FINAL REPORT

TITLE: Acid Deposition Monitoring in an Alpine Snowpack

California Air Resources Board Contract A4-038-32

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Effective Date of CA Order:	July 2, 1984
CA Order Expiration Date:	June 1, 1986
Amount of CA Order:	$13,475.00
Expenditures July 2, 1984 through March 30, 1985:	$ 6,104.64
Expenditures April 1, 1985 through June 30, 1985:	$ 3,588.51
Reporting Period (Fourth Quarter):	April 1, 1985 through June 30, 1985
Report Submission Date:	August 15, 1986

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ABSTRACT:

Regular weekly sampling and chemical analysis of rain, snow and dry deposition was carried out at a site 3,000 m ASL on Mammoth Mountain as part of the Air Resources Board's California Acid Deposition Monitoring Program (CADMP). The site was used for event sampling of precipitation for the three previous years. The site is significant in that it is typical of a wide range of the alpine region of the Sierra Nevada. Precipitation chemistry followed the pattern of the three previous years with mildly acidic summer rainstorms and very dilute snow with little acid. Four methods of collecting snow, including the standard ARB Network wet/dry collector were compared in an effort to devise an improved, standardized method for handling the unique conditions of an alpine site. These include high winds and high precipitation accumulations. None of the methods were satisfactory as a final solution. The failure of the wet/dry collector to handle these conditions was documented.

ACKNOWLEDGMENTS

I wish to thank Mr. Dave McCoy and the Mammoth Mountain Ski Area for providing the snow study site, constructing the instrument tower and providing access and assistance. Without their help and support this study could not have been undertaken. The site is operated under special use permit from the Inyo National Forest and the staff of the Mammoth Ranger District is acknowledged. I thank Ms. Perry Edgerton and Dr. Steven Nodvin for their help with the anion analysis and Dr. Robert Petty for his help with the cation analysis. Special thanks to Dr. Henry Offen for his help and support in procuring the contract, and the support and facilities of the Marine Science Institute and the Seirra Nevada Aquatic Research Laboratory.

This report was submitted in fulfillment of ARB Contract Number A4-038-32, "Acid Deposition Monitoring in an Alpine Snowpack," by the Marine Science Institute, University of California, Santa Barbara, under sponsorship of the California Air Resources Board. Work was completed as of July 1, 1985.

SUMMARY AND CONCLUSIONS

Regular weekly sampling and chemical analysis of rain, snow and dry deposition was carried out at a site 3,000 m ASL on Mammoth Mountain as part of the Air Resources Board's California Acid Deposition Monitoring Program (CADMP). This was in order to establish the pH and chemical composition of the deposition from year to year. The site has been used for event based sampling for the last three years. The site is significant as it is typical of the alpine region of the Sierra Nevada with total snowfall that may exceed 1,500 cm (590").

High winds and large accumulation of snow lead to special problems in collecting snow for chemical analysis. Collectors may grossly undersample due to wind or may be overwhelmed by large events. The standard Network wet/dry collector was thought to be a poor snow collector in this environment. Four methods of collecting snow for chemical analysis, including the wet/dry collector were compared with respect to volume, chemistry and utility in an effort to devise an improved, standardized method. Principal results and conclusions from this study are as follows:

1. A total of approximately 2.5" of rain was recorded from 7/17/84 to 10/9/84. pH values ranged from 4·45 to 5·21 with a volume weighted mean pH of approximately 4 74. Nitrate to sulfate, in a ratio of ≈ 1.5/1 (equivalence) contribute to the acidity.

2. A total of approximately 33" of moisture in the form of snow was recorded by weighing rain gauge from 10/9/84 to 5/7/85. Based on literature review and observations from the collection site this figure is probably low by at least 100%. pH values ranged from 4·54 to 5·98 with an approximate volume weighted mean of 5·41. Nitrate and sulfate values were generally low.

3. This weekly interval sampling data is consistent with results from event sampling at the same site for the last three years.

4. The standard ARB Network wet/dry collector was found to be a poor collector for snow at an alpine site. Catch deficiency due to wind and failure of the sensor to trigger during cold windy events led to a wide scatter in collector catch. For 10 of the 29 intervals when snow fell and the collector was operational, less than 100 mls of meltwater was available from the collector for analysis. A sample volume of approximately 100 mls is necessary for chemical analysis. These samples ranged in catch (collection efficiency) from 0% to 5%.

5. A snowboard proved to be a poor collector of snow for weekly interval sampling that is used in a monitoring context to make estimates of solute loading over a wide region. Although on many occasions the board had much more accumulation than recorded by the weighing gauge, on seven occasions no snow was accumulated on the board. Wind scour and snow redistribution are the cause. The board would be useful for event sampling and a series of boards, visited daily or twice daily might provide the best estimates of "true" precipitation.

