3	2.5	1.5	1.9	0.1	1.4	0.6	0.8	1.6	0.5	8.0	2.9	5.1	2.8
870214c	MPW014	60	30	8.1	3.5	2.4	1.9	u	2.2	1.0	2.3	3.4	3.4	11.0	9.1	1.9	1.2
870214c	MPW015	30	0	9.6	3.8	5.0	1.9	u	1.4	0.5	1.5	7.7	8.0	12.6	17.2	-4.6	0.7
870228a	MPW016	128	88	7.9	1.6	0.4	9.9	0.5	1.5	1.0	1.2	5.6	2.9	14.9	9.7	5.2	1.5
870228b	MPW017	128	88	7.5	2.1	3.4	0.7	0.1	1.0	u	1.8	4.3	3.1	7.3	9.2	-1.9	0.8
870228a	MPW018	88	52	10.1	3.2	1.4	1.3	0.1	0.7	u	u	1.9	1.7	6.7	3.6	3.1	1.9
870228b	MPW019	88	52	9.9	2.5	1.5	1.3	0.1	0.7	u	0.6	1.9	1.9	6.1	4.4	1.7	1.4
870228a	MPW020	52	0	19.1	2.3	2.5	2.5	0.5	u	u	0.5	5.0	2.9	7.8	8.4	-0.6	0.9
870228b	MPW021	52	0	19.4	2.0	2.5	2.3	0.7	0.1	0.7	u	0.2	5.0	8.3	5.2	3.1	1.6
870315a	MPW022	165	125	8.1	2.0	1.8	1.9	0.4	u	0.8	1.6	2.2	2.1	6.9	5.9	1.0	1.2
870315b	MPW023	165	125	7.6	2.1	0.4	1.9	0.1	u	0.5	0.4	1.8	2.1	5.0	4.3	0.7	1.2
870315a	MPW024	125	85	12.5	2.3	4.1	1.9	1.1	2.2	u	1.4	4.2	2.4	11.6	8.0	3.6	1.4
870315b	MPW025	125	85	12.4	3.5	4.0	1.3	0.4	1.6	0.6	0.4	4.4	3.2	11.4	8.0	3.4	1.4
870315a	MPW026	85	40	15.9	1.6	2.7	3.7	0.4	1.2	1.0	2.2	4.7	3.8	10.6	10.7	-0.1	1.0
870315b	MPW027	85	40	15.7	2.6	1.8	1.3	0.4	1.0	0.6	3.0	3.0	2.3	7.7	8.3	-0.6	0.9
870315a	MPW028	40	0	14.6	1.7	1.6	4.4	0.3	1.3	0.9	0.3	5.0	3.8	10.2	9.1	1.1	1.1
870315b	MPW029	40	0	13.7	3.6	2.5	1.3	0.2	1.0	u	4.1	u	3.4	8.6	7.5	1.1	1.1
870414a	MPW030	101	60	17.8	1.0	2.0	1.3	0.2	0.9	u	1.5	1.4	0.6	5.4	3.5	1.9	1.5
870414a	MPW031	60	30	13.4	1.9	1.9	2.5	0.1	1.5	u	0.1	3.0	1.0	7.9	4.1	3.8	1.9
870414b	MPW032	101	60	18.0	1.7	0.8	1.9	0.1	1.3	u	0.3	1.6	0.6	5.8	2.5	3.3	2.3
870414b	MPW033	60	30	13.7	2.2	1.8	2.5	0.1	2.0	u	0.5	2.9	1.4	8.6	4.8	3.8	1.8
870414a	MPW034	30	0	12.0	1.5	2.9	1.3	0.1	1.5	0.7	1.0	3.9	2.1	8.0	7.0	1.0	1.1
870414b	MPW035	30	0	12.1	2.1	3.0	1.9	0.3	1.4	0.6	2.4	4.8	2.7	9.3	9.9	-0.6	0.9
861209c	MTW001	1782	(ml)	2.5	2.3	0.9	12.	1.0	1.8	0.3	1.0	4.7	2.6	18.3	8.3	10.0	2.2
861223c	MTW002	888	(ml)	1.2	8.9	3.4	22.	2.1	5.1	1.1	16.	14.	19.	42.6	49.0	-6.4	0.9
870106c	MTW003	6949	(ml)	9.7	5.0	u	4.1	0.9	2.1	u	1.3	4.8	3.2	12.1	9.3	2.8	1.3
870113c	MTW004	72	(ml)	0.1	1.2	2.3	28.	1.6	5.2	1.5	19.	7.5	4.7	39.8	31.2	8.6	1.3
870120a	MTW006	527	(ml)	0.7	5.0	0.5	9.9	0.5	1.7	1.6	18.0	8.0	8.6	19.2	34.6	-15.4	0.6
870120b	MTW007	592	(ml)	0.8	4.7	0.5	6.8	1.9	1.4	1.4	12.0	8.7	8.0	16.7	28.7	-12.0	0.6
870127a	MTW008	760	(ml)	1.1	2.8	0.8	11.2	0.8	3.4	0.8	4.2	7.6	5.1	19.8	16.9	2.9	1.2
870127b	MTW009	909	(ml)	1.3	1.4	0.8	13.0	2.0	9.6	0.9	7.9	8.0	6.0	27.7	21.9	5.8	1.3
870203a	MTW010	2778	(ml)	3.9	5.8	3.7	7.5	1.0	2.9	0.6	4.5	8.1	7.8	21.5	20.4	1.1	1.1
870203b	MTW011	2483	(ml)	3.5	4.3	u	7.5	1.0	3.7	0.7	3.7	7.6	8.7	17.2	20.0	-2.8	0.9
870210a	MTW012	814	(ml)	1.1	6.3	7.4	4.6	1.2	1.7	0.5	2.5	5.4	9.4	21.7	17.3	4.4	1.3
870210b	MTW013	819	(ml)	1.1	6.3	7.1	6.9	0.7	2.0	0.7	4.0	4.9	9.3	23.7	18.2	5.5	1.3
870217a	MTW014	7305	(ml)	10.2	2.1	1.1	2.5	0.7	1.4	0.5	1.5	1.3	3.9	8.3	6.7	1.6	1.2
870217b	MTW015	7032	(ml)	9.8	2.1	1.1	1.8	0.2	0.3	0.2	0.7	1.4	1.4	5.7	3.5	2.2	1.6
870224a	MTW016	2176	(ml)	3.0	3.6	6.4	4.4	0.4	4.1	0.2	3.6	8.3	6.9	19.1	18.8	0.3	1.0
870224b	MTW017	2256	(ml)	3.1	3.2	6.9	3.7	u	4.1	u	2.9	8.6	6.8	17.9	18.3	-0.4	1.0
870303a	MTW018	325	(ml)	0.5	3.8	6.2	6.8	0.7	2.1	u	5.3	14.8	5.0	19.6	25.1	-5.5	0.8
870303b	MTW019	261	(ml)	0.4	3.5	7.8	10.5	0.7	4.5	1.6	10.9	18.6	6.8	28.6	36.3	-7.7	0.8
870310a	MTW020	3955	(ml)	5.5	1.9	1.6	1.9	0.3	0.8	u	0.8	3.5	2.8	6.5	7.1	-0.6	0.9
870310b	MTW021	3962	(ml)	5.5	1.6	1.9	0.7	0.3	u	u	0.3	3.4	2.9	4.5	6.6	-2.1	0.7
870324c	MTW023	2541	(ml)	3.6	1.4	4.4	5.0	0.8	2.7	0.7	4.9	10.1	3.8	15.0	18.8	-3.8	0.8
870331c	MTW024	179	(ml)	0.3	4.2	6.8	21.1	1.7	7.6	1.2	13.8	11.8	10.7	42.6	36.3	6.3	1.2
870408c	MTW025	875	(ml)	1.2	2.2	4.6	6.2	1.0	2.7	0.7	2.4	10.6	5.1	17.4	18.1	-0.7	1.0
870328a	APS001	185	150	11.0	1.4	3.6	7.8	5.5	4.6	2.0	6.7	6.0	5.2	24.9	17.9	7.0	1.4
870328a	APS002	150	120	11.3	4.8	3.3	3.1	1.6	5.7	3.0	2.7	3.3	1.9	21.5	7.9	13.6	2.7
870328a	APS003	120	90	13.4	4.8	3.5	9.3	7.5	5.0	2.6	6.0	1.3	18.5	32.7	25.8	6.9	1.3
870328a	APS004	90	60	12.5	5.0	3.8	2.5	0.6	3.1	1.2	4.8	2.0	1.3	16.2	8.1	8.1	2.0
870328a	APS005	60	30	12.6	2.7	3.7	3.1	0.6	5.0	2.9	4.0	2.7	1.8	18.0	8.5	9.5	2.1
870328a	APS006	30	0	13.3	1.8	3.0	5.6	2.4	3.2	3.0	3.6	3.2	3.3	19.0	10.1	8.9	1.9
870328b	APS007	185	150	10.7	1.6	4.1	8.9	4.9	4.4	1.5	3.4	5.9	5.2	25.4	14.5	10.9	1.8
870328b	APS008	150	120	12.0	5.4	2.6	1.9	0.9	3.0	1.2	3.0	3.4	2.5	15.0	8.9	6.1	1.7
870328b	APS009	120	90	13.8	4.1	1.1	1.1	1.0	4.6	1.0	6.0	1.3	2.0	12.9	9.3	3.6	1.4
870328b	APS010	90	60	12.6	4.6	0.9	1.1	0.6	2.7	1.5	1.9	2.0	1.7	11.4	5.6	5.8	2.0
870328b	APS011	60	30	13.3	4.1	0.7	3.3	1.0	4.5	1.5	3.4	2.1	3.9	15.1	9.4	5.7	1.6
870328b	APS012	30	0	13.6	3.1	u	7.8	2.5	3.7	2.0	3.0	2.6	4.4	19.1	10.0	9.1	1.9

