SNOWPACK ACIDITY IN THE COLORADO ROCKY MOUNTAINS

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ABSTRACT

A study of the snowpack in the Colorado Rocky Mountains was undertaken to determine current levels of acidity in the snowpack (1) due to western slope power plant effluents, (2) from emissions emanating from the Front Range Urban Corridor, or (3) from more remote sources, versus areas which should be free from such effects. It was found that snowpack samples taken downwind from power plants have median pH values of approximately 5.05 with the lowest values 4.63 to 4.70 and upslope from the Front Range Urban Corridor had median pH values around 5.19 with low values around 4.70. Samples from sites which should be free from local pollutant sources showed median pH values around 5.37 with low values of 4.85 to 5.15. Variations between valley and ridge sites will be discussed. Energy development is presently accelerating in the Rockies. The current study will provide a data base for comparison with future pH measurements.

Introduction

The existence of acids* in the snowpack has been documented around the world for many years. As early as the 1950's, studies in Scandinavia showed weighted mean pH values of precipitation during the winter to be around 4.7 to 4.8, coinsiding well with the maximum anthropogenic use of fossil fuels for heating and with the period of prevailing southerly flow across the industrialized regions of Europe (Barrett and Brodin, 1955). Around this time pH analysis of snow was carried out in eastern North America, yielding values of around 5.6 (Herman and Gorham, 1957) . Analysis of snow for pH in the western United States, however, was not undertaken until 1964. In this study the primary area of concentration was in the Sierra Nevada Mountains of California, with samples also taken from Utah and Colorado. The samples from Colorado, taken in the Denver area, yielded pH values between 6.0 and 7.1 (Feth et al., 1964). In other words, they were all slightly basic with respect to the value distilled water would have after coming into equilibrium with atmospheric CO_2. More recently a study of bulk precipitation carried out near the continental divide west of Boulder, Colorado, indicated low pH values. At the beginning of the study in 1975, pH values of 5.43 were measured. At the end of the study in 1978, values of approximately 4.63 were obtained (Lewis and Grant, 1980). From this study the authors postulated that the presence of acid precipitation in this region was due to long range transport from the west, discounting sporadic upslope events bringing pollutants from the Front Range Urban Corridor to the east. It was also implied that acid precipitation might be a prevalent phenomenon throughout the western U.S. These hypotheses were, however, questioned by others. Continuous measurements of NO, NO_2, and HNO_3 were made in the same watershed (Kelly & Steadman, 1980). (NO_x was considered to be the principle acidic component by Lewis and Grant.) These results demonstrated that when air flow was easterly, the concentrations of these pollutants were 100 times greater than when air flowed in from the west. Since Lewis and Grant sampled bulk precipitation, collected at weekly intervals,

*Under normal atmospheric conditions distilled water will dissolve atmospheric CO_2 forming carbonic acid (H_2CO_3) which will give distilled water a pH of 5.6. Hence, precipitation is considered to be acidic when the pH is less than 5.6.

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it would be likely that their results were biased by these strong, even though sporadic, upslope events.

Snowpack acidity in the Colorado Rocky Mountains was investigated in the winter and spring of 1980, and again in 1981, in order to determine how generalized acid precipitation is in Colorado, as well as to establish a baseline of data for comparison with future studies. This becomes particularly important with the increased energy development taking place in western Colorado.

The majority of the precipitation in Colorado at the higher elevations falls as snow during the winter months, building the winter snowpack, which then remains until the spring thaw. The snowpack has the advantage of being the accumulated total of the season's precipitation, which preserves ionic constituents, such as acids, until the first runoff takes place. To investigate the acid precipitation problem, areas where acidic precipitation seemed likely, as well as areas where it was not likely, were chosen; snowpits were dug, and snow samples were collected. Nine sites, scattered throughout the mountain areas of the state were used to determine acidity differences with respect to elevation and geographic location.