6. The modified Lewis collector is a poor candidate for further development as a snow collector. Its blocky shape makes it susceptible to wind effects and difficult to shield. A.C. power is required and the collector is prone to mechanical/electrical failure and also it may be overwhelmed during large events. Cleaning is difficult and requires large volumes of water to be transported to the collection site. Contamination of the sample appears to be a problem.

7. The snow tube/snow bag with alter shield appears to be the best candidate for further development as a snow collector. Leakage and contamination from the bag were the most significant problems. Elimination of the bag and development of a polyvinyl chloride (PVC) collector that would be capped and exchanged like wet/dry collector buckets should be tried next. The shape and size of the collector would mimic that of a rain gauge making it easy to shield.

RECOMMENDATIONS

1. Maintain deposition monitoring at an alpine site to continue to provide data on precipitation chemistry typical of a wide range of the Sierra Nevada.

2. Continue development of a reliable, standardized snow sampling scheme for such sites.

3. Initiate a program to establish, as precisely as possible, a measure of "true" precipitation at such a site in order to make estimates of catch deficiencies of the standard weighing rain gauge under these conditions. This is critical to estimates of solute loading.

4. Simultaneously initiate a program to record wind direction and speed in an effort to correlate this with catch deficiency and possibly provide a correction factor for different wind speeds that might further refine loading estimates.

5. Use data derived in 3. and 4. above to further refine collector and make estimates as to how representative the sample is.

6. Initiate a program to provide estimates as to the contribution of dryfall to snow chemistry in bulk snow collectors.

7. Initiate a study to examine the reliability of existing analytical methods for very dilute snow samples. Attention should be focused on sensitivity, detection limits and potential sources of contamination. This is most important for cations.

INTRODUCTION

Acid deposition is now recognized to be a serious environmental problem in North America (1,2). Dilute lakes and streams with low buffer capacity, such as occur in the Sierra Nevada, are especially sensitive to acid deposition (3,4). Acid deposition occurs in the form of wet precipitation or dry deposition.

Evidence clearly shows some acid rain in the Sierra Nevada (5,6). However, snow constitutes as much as 80% of the precipitation falling on the Sierra Nevada. Careful, long-term monitoring and chemical analysis of snowfall at a representative site are needed to judge the significance of acid precipitation (7).

Alpine and sub-alpine sites present very special problems with respect to precipitation sampling. At the 3000 m ASL on Mammoth Mountain, California total deposition may exceed 1,500 cm with accumulation of 500 cm and individual events of 100 cm. Collection by standard network methods with a wet/dry collector fails as snow overfills the bucket (8). At the Hodgdon Meadow site in Yosemite National park at 1,560 m ASL at least two such failures have been documented (9). The other problem associated with sampling at such site is wind. A proposed NADP site at 3,680 m ASL on Niwot Ridge in Colorado has not been operated due in part to sampling problems (10). Winter winds average approximately 40 mph. A standard wet/dry collector ends up with almost no snow in the wet bucket and full of snow in the dry bucket.

The Kapiloff Acid Deposition Act of 1982 (California Health and Safety Code, Sections 39010.5, 39010.6, and 39000 et seq.) provides for the design and implementation of a comprehensive research and monitoring program to identify areas in California that are especially sensitive to acid deposition and to assess the extent of and significant impacts of acid deposition. Continued monitoring is required at an alpine site as part of a regular statewide network. Special efforts must be made to compare a variety of methods for sampling the alpine snowpack.

The objectives of this research on acid deposition in the alpine region of the Sierra Nevada were the following:

A. Initiate regular weekly sampling and chemical analysis of rain, snow and dry deposition as part of the Air Resources Board's California Acid Deposition Monitoring Program (CADMP). This is in order to establish the pH and chemical composition of deposition and its variability from season to season and year to year. This work was a continuation of the event-basis sampling at this site for the last three years.

B. Compare four different methods for chemical sampling of an alpine snowpack with effort directed toward developing an accurate, reliable, standardized method.

METHODS

Sampling was performed at a site at 3,000 m ASL on Mammoth Mountain approximately 4 km west of the town of Mammoth Lakes, California. The site is in a flat area located just below tree lines. The site is located on Inyo National Forest land within the Mammoth Mountain Ski Area. The site is approximately 150 m from the nearest building, 200 m from the nearest chain lift, and 20 m in elevation above each. All lifts on Mammoth Mountain are electric. The site is approximately 1.5 km from and 300 m above the nearest paved road (State Highway 203). Access during the summer is via dirt road with four-wheel drive. The site is located on a spur road that gets virtually no traffic. The main dirt access road is approximately 150 m away and 20 m below the site and receives very little traffic. Access during the winter is available only by using the ski lifts.