Table 4.7A. (continued)

u = below limit of detection

Date/Profile	Sample	Zt	Zb	SWE	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}	Σ+	Σ−	(Σ+) − (Σ−)	Σ+/Σ−
870328a	CPS001	159	120	11.1	6.3	3.9	0.7	0.5	3.1	0.5	4.8	4.6	3.7	15.0	13.1	1.9	1.1
870328a	CPS002	120	80	16.0	4.3	1.6	0.7	0.3	3.0	0.6	4.5	1.1	1.4	10.5	7.0	3.5	1.5
870328a	CPS003	80	40	16.2	3.7	1.1	u	0.3	1.6	u	1.3	1.9	1.2	6.7	4.4	2.3	1.5
870328a	CPS004	40	0	18.2	0.6	1.7	2.3	1.0	7.8	0.8	2.5	3.1	2.6	14.2	8.2	6.0	1.7
870328b	CPS005	161	120	11.7	5.1	3.7	0.7	0.5	3.6	0.5	6.7	4.5	3.4	14.1	14.6	-0.5	1.0
870328b	CPS006	120	80	15.0	4.3	1.5	1.3	0.1	2.8	u	1.9	0.8	0.5	10.0	3.2	6.8	3.1
870328b	CPS007	80	40	15.6	4.1	1.3	u	0.4	1.8	0.6	2.1	2.2	1.4	8.2	5.7	2.5	1.4
870328b	CPS008	40	0	17.0	3.5	0.7	2.5	1.3	2.1	0.6	8.5	1.3	2.6	10.7	12.4	-1.7	0.9
880325a	HPS001	225	185	7.2	4.5	1.5	2.5	0.8	6.3	0.8	2.9	2.9	2.5	16.4	8.3	8.1	2.0
880325a	HPS002	184	145	10.2	3.7	2.5	1.9	1.0	2.3	0.6	1.6	3.2	3.3	12.0	8.1	3.9	1.5
880325a	HPS003	145	105	12.2	6.9	7.0	3.7	1.6	7.4	0.6	4.9	8.6	9.7	27.2	23.2	4.0	1.2
880325a	HPS004	105	65	13.4	5.4	0.4	6.0	2.4	5.9	3.0	4.4	1.9	2.2	23.1	8.5	14.6	2.7
880325a	HPS005	65	25	14.2	5.4	1.0	2.5	0.7	2.7	0.6	2.3	3.0	3.0	12.9	8.3	4.6	1.6
880325a	HPS006	25	0	9.5	11.5	4.0	3.9	1.3	2.0	1.5	2.7	6.3	10.7	24.2	19.7	4.5	1.2
880325b	HPS007	230	190	7.0	4.2	2.0	1.9	0.9	3.1	0.6	2.1	3.0	2.7	12.7	7.8	4.9	1.6
880325b	HPS008	190	150	10.4	5.4	2.2	1.9	0.9	1.8	0.6	1.8	3.3	3.5	12.8	8.6	4.2	1.5
880325b	HPS009	150	110	13.2	7.8	7.6	6.0	2.7	8.7	2.0	7.2	10.3	13.0	34.8	30.5	4.3	1.1
880325b	HPS010	110	70	13.4	5.8	1.1	2.5	1.3	4.8	0.6	4.9	2.7	3.3	16.1	10.9	5.2	1.5
880325b	HPS011	70	30	14.8	5.6	u	3.9	2.5	4.8	2.0	2.8	2.7	5.5	18.8	11.0	7.8	1.7
880325b	HPS012	30	0	12.2	10.0	5.1	3.9	1.4	2.8	2.0	0.2	6.0	8.8	25.2	15.0	10.2	1.7
880323a	DPS001	143	110	8.0	7.2	0.5	1.1	1.0	2.7	1.0	2.4	5.6	3.6	13.5	11.6	1.9	1.2
880323a	DPS002	110	75	10.7	6.6	1.0	1.1	1.5	2.1	2.0	2.4	3.5	2.3	14.3	8.2	6.1	1.7
880323a	DPS003	75	40	13.1	4.3	u	3.3	1.0	2.2	1.5	1.9	1.6	1.4	12.3	4.9	7.4	2.5
880323a	DPS004	40	0	15.1	4.5	0.5	4.4	3.2	3.7	2.5	2.2	2.0	2.2	18.8	6.4	12.4	2.9
880323b	DPS005	150	115	8.4	7.6	2.3	2.2	0.9	2.5	0.6	1.8	5.4	3.3	16.1	10.5	5.6	1.5
880323b	DPS006	115	80	10.1	6.6	0.9	2.2	1.3	2.4	2.8	2.1	3.4	2.5	16.2	8.0	8.2	2.0
880323b	DPS007	80	45	12.3	5.0	u	4.4	1.9	7.5	2.0	3.3	0.7	1.5	20.8	5.5	15.3	3.8
880323b	DPS008	45	0	17.5	4.9	u	4.4	2.2	3.9	3.5	2.2	0.6	2.5	18.9	5.3	13.6	3.6
870330a	BPS001	58	27	10.7	4.7	2.1	1.3	0.7	0.3	0.1	0.6	2.9	2.0	9.2	5.5	3.7	1.7
870330a	BPS003	27	0	8.3	5.6	3.9	2.1	1.5	0.7	1.4	2.3	0.9	3.2	15.2	6.4	8.8	2.4
870330b	BPS002	58	27	9.6	6.2	2.0	1.8	1.4	0.6	0.3	1.0	0.6	1.9	12.3	3.5	8.8	3.5
870330b	BPS004	27	0	7.7	7.2	2.6	2.3	1.2	1.1	1.2	1.6	4.2	3.7	15.6	9.5	6.1	1.6
870326a	MPS001	150	120	6.5	5.5	2.0	1.0	0.6	0.4	0.1	1.3	4.9	2.0	9.6	8.2	1.4	1.2
870326a	MPS002	120	90	9.8	3.4	2.9	1.6	0.6	0.4	0.1	0.3	3.3	2.3	9.0	5.9	3.1	1.5
870326a	MPS003	90	60	11.0	1.3	1.2	5.4	0.6	0.2	0.1	0.9	1.9	1.4	8.8	4.2	4.6	2.1
870326a	MPS004	60	30	10.7	1.1	1.9	5.7	0.5	0.2	0.1	2.0	2.9	2.5	9.5	7.4	2.1	1.3
870326a	MPS005	30	0	10.8	1.5	3.0	5.7	1.3	0.9	0.9	0.6	9.8	3.2	13.3	13.6	-0.3	1.0
870326b	MPS006	150	120	6.2	2.5	2.1	4.6	0.7	0.3	0.1	1.7	6.2	2.1	10.3	10.0	0.3	1.0
870326b	MPS007	120	90	10.0	0.4	2.3	1.5	0.7	0.4	0.3	1.0	5.2	2.7	5.6	8.9	-3.3	0.6
870326b	MPS008	90	60	10.7	1.3	2.1	3.9	0.7	0.5	0.1	0.6	2.9	1.8	8.6	5.3	3.3	1.6
870326b	MPS009	60	30	10.8	1.1	1.8	5.7	0.6	0.3	0.1	2.2	3.2	2.4	9.6	7.8	1.8	1.2
870326b	MPS010	30	0	11.0	1.0	4.2	7.5	0.8	0.1	0.1	0.4	4.9	3.0	13.7	8.3	5.4	1.7
870327a	KPS001	146	120	5.7	6.6	2.0	3.3	1.3	3.0	1.5	3.2	4.2	3.7	17.7	11.1	6.6	1.6
870327a	KPS002	120	90	8.7	9.1	1.4	4.0	6.8	2.4	4.0	3.9	5.4	3.6	27.7	12.9	14.8	2.1
870327a	KPS003	90	60	10.2	6.2	0.3	3.3	2.0	6.7	2.0	9.7	2.2	3.1	20.5	15.0	5.5	1.4
870327a	KPS004	60	30	10.7	6.6	u	5.6	1.8	3.2	2.0	3.4	3.8	2.7	19.2	9.9	9.3	1.9
870327a	KPS005	30	0	10.8	6.6	u	5.6	1.8	3.2	2.0	3.4	3.8	2.7	19.2	9.9	9.3	1.9
870327b	KPS006	146	120	6.0	5.9	2.9	3.3	1.4	3.0	1.5	2.9	4.2	3.9	18.0	11.0	7.0	1.6
870327b	KPS007	120	90	8.9	12.9	u	4.4	4.5	3.6	4.0	3.3	2.7	3.8	29.4	9.8	19.6	3.0
870327b	KPS008	90	60	10.4	6.6	0.8	4.4	2.8	5.9	2.0	11.0	0.7	3.3	22.5	15.0	7.5	1.5
870327b	KPS009	60	30	11.1	6.6	u	5.6	3.5	3.0	2.5	2.8	1.3	3.1	21.2	7.2	14.0	2.9
870327b	KPS010	30	0	11.4	6.6	u	5.6	3.5	3.0	2.5	2.8	1.3	3.1	21.2	7.2	14.0	2.9
870323a	SPS001	21	0	5.2	5.2	19.0	3.2	2.0	6.7	0.4	14.4	18.7	10.6	36.5	43.7	-7.2	0.8
870323b	SPS002	21	0	5.2	6.5	20.0	4.3	2.1	6.0	0.2	14.4	16.9	10.7	39.1	42.0	-2.9	0.9
870324a	LPS001	129	89	9.7	5.2	8.1	2.1	1.5	3.7	0.1	9.6	8.4	6.4	20.7	24.4	-3.7	0.8
870324a	LPS002	89	49	13.6	8.9	6.5	2.5	1.1	0.5	0.3	7.4	5.4	10.7	19.8	23.5	-3.7	0.8
870324a	LPS003	49	0	14.3	7.4	3.7	2.9	2.8	10.3	0.9	28.1	4.5	8.1	28.0	40.7	-12.7	0.7
870324b	LPS004	129	89	9.5	4.5	8.0	2.9	1.7	3.6	0.1	9.1	8.5	6.2	20.8	23.8	-3.0	0.9
870324b	LPS005	89	49	13.7	8.3	5.9	2.5	1.3	1.2	0.3	2.5	5.5	14.4	19.5	22.4	-2.9	0.9
870324b	LPS006	49	0	14.5	7.4	4.8	3.2	2.9	11.3	0.4	29.1	5.6	8.9	30.0	43.6	-13.6	0.7
870000a	LBD001	na	na	na	1.9	17.0	10.4	2.6	6.4	0.4	6.2	24.3	19.0	38.7	49.5	-10.8	0.8