Sites

All of the snowpit sites were located in Colorado at elevations greater than 2750 m (9000 ft.), with the exception of Milner, with several at elevations greater than 3200 m (10,500 ft.) (See Figure 1). At the various sites snow depths at these elevations ranged from 185 cm at Guanella Pass, where much of the snow had been transported away by the wind, to deeper than 350 cm. at Wolf Creek Pass where digging was stopped because of the difficulty encountered in removing the snow from the pit. Relatively flat, open areas away from roadways and sheltered from the wind as much as possible were chosen as sites. Concentrating on areas higher than 2750 m (9000 ft.) ensured a cold snowpack.

Sampling sites were spread over most of the mountain regions of Colorado (Figure 1). These sites were chosen such that some would be considered as clean sites, that is they would be relatively free from local acidic contamination, and some as contaminated sites (those likely to contain some acidic components). The basis for the discrimination of a particular site was its location with respect to prevailing air flow and either coal-fired powerplants or the Front Range Urban Corridor. The sites at Rabbit Ears Pass, Wolf Creek Pass, Milner, and Long Lake were expected to be contaminated sites, while it was anticipated that Climax and McClure Pass would be clean. It was unknown, however, into which category the sites at Red Mountain Pass, Guanella Pass, and Blue Lake would be likely to fall.

The previously mentioned sets of data were taken in February and March of 1980. To check the impact of snowpack aging on the ionic content, samples were taken again at Rabbit Ears Pass and Blue Lake in May, 1980. To check the temporal consistency of the data, samples were again taken at Wolf Creek Pass, Blue Lake, Rabbit Ears Pass, and Climax in the spring of 1981.

Sampling and Analysis

To obtain samples throughout the snowpack, pits were dug to the ground, with the exception of Wolf Creek Pass, at the various sites. After a pit was dug, a clean polyethylene bag was used to brush down the wall of the snowpit where samples were to be taken. Once this was accomplished, samples were taken, starting at the surface, working down. Samples were taken in washed, square, one quart polyethylene containers, which were pressed into the wall of the snowpit at the desired place. Samples were usually taken contiguously in the upper layers of the snowpack, then randomly sampled in the lower layers. This was necessary because of transportation problems. Travel into the sites was done via cross country skis, and even using a large pack, only a maximum of twenty-one containers could be carried at any one time. Hence, due to the extreme depths of the snowpack at many of the sites, having only twenty-one containers did not allow sampling of the entire depth of the snowpack. Once the samples were obtained, the containers were sealed with polyethylene lids and placed in zip-lock bags. The containers were maintained below freezing, until analysis could be accomplished in the laboratory.