A. Deposition Monitoring:

Monitoring of wet and dry deposition was performed as per ARB network procedures (8). An Aerochemetrics wet/dry collector and an 8-inch Belfort weighing rain gauge with Alter shield were mounted on the ground on July 17, 1984. The monitoring was done here until November 9, 1984 when the instruments were located atop a 6 m steel tower constructed for the benefit of the principal investigators by Mammoth Mountain Ski Area. The high tower is necessary because of the extreme snow accumulation which may exceed 5 m. The wet/dry collector was inoperable from this time until December 4, 1984, when electrical power was provided to the tower.

The 8-inch weighing rain gauge was replaced by a 30-inch (capacity) weighing rain gauge on February 6, 1985 to allow the gauge to be charged with a sufficient volume of antifreeze.

Upon collection, the samples were transported 33 km to the Sierra Nevada Aquatic Research Laboratory for analysis. Snow samples were allowed to melt at room temperature. Samples were worked up as per ARB network procedures. pH was measured with a digital pH meter (Fisher Acumet 825 MP) equipped with a low ionic strength media electrode (Jena Glass Works; Sargeant Welch S-30072-15). The meter was calibrated with pH 7 and pH 4 buffers, and washed for 10 minutes with stirred, distilled water. The pH determination was made after a 5 minute equilibration in an unstirred sample. Electrical conductance of unfiltered samples was measured with a digital conductance meter (YSI Model 32) equipped with a K = 0.1 probe. The samples are then shipped unfiltered to the ARB lab. Dryfall samples were taken every 8 weeks, except for a period when the dryfall analysis was suspended. Dryfall sample buckets were shipped directly to the ARB lab.

B. Comparison of Snow Sampling Methods:

Snow was sampled, concurrent with the regular monitoring schedule, by four different methods. A wet/dry collector was used (as described above) as one method. This method is designed to separate wet and dry deposition. The other three methods sample bulk deposition.

The second method is referred to herein as the snowboard. This method allows weekly deposition to accumulate on top of a board to which a pipe, calibrated for depth of accumulated snow, is attached. The board sits on the surface of the snowpack, and must be dug out and replaced on the surface weekly. An integrated snow sample is taken off the board with a polyvinyl chloride (PVC) coring device modeled after a Mt. Rose snow sampler. The device was developed by J. L. Stoddard as part of a grant from the University of California Water Resources Center, from readily available material. The body of the sampler is made from 2" schedule 40 PVC pipe, 70 cm long with an internal diameter of 4.6 cm. One end of the device is beveled (with the outer diameter cut away), the other is fitted with a tapped plug to which threaded rods may be attached. If snow depth on the board exceeds the length of the sampler, the snow is sampled in sections. Prior to the first use, the sampler was soaked in 10% HCL, then rinsed copiously. Tests in which deionized, distilled water was left soaking inside the sampler for 12 hours showed no significant increase in conductivity. Water equivalence of the snow column was determined with a commercially available kit (Snow Research Associates).

The third sampling method uses a large plywood and plexiglass collector modified from a design described by Lewis (11). This collector is referred to herein as Lewis collector. The collector is a plexiglass funnel with a sharp edge 45.7 cm x 45.7 cm (18" x 18") opening built into a plywood cabinet. The funnel is attached to a 4 l. sample bottle with a tight screw seal. The funnel is warmed directly with heat tape on the back side to melt the falling snow and the interior of the cabinet is headed with a shielded 60-watt light bulb to keep the neck of the funnel from freezing. Both the heat tape and light bulb are controlled by an external thermostat that turns on at temperatures below 3.3°C (38°F). The narrow-necked bottle funnel reduces sample evaporation. Snow water equivalence is calculated from meltwater volume and the area of the collector opening.

The fourth method is referred to herein as the snow bag. The original intent was to use a 32 gallon plastic trash can with a plastic trash bag liner after Likens et al. (12). The large trash can opening should minimize wind effects on sample volume. No bags were located during the startup phase of this project that would fit the trash can and were strong enough to support the weight of large snow samples during transport. Bags, constructed of clear 6 mil polyethylene were located that were approxiamtely 37.5 cm (15") in diameter. These fit nicely inside a piece of 15" (nominal) schedule 80 PVC pipe. The pipe section, 1 m high, is supported upright with the bag inside and stretched over the opening of the pipe. The reduced size of the pipe was likely to increase wind effects. An Alter shield was placed around the collector midway (Feb 6, 1985) through the season.