Table 4.7B. Chemical concentrations (ueq L^{-1}) and charge balances of samples with organic acid analyses.

u = below limit of detection

Date/Profile	Sample	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}	$CH_3CH_2O^-$	HCO_2^-	Σ+	Σ−	(Σ+) − (Σ−)	Σ+/Σ−
870328a	APS003	4.8	3.5	9.3	7.5	5.0	2.6	6.0	1.3	18.5	3.9	1.0	32.7	30.7	2.0	1.1
870328a	APS006	1.8	3.0	5.6	2.4	3.2	3.0	3.6	3.2	3.3	u	0.1	19.0	10.2	8.8	1.9
870305a	CBD047	5.1	4.0	2.5	0.6	2.2	0.6	1.4	6.2	5.3	u	u	15.0	12.9	2.1	1.2
870305b	CBD048	6.6	3.7	1.3	0.5	5.1	0.8	4.5	5.9	5.1	u	u	18.0	15.5	2.5	1.2
870306a	CBD049	4.1	0.6	1.3	0.1	1.3	0.9	u	1.9	0.5	0.4	u	8.3	2.8	5.5	3.0
870306b	CBD050	3.7	0.3	u	0.2	0.8	u	u	1.8	0.3	1.0	u	5.0	3.1	1.9	1.6
870309a	CBD051	6.0	1.7	0.7	0.3	2.4	0.5	2.2	2.6	1.7	1.5	1.8	11.6	9.8	1.8	1.2
870311a	CBD053	4.8	11.2	1.3	0.7	5.1	0.5	3.5	9.7	5.3	u	u	23.6	18.5	5.1	1.3
870311b	CBD054	7.2	11.3	1.3	0.5	4.2	0.5	4.1	9.9	5.3	0.9	u	25.0	20.2	4.8	1.2
870313a	CBD055	3.5	1.1	u	0.2	2.0	1.0	2.1	1.6	1.0	u	u	7.8	4.7	3.1	1.7
870313b	CBD056	3.5	1.1	0.7	0.1	1.0	u	1.2	1.4	1.0	2.2	0.3	6.4	6.1	0.3	1.0
870314a	CBD057	7.8	1.2	0.7	0.5	2.7	0.8	3.0	5.9	2.2	0.8	u	13.7	11.9	1.8	1.2
870314b	CBD058	8.5	1.6	2.2	0.5	2.9	0.4	2.8	6.0	2.2	0.2	0.7	16.1	11.9	4.2	1.4
870315a	CBD059	4.6	2.3	1.9	0.8	4.9	0.8	7.3	3.2	4.3	u	u	15.3	14.8	0.5	1.0
870318a	CBD061	7.1	9.1	1.9	1.1	4.2	0.8	4.0	7.8	8.5	u	u	24.2	20.3	3.9	1.2
870318b	CBD062	7.9	10.2	0.7	0.9	3.7	0.9	5.7	9.0	9.1	u	u	24.3	23.8	0.5	1.0
870319a	CBD063	5.3	4.9	0.7	1.0	5.0	0.7	7.9	4.0	3.7	0.3	u	17.6	15.9	1.7	1.1
870319b	CBD064	5.8	5.0	0.7	1.1	6.0	0.6	9.0	4.1	4.0	0.9	u	19.2	18.0	1.2	1.1
870322a	CBD065	7.9	3.2	1.3	0.6	10.9	1.6	12.5	6.0	3.0	u	u	25.5	21.5	4.0	1.2
870322b	CBD066	8.1	2.8	1.9	0.5	9.6	1.0	13.3	6.2	3.4	1.0	u	23.9	23.9	0.0	1.0
870323a	CBD067	4.5	1.0	u	0.3	3.9	1.5	5.7	2.5	0.9	0.9	0.7	11.2	10.7	0.5	1.0
870323b	CBD068	4.9	1.1	0.7	0.2	3.0	0.5	3.6	1.8	0.6	0.8	1.2	10.4	8.0	2.4	1.3
870403a	CBD069	8.3	11.9	4.6	1.0	17.0	0.9	18.7	14.6	8.7	1.5	3.2	43.7	46.7	-3.0	0.9
870403b	CBD070	8.9	11.6	5.0	1.2	20.0	1.2	24.9	14.8	10.0	1.2	2.2	47.9	53.1	-5.2	0.9
870310a	CBW023	5.0	1.6	0.7	0.3	2.0	0.6	1.5	2.3	1.6	0.6	u	10.2	6.0	4.2	1.7
870310b	CBW024	5.0	1.5	0.7	0.1	1.7	u	3.1	1.3	1.6	0.7	1.4	9.0	8.1	0.9	1.1
870317a	CBW025	6.2	1.8	1.9	1.2	5.9	0.6	5.5	4.0	3.6	u	u	17.6	13.1	4.5	1.3
870317a	CBW026	3.7	1.0	0.7	0.1	1.0	u	0.4	1.3	0.9	0.5	1.2	6.5	4.3	2.2	1.5
870317b	CBW028	4.1	1.0	u	0.2	1.2	u	0.6	1.3	0.9	0.7	1.5	6.5	5.0	1.5	1.3
870324a	CBW029	7.6	4.2	1.3	0.8	6.0	0.8	7.1	4.7	3.9	0.4	u	20.7	16.1	4.6	1.3
870324b	CBW030	6.5	4.6	u	0.5	5.4	u	10.7	4.8	4.1	u	u	17.0	19.6	-2.6	0.9
870314c	CP0035	6.3	1.6	0.7	0.7	3.1	0.6	4.2	4.1	2.9	5.2	u	13.0	16.4	-3.4	0.8
870314c	CP0036	3.3	1.7	1.3	0.3	1.0	u	0.5	1.6	1.0	0.4	u	7.6	3.5	4.1	2.2
870314c	CP0037	4.1	1.2	u	0.5	3.5	0.5	4.9	1.6	1.8	0.5	u	9.8	8.8	1.0	1.1
870314c	CP0039	5.1	1.1	0.7	0.3	1.8	u	1.6	1.9	2.0	0.7	u	9.0	6.2	2.8	1.5
870411a	CP0040	4.5	1.5	1.3	0.4	1.7	1.5	3.1	1.8	1.3	0.2	0.4	10.9	6.8	4.1	1.6
870411a	CP0041	3.4	1.0	u	0.2	1.6	0.6	0.9	1.6	1.0	0.4	u	6.8	3.9	2.9	1.7
870411a	CP0042	2.8	1.8	1.9	0.2	2.3	u	1.9	3.0	2.6	0.7	u	9.0	8.2	0.8	1.1
870411b	CP0043	2.9	0.8	u	0.2	2.5	1.2	2.7	0.8	0.5	u	u	7.6	4.0	3.6	1.9
870411b	CP0044	3.6	0.6	0.7	0.5	3.2	0.5	6.1	1.2	0.7	0.4	0.3	9.1	8.7	0.4	1.0
870424a	CP0046	3.4	1.0	1.9	0.3	1.5	1.0	1.2	1.7	1.0	1.0	u	9.1	4.9	4.2	1.9
870424a	CP0047	1.8	0.9	0.7	0.4	3.0	0.9	1.4	1.4	1.2	1.1	1.2	7.7	6.3	1.4	1.2
870424b	CP0048	3.1	0.7	1.9	0.6	1.5	0.9	0.9	1.5	0.9	0.8	u	8.7	4.1	4.6	2.1
870424b	CP0049	3.5	0.9	u	0.2	1.8	u	4.3	0.8	1.3	1.6	u	6.4	8.0	-1.6	0.8
870303a	CT0021	16.6	17.7	19.2	5.9	177.0	7.3	100.0	33.2	20.9	u	u	243.7	154.1	89.6	1.6
870303b	CT0022	14.8	11.1	16.0	5.1	184.0	4.0	81.0	24.1	18.1	u	0.3	235.0	123.5	111.5	1.9
870310a	CT0023	6.8	3.4	3.7	0.5	1.8	0.6	1.8	6.4	5.6	0.6	1.3	16.8	15.7	1.1	1.1
870310b	CT0024	5.5	3.5	4.4	0.4	1.7	0.9	3.1	6.5	5.1	u	u	16.4	14.7	1.7	1.1
870317a	CT0025	8.7	2.8	3.1	0.7	3.5	2.0	4.7	3.9	3.2	u	u	20.8	11.8	9.0	1.8
870317b	CT0026	6.5	3.0	1.9	1.2	3.8	3.6	3.6	3.8	2.8	0.7	1.5	20.0	12.4	7.6	1.6
870407a	CT0031	10.2	13.6	12.4	2.0	13.2	2.3	18.4	21.7	15.7	0.6	u	53.7	56.4	-2.7	1.0
870407b	CT0032	10.5	13.4	12.4	1.9	12.0	1.2	23.8	19.7	16.0	u	u	51.4	59.5	-8.1	0.9
870421a	CT0035	7.4	12.5	11.1	3.9	12.2	3.9	7.0	14.0	13.0	u	u	51.0	34.0	17.0	1.5
870421b	CT0036	6.6	6.6	9.9	2.8	13.1	3.2	7.3	13.5	13.4	u	u	42.2	34.2	8.0	1.2
870505a	CT0039	10.2	16.9	11.8	2.3	5.6	1.6	9.7	19.8	19.4	u	u	48.4	48.9	-0.5	1.0
870505b	CT0040	10.7	16.8	8.7	2.4	5.3	1.6	5.8	21.3	21.0	u	u	45.5	48.1	-2.6	0.9

Table 4.7B. (continued)