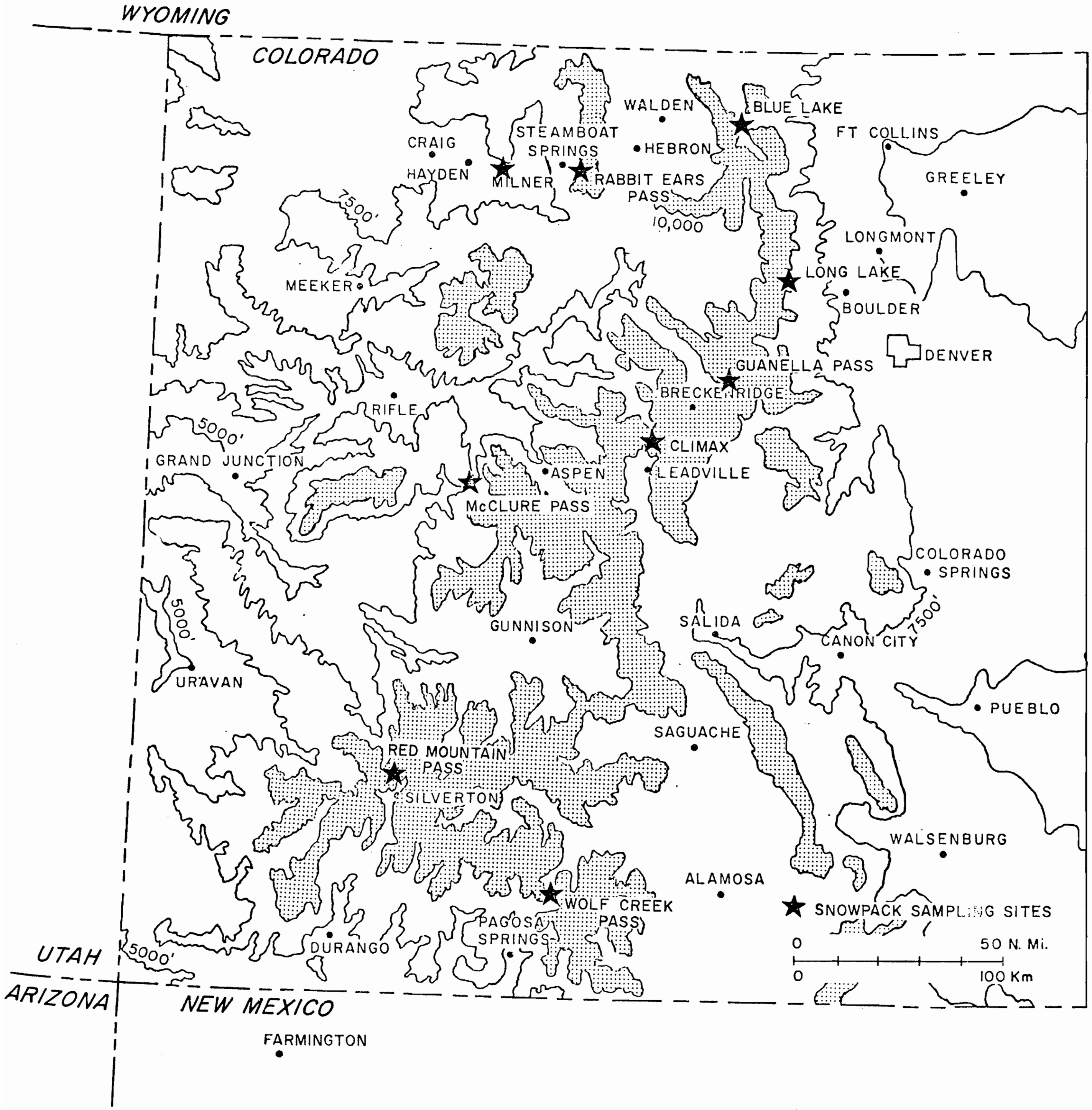


Figure 1. The mountain regions of Colorado showing the snowpack sampling sites.

Analysis was carried out in a laboratory at the Atmospheric Science Department of Colorado State University. The procedure used was as follows: 1) Samples were removed from the freezer and allowed to melt in their sampling containers. 2) A portion of the melted sample, approximately 25 ml, was removed from the container with a clean syringe and placed in a clean, 30 ml pyrex beaker. 3) The sample temperature was then taken to correct for temperature deviations of the specific conductivity and pH. 4) Specific Conductivity measurement was then made, using a Beckman Model RC16B2 conductivity bridge with a YSI 3402 conductivity cell with a cell constant of 0.1, and recorded. 5) Measurement of the sample pH was then made, using an Altex 3500 digital pH meter with an Altex 531013 pH combination electrode, and recorded. All containers were thoroughly cleaned with distilled, deionized water with a conductivity less than 1 μmho cm^{-1} before each use. The probes were thoroughly rinsed between each measurement.