As with ARB Network samples, samples from the other collectors were transported immediately to SNARL. Samples were allowed to melt at room temperature and then measured for volume, pH and conductivity following ARB Network procedures. Aliquots were then filtered through 0.4 µm membrane filters (Nucleopore) and refrozen for subsequent analysis. The original intent was to analyze samples immediately, without refreezing, by ion chromatography for both anions and cations. Consequently no wet chemistry analysis for the storage-sensitive constituents (NH_4^+, PO_4^-) was planned. Cation analysis on the ion chromatograph at SNARL (Dionex Model 2310i) was never developed to adequate sensitivity for these samples. Anions were analyzed in two runs on the refrozen samples. Cation analyses (except NH_4^+) were performed on an atomic absorption spectrophotometer (Varian Techtron Model AA6) with an air-acetylene flame. Samples for calcium and magnesium were spiked with lanthanum chloride. As a result no analyses for ammonium (NH_4^+) were performed.

RESULTS

Sample volumes collected for each sampling interval are summarized in Table 1. Meltwater volumes are shown for the wet/dry collector, snow bag and Lewis collector. Water equivalence of the snow samples are calculated from the meltwater volume and the area of the collector opening. For the snow board, depth of snow is indicated. Water equivalence was determined at the time of sampling. Catch is calculated as the ratio to the water equivalence from the Universal weighing rain gauge with Alter shield. The weighing rain gauge is arbitrarily assigned a catch value of 100% to have something to compare the other methods to. The sampling deficiencies of this collector scheme are well documented (13) and will be discussed later. If a collector was operational during a particular interval some value is indicated for that collector during that interval, even if the collector had mechanical failure or no sample was collected. If no value is indicated then the collector was not operational during that interval.

For the 52 weeks of operation, precipitation was recorded during 35 of the approximately weekly intervals. Of these, 21 intervals had exclusively snow events. During these 21 intervals, 4 collectors were fully operational for 13 intervals, 2 collectors only for an additional 7 intervals, and 1 interval with only 1 collector operational. Table 2 summarizes the catch data from these snow event intervals. Of particular note are the range of catch values for each collector. Wet/dry collector values ranged from 0% to 88%. The collector was operational for 29 of the 33 intervals with precipitation. During 10 of these intervals, less than 100 mls of sample was collected; however, for 2 of these a power failure was responsible. For the 20 snow events the snow board was out, no sample was accumulated 7 times.

Table 3 provides the chemical analysis data for all samples where adequate volume was available. No data is presented for PO_4^- or any cations. All of the samples except for those on 12/18/84, 1/8/85 and 3/5/85 had PO_4^- concentrations below the 5 μeq/l detection limit of the SNARL ion chromatograph. Samples from these intervals had concentrations of 5-6 μeq/l. Other methods (e.g. molybdenum blue method) have much greater sensitivity for PO_4^-. Cation analyses were performed but the data is too scattered and unreliable to be reported here. Sample concentrations are close to the detection limit of atomic absorption analysis with a flame. Consequently many samples appear to have cation concentrations of zero while others are in the hundreds of μeq/l. Charge balance calculations range from an excess of 44 for anions to an excess of 1709 for cations. Reporting the data might mislead a reader into thinking the scatter was real. The work required to analyze these samples properly for cations is beyond the scope of this project.

DISCUSSION

Sampling of winter snowfall for the purposes of chemical analysis of an alpine snowpack, is two separate but related problems. The first is the question of gauging: what is the "true" precipitation? The second deals with catching a sample specifically for chemical analysis, where the following criteria come into play.

- is the sample representative of the event?
- is there adequate sample in small events?
- is the collector overwhelmed in large events?
- is the sample or collector transportable?
- does the collector have little or no electrical power requirements?
- is the sample free from chemical contamination, and the collector easy to clean?
- is the collector affordable to construct or purchase?
- is there a chance of sample resuspension?
- is there potential for mechanical failure?

Hundreds of articles have been written on the subject of rain and snow gauges and gauge catch deficiencies. Literature review articles contain in excess of 1,600 references in the general field of precipitation measurement (13, 14, 15). An additional review of this subject is beyond the scope of this report. In brief, the effect of wind action is recognized to be the primary contributor to gauge catch deficiency. Undermeasurement of snow is most severe in non-forest regions where gauges are most exposed to wind. High winds and lack of forest cover are typical at higher elevations where the snowpack reaches its greatest depth. Thus the area that is most difficult to gauge is also very significant with respect to water resources or chemical loading. Much of the current body of work concerns itself with relatively low wind velocities, small amounts of deposition and colder temperatures. It is clear that additional work is required on the deficiencies of various gauging systems under conditions typical of the higher Sierra Nevada.