u = below limit of detection

Date/Profile	Sample	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}	$CH_3CH_2O^-$	HCO_2^-	Σ+	Σ−	(Σ+) − (Σ−)	Σ+/Σ−
870128a	MBD006	4.1	7.3	6.0	1.0	2.6	1.1	2.1	11.8	7.2	u	u	22.1	21.1	1.0	1.0
870203a	MBD008	0.9	0.6	6.0	0.8	2.1	2.9	1.4	7.5	0.9	3.4	u	11.3	13.2	-1.9	0.9
870203b	MBD009	3.4	0.2	5.8	0.5	1.2	0.3	u	1.2	0.5	0.4	u	11.4	8.6	2.8	1.3
870210a	MBD011	6.2	6.3	5.8	0.5	1.6	0.6	1.2	5.2	8.4	1.3	1.8	21.0	17.9	3.1	1.2
870210b	MBD012	6.8	6.8	4.6	0.5	1.4	0.6	0.9	5.2	8.7	1.0	1.8	20.7	17.6	3.1	1.2
870211b	MBD014	2.6	3.7	3.7	0.5	2.0	0.6	0.8	6.0	3.4	0.4	2.5	13.1	13.1	0.0	1.0
870213a	MBD016	1.2	2.0	1.0	0.3	u	0.6	u	1.0	0.3	1.5	0.7	5.1	3.5	1.6	1.5
870213b	MBD018	1.2	0.1	1.3	u	u	u	u	0.4	0.2	0.3	0.4	2.6	1.3	1.3	2.0
870310a	MBD029	2.8	4.7	1.3	0.5	2.1	0.5	1.2	3.4	4.7	u	u	11.9	9.3	2.6	1.3
870315a	MBD031	1.3	1.8	3.7	0.5	1.0	1.0	1.0	2.7	2.5	1.0	1.7	9.3	8.9	0.4	1.0
870315b	MBD032	1.4	1.1	1.9	1.2	1.5	1.3	1.2	0.9	2.2	u	u	8.4	4.3	4.1	2.0
870319a	MBD033	19.1	5.7	1.3	1.5	5.6	0.8	6.1	21.4	7.1	1.7	2.3	34.0	38.6	-4.6	0.9
870319b	MBD034	15.5	5.6	1.9	2.1	5.9	0.6	7.8	21.0	8.9	1.7	1.6	31.6	41.0	-9.4	0.8
870321a	MBD035	5.8	2.4	3.1	0.9	1.8	0.6	2.1	7.8	3.9	u	u	14.6	13.8	0.8	1.1
870321b	MBD036	8.3	2.8	0.7	0.4	1.3	u	1.5	8.5	2.0	u	u	13.5	12.0	1.5	1.1
870326a	MBD037	1.9	1.8	2.5	0.6	2.2	0.8	0.8	4.0	1.7	1.1	1.5	9.8	9.1	0.7	1.1
870326b	MBD038	2.0	1.5	1.9	0.5	1.5	0.8	u	2.6	1.6	u	u	8.2	4.2	4.0	2.0
870106a	MBW005	2.2	1.0	7.1	1.0	2.1	0.6	1.2	5.1	3.0	0.2	u	14.0	9.5	4.5	1.5
870127a	MBW007	1.4	1.1	7.5	0.6	3.0	0.7	2.8	4.9	3.9	u	u	14.3	11.6	2.7	1.2
870203a	MBW009	1.5	4.8	5.2	0.7	2.1	0.7	2.2	6.8	4.0	0.4	u	15.0	13.4	1.6	1.1
870224a	MBW015	3.3	1.0	2.5	0.5	1.2	1.2	1.2	7.3	4.0	1.0	u	9.7	13.5	-3.8	0.7
870131a	MPW006	5.0	5.5	4.6	0.7	2.1	0.6	1.3	9.7	5.6	u	u	18.5	16.6	1.9	1.1
870228b	MPW021	2.0	2.5	2.3	0.7	0.1	0.7	u	0.2	5.0	3.1	u	8.3	8.3	0.0	1.0
870315a	MPW022	2.0	1.8	1.9	0.4	u	0.8	1.6	2.2	2.1	1.1	u	6.9	7.0	-0.1	1.0
870315b	MPW023	2.1	0.4	1.9	0.1	u	0.5	0.4	1.8	2.1	0.8	1.3	5.0	6.4	-1.4	0.8
870315a	MPW024	2.3	4.1	1.9	1.1	2.2	u	1.4	4.2	2.4	1.4	u	11.6	9.4	2.2	1.2
870315b	MPW025	3.5	4.0	1.3	0.4	1.6	0.6	0.4	4.4	3.2	0.5	1.8	11.4	10.3	1.1	1.1
870315a	MPW026	1.6	2.7	3.7	0.4	1.2	1.0	2.2	4.7	3.8	1.0	1.5	10.6	13.2	-2.6	0.8
870315b	MPW027	2.6	1.8	1.3	0.4	1.0	0.6	3.0	3.0	2.3	u	u	7.7	8.3	-0.6	0.9
870315b	MPW029	3.6	2.5	1.3	0.2	1.0	u	4.1	u	3.4	u	0.5	8.6	8.0	0.6	1.1
870414b	MPW035	2.1	3.0	1.9	0.3	1.4	0.6	2.4	4.8	2.7	u	u	9.3	9.9	-0.6	0.9
870210a	MTW012	6.3	7.4	4.6	1.2	1.7	0.5	2.5	5.4	9.4	u	u	21.7	17.3	4.4	1.3
870210b	MTW013	6.3	7.1	6.9	0.7	2.0	0.7	4.0	4.9	9.3	u	u	23.7	18.2	5.5	1.3
870217a	MTW014	2.1	1.1	2.5	0.7	1.4	0.5	1.5	1.3	3.9	u	0.6	8.3	7.3	1.0	1.1

Table 4.7C. Chemical concentrations and loadings of snowpack (pit) profiles, Central Sierra Snow Lab and Mammoth Mtn.