The pH measurements were automatically corrected for temperature deviations by the meter. The conductivity measurements were all corrected for temperature to a standard of 25°C with the formula, $C_{25} = C_T/(1.0 + 0.025\Delta T)$, where $\Delta T = T - 25$, T being the sample temperature in °C, C_T is the measured conductivity at temperature, T, in μmhos cm^{-1}, and C_{25} is the specific conductivity in μmhos cm^{-1} corrected to 25°C.

Results

Using the analysis technique described above, the pH values for the samples at the various sites were determined. It should be kept in mind when examining the pH values that precipitation is considered to be acidic when the pH value is less than 5.6.

The median pH value of the samples from each site was determined and this was used to segregate the sites into those categorized as clean and those categorized as contaminated. A sharp break can be seen in the spread of the medians between median values of 5.18 to 5.35. The sites with median values less than 5.2 were Rabbit Ears Pass, Wolf Creek Pass, Blue Lake, Milner, and Long Lake. This corresponded well with the sites, selected earlier, which were expected to be affected by local pollutant sources. Only the data values are discussed here. Potential sources and other reasons for the given pH values are discussed in the following section.

Figures 2 through 10 show the variations of pH within the snowpack at the various sites. In these figures the abscissa is marked in units of pH, while the ordinate is marked according to sample numbers and depth. Figures 7 through 10 contain the pH profiles for the cleaner sites. In discussing the acidic properties of the snow from the various sites, the bottom samples were disregarded since they often contain organic matter from the ground.

Of the five more polluted sites, snow from Rabbit Ears Pass (Figure 2) has the most consistently low pH values. The median pH value at this site is 5.04. Ten of twenty-one samples have pH values less than 5.0. As seen in Figure 2, the highest pH value at this site is only 5.51, almost neutral with respect to equilibrium with atmospheric CO_2, but still slightly on the acidic side. The lowest pH value found here was 4.70.

The Wolf Creek Pass site had similar characteristics to the Rabbit Ears site, except individual values showed more variability. Here the median pH value was 5.09, the lowest value was 4.63 and the high was 6.92. These values represent concentrations of hydrogen ions approximately 10 times greater and 25 times less than equilibrium with atmospheric CO_2. Nine of the twenty-one samples here had values below 5.0. As seen in Figure 3, the depth of the snow at this site was greater than three meters, this meant that much of the snowpack here remained unsampled. It is quite possible that values exceeding these extremes might have existed, but deeper samples were not collected.

The samples from the Blue Lake site again show a certain degree of variability. The median pH value once again falls to a value of 5.10 which is very similar to Wolf Creek Pass. Figure 4 shows that the lowest pH value is only 4.92, a concentration almost one-half of the lowest value at Wolf Creek Pass. The highest value is 5.99, the only value which is alkaline, except for the bottom sample.

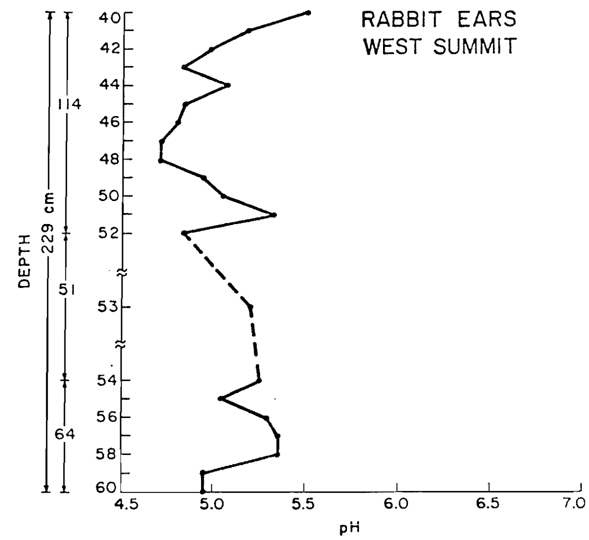


Figure 2. Snowpit profile, pH versus depth and sample number. Dotted lines indicate areas of unsampled snow.