Table 1 shows total precipitation recorded from 7/17/84 to 7/26/85 at the Mammoth Mountain site as 36.59", as measured by an Alter shielded, high-capacity (30") weighing rain gauge. Goodison (16) has demonstrated a gauge catch/ground true ratio of .45 at wind speeds of 7 M/sec (15.7 mph) for this type of gauge. Although we have no good estimate of true precipitation for this site, it is likely that gauge deficiency exceeds 50% and any calculation of loading would be highly inaccurate.

Part of the basis of this study was the supposition that the standard wet/dry collector used in both NADP and CADMP monitoring programs is a poor collector for snow at an alpine site. This has been confirmed. Although catch efficiencies for rain and rain/snow mixtures are high, only two intervals exceeded 50% catch for snow. For 8 intervals, less than 100 mls of melted snow sample was accumulated, even though the collector was fully operational during the interval. For 2 other intervals no sample was accumulated due to electrical power outage. Other problems with the collector were observed. Because of the shallow depth, samples accumulated during calm portions of the storm are subject to subsequent resuspension during windy portions. During cold, windy events adequate moisture will not accumulate on the sensor to open the wet bucket. This was observed at least 10 times, and is further evidenced by occasional accumulation of precipitation in the dry bucket.

In considering the effectiveness of the snowboard as a collector for weekly interval sampling the question of what you are trying to measure is brought sharply into focus. Do we want to know the total moisture and its associated chemistry falling in a given location or do we want to know the snow accumulating in a location that will later contribute to the meltwater at that point? The answer to the question has to do with the size of the area being considered. For a specific watershed, or subunit thereof, where snow can be widely redistributed the latter might give a more accurate representation, if such data was measured at various points around the watershed. For larger areas, where precipitation volume and chemistry data from a few sites is being used to make extrapolations over the larger region, the former is preferable. For the former the snow board is a poor collector. Although frequently the board had more accumulation than the weighing rain gauge, demonstrating that gauge's sampling deficiency, on 7 occasions there was no sample on the board, presumably due to wind scour and snow redistribution. The collector is also a problem in the spring and fall of the year when it must be backed up by another collector in case of rain events.

Of all the collector schemes tested, the snow bag or snow tube system has the greatest potential. The failures associated with this system are almost exclusively due to mechanical failure; leakage of the bag. Careful examination of the chemistry data from Table 3 shows a lot of high solute concentrations as compared to the wet/dry collector and the snow board. It is the author's opinion that this is probably due to the difficulty in adequately cleaning the bags in the first place, although I have no data with which to back this up. The advantages of this system are: the relatively high catch helps insure the sample will be representative of the event, the collector is fairly large and also deep so it collects adequate sample in small events, is not overwhelmed in large ones and resuspension is minimized. The collector is inexpensive to construct and has no electrical power requirements.

The modified Lewis collector has a number of problems that would argue against further attempts to develop a collector around this design. Its square blocky shape makes it difficult to shield and highly variable for catch. The heaters required to melt the incoming snowfall require too much power to allow batteries to be used. Available A.C. power is a requirement. Because the collector itself is not easily transportable, large volumes of water must be hauled to the sampling site to periodically clean the collector. This collector appears to be the worst as far as contamination goes. The collector was used for three years by the author to gather adequate sample in small rain events, and for this it works well, but the potential to overwhelm the collector during intervals with high snow accumulation is great.

Table 4 provides a matrix for the four collector schemes to be evaluated against the criteria. Values from 1 to 5 were assigned subjectively based on the author's experience, with 5 being best, 1 worst. Some of the criteria may overlap in their application.

None of the collectors are adequate for recommendation as a standardized snow collection scheme at this time. However, certain conclusions may be drawn and recommendations made for future work. Since the wet/dry collector does not properly segregate wet and dry deposition during the winter months it would seem resonable to drop this segregation requirement from the design of future collection schemes, especially since there is no obvious way to leave it in. It would seem prudent though to try to establish limits on the contribution of dryfall to snowmelt chemistry in an alpine snowpack. This could possibly be done by replicate sampling of the snow surface immediately following snowfall and then daily until the next snow event. Changes in chemistry could then be attributed to dryfall accumulation on the snow surface.

The collector scheme that appears most viable for future development is the snow bag/snow tube with Alter shield. The collector could be designed to be watertight and then the bag liner could be eliminated. If the height of the collector was reduced to approximately 30" a site could be provided with two of them that would be capped and exchanged just like wet/dry collector buckets. This would allow cleaning in the lab and there would be no chance for leakage. The reduced height, to allow for easy transportability, could be a problem during intervals with high deposition. During these infrequent events, the interval could be reduced to 3 or 4 days. Since the collector mimics a weighing rain gauge in shape and size, any available data on rain gauge catch could be applied to the snow collector.