Central Sierra Snow Lab

Core	SWE(m)	µS cm^{-1}	pH	µeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
Date: 870113													
A	0.230	4.2	5.11	L^{-1}	7.7	2.6	4.9	1.3	4.1	0.8	2.9	6.6	4.3
				m^{-2}	1766.0	602.8	1117.6	307.7	937.8	180.0	671.8	1524.5	996.3
B	0.238	4.7	5.07	L^{-1}	8.6	3.1	3.7	1.3	4.5	0.6	3.2	7.4	4.7
				m^{-2}	2045.3	734.8	892.4	320.6	1061.3	135.1	750.9	1752.6	1124.0
Mean	0.234	4.4	5.09	L^{-1}	8.1	2.9	4.3	1.3	4.3	0.7	3.0	7.0	4.5
				m^{-2}	1905.6	668.8	1005.0	314.2	999.6	157.6	711.4	1638.6	1060.1
Date: 870131													
A	0.281	4.1	5.09	L^{-1}	8.1	2.9	2.2	0.7	2.8	0.3	2.8	5.6	3.7
				m^{-2}	2280.8	805.3	629.9	188.2	784.9	72.8	796.2	1560.4	1033.9
B	0.281	4.2	5.12	L^{-1}	7.7	2.6	1.8	0.4	2.8	0.5	2.7	5.7	3.8
				m^{-2}	2151.0	734.6	497.3	124.1	788.0	144.9	760.3	1591.2	1069.8
Mean	0.281	4.1	5.10	L^{-1}	7.9	2.7	2.0	0.6	2.8	0.4	2.8	5.6	3.7
				m^{-2}	2215.9	769.9	563.6	156.2	786.4	108.8	778.3	1575.8	1051.8
Date: 870214													
A	0.450	3.2	5.31	L^{-1}	4.9	2.0	1.9	0.4	2.7	0.7	3.5	3.3	2.4
				m^{-2}	2192.4	880.9	851.4	187.5	1213.5	306.1	1571.4	1468.1	1060.0
B	0.469	2.6	5.40	L^{-1}	4.0	1.4	1.6	0.2	2.1	0.6	2.4	2.4	1.8
				m^{-2}	1873.4	668.9	757.3	86.2	987.9	275.8	1124.5	1120.1	863.8
Mean	0.460	2.9	5.35	L^{-1}	4.4	1.7	1.8	0.3	2.4	0.6	2.9	2.8	2.1
				m^{-2}	2032.9	774.9	804.3	136.9	1100.7	291.0	1348.0	1294.1	961.9
Date: 870228													
A	0.460	3.9	5.25	L^{-1}	5.6	1.5	1.6	0.5	3.2	0.7	3.0	3.6	2.3
				m^{-2}	2594.4	698.1	721.6	232.1	1486.4	327.4	1393.4	1665.4	1073.0
B	0.447	4.0	5.20	L^{-1}	6.4	2.4	1.9	0.4	3.3	0.6	3.9	3.2	2.9
				m^{-2}	2845.9	1065.9	859.5	188.1	1465.2	249.8	1753.4	1425.9	1305.4
Mean	0.454	3.9	5.22	L^{-1}	6.0	1.9	1.7	0.5	3.3	0.6	3.5	3.4	2.6
				m^{-2}	2720.2	882.0	790.6	210.1	1475.8	288.6	1573.4	1545.7	1189.2
Date: 870314													
C	0.567	3.0	5.36	L^{-1}	4.4	1.3	0.6	0.4	2.3	0.2	2.5	2.0	1.7
				m^{-2}	2482.1	710.5	334.4	213.1	1308.0	93.5	1436.8	1107.1	960.9
Date: 870411													
A	0.460	1.9	5.44	L^{-1}	3.6	1.4	1.0	0.3	1.8	0.7	2.0	2.1	1.6
				m^{-2}	1656.6	651.2	472.1	124.0	849.3	336.6	905.0	962.6	730.4
B	0.502	1.7	5.55	L^{-1}	2.8	0.8	1.2	0.5	2.8	0.9	3.5	1.2	0.8
				m^{-2}	1428.9	400.2	609.1	229.7	1418.9	438.5	1776.7	611.1	411.4
Mean	0.481	1.8	5.49	L^{-1}	3.2	1.1	1.1	0.4	2.4	0.8	2.8	1.6	1.2
				m^{-2}	1542.7	525.7	540.6	176.9	1134.1	387.5	1340.8	786.9	570.9
Date: 870424													
A	0.275	2.4	5.61	L^{-1}	2.4	0.9	1.2	0.4	2.4	0.9	1.3	1.5	1.1
				m^{-2}	669.4	258.4	323.3	99.1	661.5	258.4	363.2	417.7	308.2
B	0.271	2.0	5.48	L^{-1}	3.3	0.8	0.8	0.4	1.7	0.4	2.8	1.1	1.1
				m^{-2}	900.5	219.9	228.0	102.2	451.8	108.0	757.3	300.8	304.3
Mean	0.273	2.2	5.54	L^{-1}	2.9	0.9	1.0	0.4	2.0	0.7	2.1	1.3	1.1
				m^{-2}	784.9	239.1	275.6	100.7	556.7	183.2	560.2	359.2	306.2

Table 4.7C. (continued)

Mammoth Lakes

Core	SWE(m)	μS cm^{-1}	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
Date: 870117													
A	0.176	2.7	5.58	L^{-1}	2.6	1.6	3.7	1.0	1.2	0.5	2.6	5.5	4.1
				m^{-2}	461.6	279.0	645.4	168.2	212.4	79.8	453.8	960.4	723.8
B	0.196	2.5	5.68	L^{-1}	2.1	2.3	3.5	1.0	1.6	0.5	2.1	4.9	3.9
				m^{-2}	413.0	455.4	678.9	196.0	304.7	88.7	403.7	955.7	769.4
Mean	0.186	2.6	5.63	L^{-1}	2.4	2.0	3.6	1.0	1.4	0.5	2.3	5.2	4.0
				m^{-2}	437.3	367.2	662.2	182.1	258.6	84.2	428.8	958.0	746.6
Date: 870131													
A	0.138	2.9	5.48	L^{-1}	3.3	3.7	4.8	0.6	1.9	0.6	0.7	7.2	4.5
				m^{-2}	456.0	517.2	666.0	88.8	266.4	82.8	101.4	987.6	616.8
B	0.134	3.1	5.53	L^{-1}	3.0	3.0	2.8	0.5	1.6	0.6	0.7	6.9	4.1
				m^{-2}	399.6	399.6	371.0	61.0	215.8	80.4	88.2	918.8	542.8
Mean	0.136	3.0	5.50	L^{-1}	3.1	3.4	3.8	0.6	1.8	0.6	0.7	7.0	4.3
				m^{-2}	427.8	458.4	518.5	74.9	241.1	81.6	94.8	953.2	579.8
Date: 870214													
C	0.333	2.6	5.50	L^{-1}	3.2	2.4	1.8	0.1	1.5	0.5	1.4	3.6	3.4
				m^{-2}	1063.2	792.2	582.9	15.6	497.8	172.8	463.4	1197.8	1121.4
Date: 870228													
A	0.371	2.1	5.62	L^{-1}	2.4	1.8	3.7	0.4	0.5	0.2	0.5	4.3	2.6
				m^{-2}	888.9	650.5	1390.9	145.1	189.2	79.0	190.3	1589.3	954.7
B	0.318	2.2	5.66	L^{-1}	2.2	2.4	1.6	0.4	0.5	0.3	0.6	1.7	3.6
				m^{-2}	693.0	763.5	512.4	118.2	158.7	100.8	194.4	539.4	1140.6
Mean	0.344	2.1	5.64	L^{-1}	2.3	2.1	2.8	0.4	0.5	0.3	0.6	3.1	3.0
				m^{-2}	790.9	707.0	951.7	131.6	174.0	89.9	192.4	1064.3	1047.6
Date: 870315													
A	0.511	2.4	5.73	L^{-1}	1.9	2.6	3.2	0.5	1.3	0.7	1.4	4.3	3.2
				m^{-2}	952.1	1321.2	1622.1	277.3	655.6	355.2	698.2	2180.5	1629.1
B	0.494	2.3	5.52	L^{-1}	3.0	2.3	1.4	0.3	1.0	0.4	2.3	2.3	2.8
				m^{-2}	1495.0	1151.5	687.8	147.4	492.4	206.6	1112.7	1153.4	1383.3
Mean	0.502	2.4	5.61	L^{-1}	2.4	2.5	2.3	0.4	1.1	0.6	1.8	3.3	3.0
				m^{-2}	1223.5	1236.4	1155.0	212.3	574.0	280.9	905.5	1666.9	1506.2
Date: 870414													
A	0.432	1.9	5.85	L^{-1}	1.4	2.2	1.7	0.1	1.3	0.2	0.9	2.6	1.1
				m^{-2}	612.6	958.6	722.4	61.0	541.2	84.0	400.4	1119.2	492.8
B	0.438	1.8	5.71	L^{-1}	2.0	1.7	2.1	0.2	1.5	0.2	0.9	2.9	1.4
				m^{-2}	861.5	753.6	914.4	68.0	677.4	72.6	412.9	1266.1	626.5
Mean	0.435	1.8	5.77	L^{-1}	1.7	2.0	1.9	0.1	1.4	0.2	0.9	2.7	1.3
				m^{-2}	737.1	856.1	818.4	64.5	609.3	78.3	406.7	1192.6	559.6

Table 4.7D. Chemical concentrations and loadings of snowpack (pit) profiles, 10 sites surveyed in late March 1987.

Alpine Meadows

Location: 39°08′ N,120°15′ W
Elevation (m): 2200
Date: 870328

Core	SWE(m)	μS cm^{-1}	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
A	0.741	3.5	5.46	L^{-1}	3.4	3.5	5.3	3.1	4.4	2.5	4.6	3.0	5.5
				m^{-2}	2544.2	2578.1	3902.4	2260.6	3263.2	1821.8	3428.9	2222.9	4093.9
B	0.760	2.8	5.41	L^{-1}	3.9	1.5	3.9	1.7	3.8	1.5	3.5	2.8	3.2
				m^{-2}	2931.5	1109.0	2970.4	1318.9	2907.5	1103.0	2651.4	2103.6	2463.7
Mean	0.750	3.2	5.44	L^{-1}	3.6	2.5	4.6	2.4	4.1	1.9	4.1	2.9	4.4
				m^{-2}	2737.8	1843.6	3436.4	1789.8	3085.4	1462.4	3040.1	2163.3	3278.8

Eastern Brook Lake

Location: 37°26′ N,118°44′ W
Elevation (m): 3150
Date: 870330

Core	SWE(m)	μS cm^{-1}	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
A	0.190	4.1	5.29	L^{-1}	5.1	2.9	1.6	1.0	0.5	0.7	1.3	2.0	2.5
				m^{-2}	967.7	548.4	313.4	199.4	90.2	126.9	255.1	385.0	479.6
B	0.173	5.0	5.18	L^{-1}	6.6	2.3	2.0	1.3	0.8	0.7	1.3	2.2	2.7
				m^{-2}	1149.6	392.2	349.9	226.8	142.3	121.2	219.2	381.0	467.3
Mean	0.181	4.5	5.23	L^{-1}	5.8	2.6	1.8	1.2	0.6	0.7	1.3	2.1	2.6
				m^{-2}	1058.7	470.3	331.6	213.1	116.2	124.1	237.2	383.0	473.5