The last area for continued investigation would be to get a better grasp on shielded weighing rain gauge catch at a site with high wind and high deposition. This would require a major effort at measuring the "true" precipitation volume, probably by visiting multiple snow board sites daily or twice daily. This data, in conjunction with the rain gauge record and wind speed and direction data would allow the establishment of reliability limits for the weighing rain gauge or possibly correction factors for various wind speeds. If a snow tube type collector was employed estimates of sample representativeness would be available.

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TABLE 1: Collector sample volumes and catch

			Wet/Dry Collector			Snow Board		
Interval ending	Precip. type	Rain gage (in.)	Vol. (mls.)	Water equiv. (in.)	Catch	Depth (in.)	Water equiv. (in.)	Catch
7/24/84	R	0.70	1,373	0.80	114%			
7/31/84	R	0.05	74	.04	80%			
8/7/84		0.00	0					
8/14/84	R	0.08	32	0.08	100%			
8/21/84	R	0.04	84	0.05	120%			
8/28/84	R	0.30	479	0.28	93%			
9/3/84	R	0.18	306	0.18	100%			
9/11/84		0.00	0					
9/18/84		0.00	0					
9/25/84	R	0.38	682	0.40	105%			
10/2/84	R/S	0.63	596	0.35	56%			
10/9/84	R/S	0.10	174	0.10	100%			
10/16/84	S	0.67	116	0.07	10%			
10/23/84	S	0.76	0			10.0	2.2	283%
10/30/84	S	0.37	81	0.05	13%	0.0		0%
11/6/84	S	0.72	77	0.04	6%	2.0	0.3	47%
11/14/84	S	7.16				18.0	2.8	39%
11/20/84	S	no record				0.0		
11/27/84	S	2.15				12-13	2.6	121%
12/4/84	S	4.20				9.5	2.3	55%
12/11/84	S	~2.0	915	0.53	~30%	7.0	0.8	40%
12/18/84	S	1.40	224	0.13	9%	11.0	1.2	86%
12/26/84	S	0.40	605	0.35	88%	4.5	0.8	200%
12/31/84		0.0	0			0.0		
1/8/85	S	1.20	147	0.09	8%	10.0	1.3	108%
1/15/85		0.00	0			0.0		
1/22/85		0.00	0			0.0		
1/29/85	S	0.90	408	0.24	27%	5.0	1.1	122%
2/5/85	S	0.35	32	0.02	6%	0.0	0.0	0%
2/12/85	S		8	T	0%	27.0	5.1	-%
2/19/85		0.00	0			0.0		
2/26/85		0.00	0			0.0		
3/5/85	S	0.80	219	0.13	16%	0.0		
3/12/85	S	3.90	218	0.13	3%	17.0	2.8	72%
3/19/85	S	0.35	249	0.18	51%	0.0	0.0	0%
3/26/85	S	0.70	146	0.15	21%	0.0	0.0	0%
3/28/85	S	4.15	0		0%	10.0	1.5	36%
4/9/85		0.00	0			0.0		
4/16/85		0.00	0			0.0		
4/23/85	S	0.90	109	0.06	7%	0.0		0%
4/30/85		0	0			0		
5/7/85		0	0			0		
5/15/85	R/S	0.40	193	0.12	30%	0.0		0%
5/21/85		0	0					
5/28/85		0	0					
6/4/85	R/S	0.30	876	0.53	177%			

TABLE 1 (continued)

			Wet/Dry Collector			Snow Board		
Interval ending	Precip. type	Rain gage (in.)	Vol. (mls.)	Water equiv. (in.)	Catch	Depth (in.)	Water equiv. (in.)	Catch
6/11/85		0	0					
6/18/85		0	0					
6/25/85		0	0					
7/3/85	R	0.30	0	0.00	0%			
7/19/85	R	0.05	0	0.00	0%			
7/26/85		0	0					
	Total	36.59						

R = rain
S = snow
R/S = rain snow mix

$$\text{Catch} = \frac{\text{water equiv. (in.)}}{\text{rain gage (in.)}} \times 100\%$$

TABLE 1 (continued)