Central Sierra Snow Lab

Location: 39°20′ N,120°22′ W
Elevation (m): 2100
Date: 870328

Core	SWE(m)	μS cm^{-1}	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
A	0.615	3.1	5.47	L^{-1}	3.4	1.9	1.0	0.5	4.1	0.5	3.1	2.5	2.1
				m^{-2}	2095.9	1176.5	608.3	334.1	2502.9	297.1	1918.4	1558.6	1302.3
B	0.593	2.8	5.38	L^{-1}	4.2	1.7	1.2	0.6	2.5	0.4	4.8	2.0	1.9
				m^{-2}	2476.3	979.7	701.9	356.9	1479.0	254.1	2841.5	1210.7	1133.2
Mean	0.604	3.0	5.42	L^{-1}	3.8	1.8	1.1	0.6	3.3	0.5	3.9	2.3	2.0
				m^{-2}	2286.1	1078.1	655.1	345.5	1991.0	275.6	2380.0	1384.7	1217.7

Mt. Dyer

Location: 40°15′ N,121°02′ W
Elevation (m): 2165
Date: 870323

Core	SWE(m)	μS cm^{-1}	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
A	0.469	3.2	5.27	L^{-1}	5.4	0.5	2.8	1.8	2.7	1.9	2.2	2.8	2.2
				m^{-2}	2525.0	222.5	1302.4	854.7	1287.6	868.0	1029.9	1334.1	1049.7
B	0.483	3.4	5.24	L^{-1}	5.8	0.6	3.6	1.7	4.3	2.5	2.4	2.0	2.4
				m^{-2}	2777.5	284.1	1718.2	825.6	2057.4	1191.7	1154.2	988.1	1151.7
Mean	0.476	3.3	5.25	L^{-1}	5.6	0.5	3.2	1.8	3.5	2.2	2.3	2.4	2.3
				m^{-2}	2651.3	253.3	1510.3	840.2	1672.5	1029.8	1092.1	1161.1	1100.7

Heavenly Valley

Location: 38°56′ N,119°55′ W
Elevation (m): 2950
Date: 870325

Core	SWE(m)	μS cm^{-1}	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
A	0.667	3.5	5.21	L^{-1}	6.2	2.7	3.5	1.3	4.4	1.2	3.2	4.3	5.2
				m^{-2}	4126.1	1792.6	2354.7	899.3	2955.0	821.7	2142.5	2863.5	3437.3
B	0.710	4.0	5.18	L^{-1}	6.6	3.0	3.5	1.7	4.6	1.4	3.4	4.8	6.5
				m^{-2}	4711.2	2141.6	2510.6	1228.0	3247.8	988.8	2380.0	3406.2	4598.8
Mean	0.689	3.8	5.19	L^{-1}	6.4	2.9	3.5	1.5	4.5	1.3	3.3	4.6	5.8
				m^{-2}	4418.7	1967.1	2432.6	1063.6	3101.4	905.2	2261.3	3134.8	4018.0

Emerald Lake

Location: 36°36′ N,118°40′ W
Elevation (m): 2900
Date: 870318

Core	SWE(m)	μS cm^{-1}	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
A	0.498	3.1	5.52	L^{-1}	3.0	2.7	2.7	1.0	0.2	0.1	1.4	3.5	2.8
				m^{-2}	1494.0	1344.6	1344.6	498.0	99.6	49.8	697.2	1743.0	1394.4
B	0.498	2.7	5.42	L^{-1}	3.8	2.3	1.8	0.6	0.1	0.1	1.0	3.4	2.8
				m^{-2}	1892.4	1145.4	896.4	298.8	49.8	49.8	498.0	1693.2	1394.4
Mean	0.498	2.9	5.47	L^{-1}	3.4	2.5	2.3	0.8	0.1	0.1	1.2	3.5	2.8
				m^{-2}	1693.2	1245.0	1120.5	398.4	74.7	49.8	597.6	1718.1	1394.4

Figure 4.7D. (continued)

Kirkwood

Location: 38°40′ N,120°05′ W
Elevation (m): 2450
Date: 870327

Core	SWE(m)	µS cm^{-1}	pH	µeq	H$^+$	NH$_4^+$	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	Cl$^-$	NO$_3^-$	SO$_4^{2-}$
A	0.461	4.2	5.16	L^{-1}	7.0	0.6	4.5	2.7	3.8	2.3	4.9	3.8	3.1
				m^{-2}	3219.3	266.4	2076.7	1256.7	1751.2	1067.5	2242.1	1750.6	1420.8
B	0.478	4.3	5.11	L^{-1}	7.7	0.5	4.8	3.3	3.7	2.5	4.7	1.8	3.4
				m^{-2}	3673.5	257.2	2307.2	1563.2	1789.0	1216.5	2241.7	857.6	1612.9
Mean	0.469	4.2	5.13	L^{-1}	7.3	0.6	4.7	3.0	3.8	2.4	4.8	2.8	3.2
				m^{-2}	3446.4	261.8	2191.9	1409.9	1770.1	1142.0	2241.9	1304.1	1516.9

Lower Big Draw

Location: 34°07′ N,116°50′ W
Elevation (m): 2900
Date: 870324

A	0.376	7.1	5.13	L^{-1}	7.4	5.8	2.5	1.8	5.1	0.5	15.8	5.8	8.6
				m^{-2}	2773.0	2198.8	958.4	695.5	1899.8	179.2	5955.9	2192.7	3234.3
B	0.377	7.2	5.16	L^{-1}	7.0	6.0	2.9	2.0	5.7	0.3	14.4	6.3	10.2
				m^{-2}	2637.6	2264.3	1082.0	760.1	2144.9	108.6	5426.5	2373.0	3852.3
Mean	0.377	7.2	5.14	L^{-1}	7.2	5.9	2.7	1.9	5.4	0.4	15.1	6.1	9.4
				m^{-2}	2705.3	2231.5	1020.2	727.8	2022.4	143.9	5691.2	2282.9	3543.3

Mammoth Mountain

Location: 37°38′ N,119°01′ W
Elevation (m): 2900
Date: 870326

A	0.488	3.1	5.64	L^{-1}	2.3	2.2	4.2	0.7	0.4	0.3	1.0	4.5	2.3
				m^{-2}	1113.4	1073.5	2041.3	357.7	205.8	135.2	491.7	2219.6	1122.5
B	0.487	3.1	5.94	L^{-1}	1.2	2.5	4.7	0.7	0.3	0.1	1.1	4.3	2.4
				m^{-2}	562.9	1241.3	2293.1	341.1	155.5	68.7	551.2	2099.3	1182.0
Mean	0.487	3.1	5.76	L^{-1}	1.7	2.4	4.4	0.7	0.4	0.2	1.1	4.4	2.4
				m^{-2}	838.1	1157.4	2167.2	349.4	180.6	102.0	521.5	2159.5	1152.3

Snow Summit

Location: 34°14′ N,116°52′ W
Elevation (m): 2150
Date: 870323

A	0.052	9.5	5.28	L^{-1}	5.2	19.0	3.2	2.0	6.7	0.4	14.4	18.7	10.6
				m^{-2}	270.4	988.0	166.4	104.0	348.4	20.8	748.8	972.4	551.2
B	0.052	9.5	5.19	L^{-1}	6.5	20.0	4.3	2.1	6.0	0.2	14.4	16.9	10.7
				m^{-2}	338.0	1040.0	223.6	109.2	312.0	10.4	748.8	878.8	556.4
Mean	0.052	9.5	5.23	L^{-1}	5.8	19.5	3.8	2.0	6.3	0.3	14.4	17.8	10.7
				m^{-2}	304.2	1014.0	195.0	106.6	330.2	15.6	748.8	925.6	553.8

Table 4.8. Cumulative, volume-weighted mean concentrations and loadings, 1986-1987 winter, Central Sierra Snow Laboratory and Mammoth Mountain.