	Snow Bag			Lewis Collector			
Interval ending	Vol. (mls.)	Water equiv. (in.)	Catch	Vol. (mls.)	Water equiv. (in.).	Catch	Observations
7/24/84							
7/31/84							
8/7/84							
8/14/84							
8/21/84							
8/28/84							
9/3/84							
9/11/84							
9/18/84							
9/25/84							
10/2/84							1/2" mixed rain/snow in dry bucket
10/9/84							
10/16/84							
10/23/84							power failure
10/30/84							
11/6/84							
11/14/84	853	0.30	4%				at least 4 ft. of snow fell
11/20/84	895	0.31	-				
11/27/84	T		0%				bag leaked
12/4/84	655	0.23	5%				
12/11/84	T		0%	2922	0.54	~3%	bag leaked
12/18/84	1988	0.69	49%	258	0.05	4%	
12/26/84	728	0.25	63%	1128	0.22	55%	
12/31/84	0			0			
1/8/85	2127	0.74	62%	-			Lewis malfunction, frozen
1/15/85	0			0			
1/22/85	0			0			
1/29/85	772	0.27	30%	2285	0.42	47%	
2/5/85	325	0.11	31%	245	0.05	14%	intense wind scour
2/12/85	977	0.18	-	891	0.31		rain gauge down
2/19/85	0			0			high capcity rain gauge installed, resolution reduced
2/26/85	0			0			
3/5/85	955	0.33	41%	1459	0.27	34%	wind blew board over
3/12/85	5689	1.97	51%	2312*	0.42	11%	1" snow in dry budket, Lewis collector froze, backed up, overflowed
3/19/85	710	0.25	71%	1367	0.25	71%	snow in dry bucket, wind scour
3/26/85	1322	0.46	66%	1539	0.28	40%	
?/28/85	-		-	4200	0.77	19%	short interval, 130 mph winds, 40" new snow, power out, bag loose
4/9/85	0			0			

TABLE 1 (continued)

Interval ending	Snow Bag Vol. (mls.)	Snow Bag Water equiv. (in.)	Snow Bag Catch	Lewis Collector Vol. (mls.)	Lewis Collector Water equiv. (in.).	Lewis Collector Catch	Observations
4/16/85	0			0			
4/23/85	1183	0.41	46%	498	0.09	10%	
4/30/85	0			0			
5/7/85	0			0			
5/15/85	0		0%	986	0.18	45%	snow on board melted, bag leaked
5/21/85	0			0			
5/28/85	0			0			
6/4/85	T			2329	0.44	147%	bag leaked
6/11/85	0			0			
6/18/85	0			0			
6/25/85	0			0			
7/3/85							
7/9/85							
7/26/85							

TABLE 2: Summary of Snow Catch

Interval ending	Rain gauge (in.)	Wet/dry	Snow board	Snow bag	Lewis	Observations
10/16/84	0.67	10%				
10/23/84	0.76		283%			Power failure
10/30/84	0.37	13%	0%			
11/6/84	0.72	6%	47%			
11/14/84	7.16		39%	4%		At least 4' of deposition
11/20/84	No record		0"	.31"		Rain gauge down, bag leaked
11/27/84	2.15		121%	0%		
12/4/84	4.20		55%	5%		
12/11/84	~2.0	~30%	~40%	0%	~3%	Bag leaked
12/18/84	1.40	9%	86%	49%	4%	
12/26/84	0.40	88%	200%	63%	55%	
1/8/85	1.20	8%	108%	62%		Lewis malfunction, frozen snow in dry bucket
1/29/85	0.90	27%	122%	30%	47%	
2/5/85	0.35	6%	0%	31%	14%	
2/12/85	-	0"	5.1"	.18"	.31"	Intense wind
3/5/85	0.80	16%	-	41%	34%	Rain gauge down, wind blew board
over 3/12/85	3.90	3%	72%	51%	11%	Lewis froze, under-sampled
3/19/85	0.35	51%	0%	71%	71%	Snow in dry bucket, wind scour
3/26/85	.70	21%	0%	66%	40%	
3/28/85	4.15		36%		19%	120 mph winds, power out, bag gone
4/23/85	0.90	7%	0%	46%	10%	
Minimum		0%	0%	0%	3%	
Maximum		88%	283%	66%	71%	
Average (eliminating mechanical failures)		21%	71%	37%	28%	

TABLE 3: Precipitation Chemistry

Interval ending	Precip. type	Collector type	pH	Conductivity (μmhos)	$[Cl^-]$	$[NO_3^-]$	$[SO_4^{2-}]$
7/24/84	R	1	4.68	13.8	4.9	27.6	18.8
8/28/84	R	1	4.51	16.2	5.5	27.6	15.6
9/3/84	R	1	4.45	19.1	6.6	43.7	29.1
9/25/84	R	1	4.75	18.6	4.5	35.9	32.9
10/2/84	R/S	1	4.91	10.7	5.6	20.7	19.4
10/9/84	R/S	1	5.21	6.2			
10/16/84	S	1	4.98	11.5			
10/23/84	S	2	5.71	2.5	2.9	2.8	4.9
11/6/84	S	2	4.92	10.3	13.7	17.6	12.1
11/14/84	S	2	5.22	3.3	2.7	2.2	4.3
		3	4.97	6.5	3.9	8.9	8.7
11/20/84	S	3	5.50	3.3	2.7	2.2	4.3
		4	5.98	4.2	3.2	3.3	8.8
11/27/84	S	2	5.34	4.2	2.6	4.7	5.4
		3	5.47	3.3	2.6	4.0	4.4
12/4/84	S	2	5.98	1.7	7.1	1.3	3.1
		3	6.56	12.5	26.4	2.6	21.2
12/11/84	S	1	5.62	2.0	3.2	1.8	4.0
		2	5.40	2.0	1.1	1.6	3.4
		4	5.40	3.5	2.9	3.5	7.2
12/18/84	S	1	5.51	2.8	5.2	2.8	4.6
		2	5.51	2.1	2.0	1.9	2.4
		3	5.62	3.5	6.8	4.3	9.3
		4	5.25	12.8	25.2	15.9	26.1
12/26/84	S	1	5.36	1.8	3.2	3.1	2.9
		2	5.48	2.4	13.3	4.6	3.9
		3	5.22	3.4	3.0	4.3	2.8
		4	5.20	4.7	5.6	5.6	7.9
1/8/85	S	1	5.44	2.1	1.1	1.2	3.4
		2	5.36	2.3	0.7	1.0	2.5
		3	5.41	2.1	1.0	1.2	3.7
1/29/85	S	1	4.54	12.4	3.6	24.0	4.0
		2	4.66	10.5	2.7	21.3	5.7
		3	4.77	9.3	3.3	22.0	5.6
		4	4.58	14.8	4.0	37.0	8.5
2/5/85	S	3	4.89	8.5	4.6	19.8	8.8
		4	4.70	13.5	5.9	25.9	10.8
2/12/85	S	2	5.43	2.0	3.3	27.2	3.3
		3	5.31	2.3	1.3	1.2	4.8
		4	5.27	1.9	1.0	0.8	4.3
3/5/85	S	1	5.29	4.9	5.1	6.9	4.0
		2	5.42	5.8	3.2	13.2	6.9
		3	5.50	6.8	6.1	19.5	9.9
		4	4.85	20.7	12.6	43.6	25.1
3/12/85	S	1	5.39	5.0	4.4	10.7	15.7
		2	5.42	2.8	3.0	4.1	4.2
		3	5.84	4.7	4.9	7.9	6.7
		4	5.38	5.5	4.5	11.6	8.6

TABLE 3 (continued)

Interval ending	Precip. type	Collector type	pH	Conductivity (μmhos)	$[Cl^-]$	$[NO_3^-]$	$[SO_4^{2-}]$
3/19/85	S	1	5.54	8.8	6.2	22.3	17.2
		2	5.57	4.6	3.9	10.3	10.8
		3	5.70	10.4	7.3	26.4	19.4
		4	4.89	15.0	5.9	30.5	21.5
3/26/85	S	1	5.53	16.4			
		3	5.48	16.9	6.3	55.0	30.8
		4	5.51	22.1	7.7	72.7	38.4
3/28/85	S	2	5.43	1.6	2.2	6.2	5.7
		3	5.93	2.8	4.1	1.5	4.8
		4	5.47	4.2	3.2	4.0	6.5
4/23/85	S	1	5.20	7.0			
		3	5.24	11.0	9.5	27.2	18.5
		4	4.97	19.0	21.7	61.3	39.6
5/15/85	R/S	1	5.11	25.1			
		4	5.22	36.1	20.2	114.6	67.7
6/4/85	R/S	1	5.32	4.0	1.1	5.1	1.2
		3	5.69	5.4	12.5	8.1	6.6
		4	5.32	11.6	79.0	28.4	20.0

All concentrations in μeq/l
pH and conductivity adjusted to 25°C
Collector types: 1 - wet/dry
2 - snow board
3 - snow bag
4 - Lewis collector

TABLE 4: Utility of Snow Collection Methods

	wet dry	snow board	snow bag	Lewis
Sample representative of event	1	1	4	3
Adequate sample in small event	2	2	3	5
Adequate collector volume in big event	1	5	4	2
Sample free from contamination, collector easy to clean	4	5	2	1
Sample or collector transportable	4	4	2	4
Little or no electrical power requirement	3	5	5	1
Sample resuspension possible	2	1	4	4
Potential for mechanical failure	2	4	2	1
Collector affordable/easy to construct or purchase	2	5	5	2