Central Sierra Snow Lab

Sample Type	SWE(m)	$\mu S\ cm^{-1}$	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
Event Board	0.621	3.4	5.26	L^{-1}	5.5	2.3	1.8	0.7	4.3	0.5	5.1	4.1	2.8
				m^{-2}	3403.6	1435.6	1141.3	417.6	2647.4	281.4	3172.9	2519.6	1710.3
Weekly Board	0.611	3.4	5.21	L^{-1}	6.2	1.8	2.2	0.6	3.6	0.3	4.1	3.3	2.6
				m^{-2}	3759.3	1073.0	1331.8	396.5	2221.3	197.9	2504.7	2038.2	1608.4
PVC Tube	0.734	4.4	5.15	L^{-1}	7.0	2.9	4.8	1.0	5.2	0.9	6.2	5.1	5.1
				m^{-2}	5121.7	2126.8	3494.1	713.9	3828.6	662.3	4579.9	3740.9	3731.3
Snow Pit	0.604	3.0	5.42	L^{-1}	3.8	1.8	1.1	0.6	3.3	0.5	3.9	2.3	2.0
3/28/87				m^{-2}	2286.1	1078.1	655.1	345.5	1991.0	275.6	2380.0	1384.7	1217.7

Mammoth Mountain

Sample Type	SWE(m)	$\mu S\ cm^{-1}$	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
Event Board	0.575	2.4	5.55	L^{-1}	2.8	2.3	2.5	0.5	1.2	0.6	1.0	4.0	2.8
				m^{-2}	1588.9	1331.2	1435.3	278.2	686.1	339.5	570.6	2280.4	1614.1
Weekly Board	0.609	2.8	5.72	L^{-1}	1.9	1.6	4.3	0.6	1.6	0.8	1.2	4.9	3.0
				m^{-2}	1169.8	994.6	2616.3	370.4	953.0	465.3	760.6	2981.2	1799.8
PVC Tube	0.486	3.1	5.48	L^{-1}	3.3	2.0	5.2	0.7	2.1	0.3	2.8	5.5	4.6
				m^{-2}	1626.6	991.1	2528.3	360.4	1039.5	165.8	1377.8	2682.2	2231.6
Snow Pit	0.487	3.1	5.76	L^{-1}	1.7	2.4	4.4	0.7	0.4	0.2	1.1	4.4	2.4
3/26/87				m^{-2}	838.1	1157.4	2167.2	349.4	180.6	102.0	521.5	2159.5	1152.3

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* Physical samples were collected for events when chemistry samples became contaminated or when none were taken. For these physical samples, snow water equivalence is calculated and the cumulative, volume-weighted mean concentrations are substituted for the missing chemistry data. Those values are included in the cumulative table. The list of total snow water equivalence for missing chemistry samples appears below.

Mammoth Mountain				Central Sierra Snow Lab			
Sample Type	Event Board	Weekly Board	PVC Tube	Sample Type	Event Board	Weekly Board	PVC Tube
SWE added (m)	0.169	0.006	0.043	SWE(m)	0.008	___	0.065

Table 4.9. Cumulative, volume-weighted mean concentrations and loadings, 1986-1987 winter, for events with at least 1.5 cm snow water equivalent, Central Sierra Snow Laboratory and Mammoth Mountain.

Central Sierra Snow Lab

Sample Type	SWE(m)	μS cm^{-1}	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
Event Board	0.449	2.7	5.32	L^{-1}	4.8	1.7	1.7	0.5	2.7	0.4	2.8	3.2	2.2
				m^{-2}	2151.3	742.1	759.0	223.6	1213.1	162.3	1262.8	1450.5	968.1
Weekly Board	0.594	3.2	5.23	L^{-1}	5.9	1.6	2.1	0.6	3.3	0.3	3.8	2.9	2.4
				m^{-2}	3476.0	925.8	1262.9	372.7	1987.7	184.9	2255.2	1724.0	1441.4
PVC Tube	0.635	3.7	5.18	L^{-1}	6.6	2.3	4.1	0.8	3.7	0.8	4.5	4.2	4.3
				m^{-2}	4219.9	1475.8	2575.3	531.1	2376.6	523.1	2848.2	2685.1	2704.3

Mammoth Mountain

Sample Type	SWE(m)	μS cm^{-1}	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
Event Board	0.333	2.2	5.64	L^{-1}	2.3	2.2	1.8	0.4	0.8	0.5	0.7	3.2	2.2
				m^{-2}	782.4	726.8	585.5	125.4	279.7	175.2	238.2	1069.5	740.8
Weekly Board	0.572	2.7	5.74	L^{-1}	1.8	1.5	4.1	0.6	1.4	0.8	1.2	4.8	2.5
				m^{-2}	1041.8	845.8	2318.4	332.9	821.6	434.1	676.3	2730.8	1447.8
PVC Tube	0.381	2.8	5.51	L^{-1}	3.1	1.7	4.1	0.6	1.8	0.2	1.9	4.8	3.8
				m^{-2}	1191.1	662.3	1565.8	246.1	700.4	95.0	720.0	1820.1	1449.7

Table 4.10. Cumulative, volume-weighted mean concentrations and loadings, 1986-1987 winter, for events with less than 1.5 cm snow water equivalent, Central Sierra Snow Laboratory and Mammoth Mountain.

Central Sierra Snow Lab

Sample Type	SWE(m)	$\mu S\ cm^{-1}$	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
Event Board	0.164	5.2	5.13	L^{-1}	7.4	4.1	2.2	1.1	8.5	0.7	11.4	6.3	4.4
				m^{-2}	1208.3	675.1	367.9	188.4	1399.9	115.1	1869.3	1036.3	719.9
Weekly Board	0.017	10.9	4.78	L^{-1}	16.7	8.7	4.1	1.4	13.7	0.8	14.7	18.5	9.8
				m^{-2}	283.3	147.3	69.0	23.8	233.6	13.0	249.5	314.2	167.0
PVC Tube	0.034	16.5	4.88	L^{-1}	13.3	13.8	18.1	3.5	33.3	2.4	39.7	21.6	20.8
				m^{-2}	446.8	462.6	606.8	117.7	1114.0	80.7	1328.7	724.4	695.5

Mammoth Mountain

Sample Type	SWE(m)	$\mu S\ cm^{-1}$	pH	μeq	H^+	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}
Event Board	0.073	3.8	5.34	L^{-1}	4.6	3.0	5.9	0.9	2.8	0.9	2.3	7.6	5.5
				m^{-2}	333.3	215.7	427.3	68.3	203.6	62.9	163.4	551.9	400.1
Weekly Board	0.031	4.6	5.42	L^{-1}	3.8	4.5	8.8	1.1	3.9	0.9	2.5	7.1	10.8
				m^{-2}	116.6	139.3	272.1	33.9	121.7	26.4	77.2	221.0	333.9
PVC Tube	0.063	5.2	5.33	L^{-1}	4.7	3.9	11.7	1.3	4.0	0.9	8.5	9.9	9.3
				m^{-2}	293.6	242.9	738.9	84.3	248.8	58.0	537.5	625.5	584.1

Figure 4.7. Weekly minimum (lower horizontal line), mean (middle horizontal line), and maximum (upper horizontal line) solute concentrations of SO_4^{2-}, NO_3^-, Cl^-, H^+, NH_4^+, Na^+, Ca^{2+}, Mg^{2+}, and K^+ from PVC tube, summed daily board (to weekly totals), and weekly board samples, winter of 1986-1987 (CSSL, Mammoth Mountain). Offscale values shown by open-ended column.