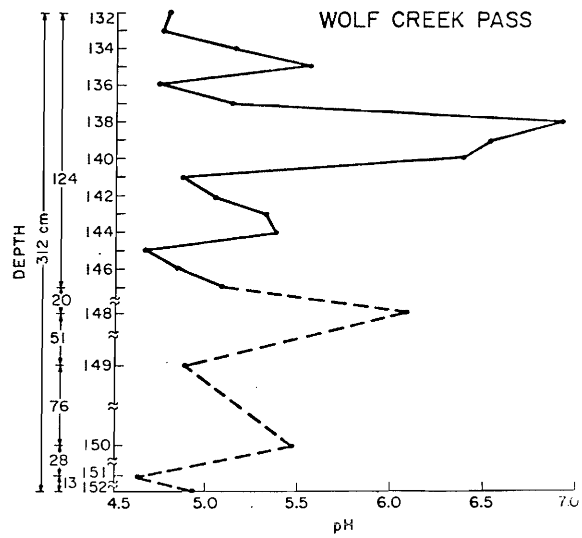


Figure 3. Same as figure 2.

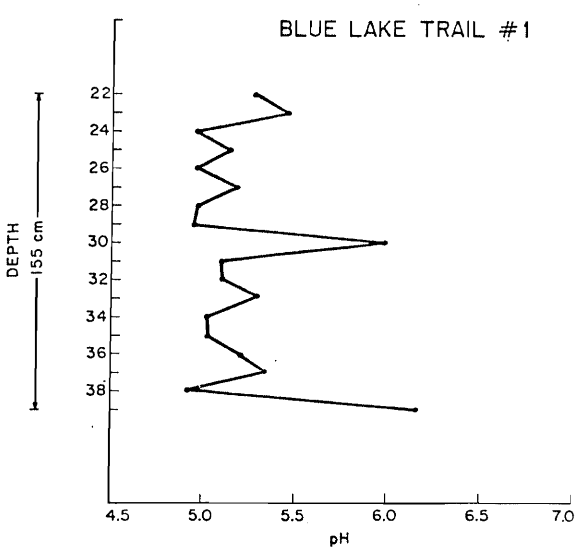


Figure 4. Same as figure 2.

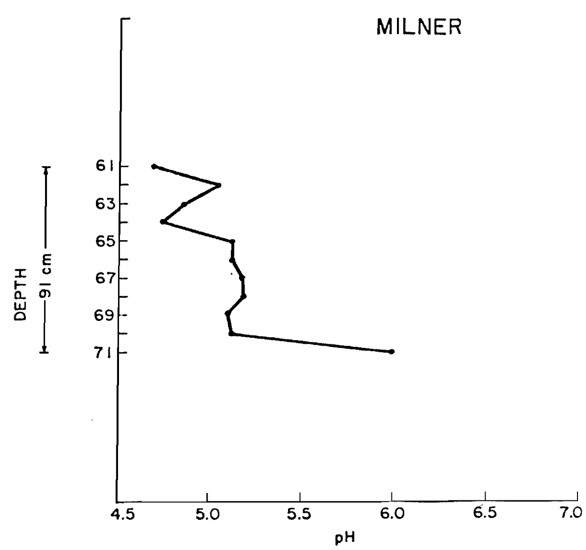


Figure 5. Same as figure 2.

The most outstanding feature of the pH profile of the Milner snowpit (Figure 5) is that the top four samples show some variability, then the remaining samples are fairly uniform in value. The median value at this site was 5.12.

The site at Long Lake, just west of Boulder, near the continental divide, showed a pH profile similar to the first three discussed (Figure 6). The low value was 4.73 and the highest value was 5.49, more similar to Rabbit Ears pass than Wolf Creek and Blue Lake. The median value was 5.18.

The four sites which were relatively clean showed median pH values ranging from 5.35 to 5.43. These median values fall slightly to the acidic side compared with equilibrium with atmospheric CO_2.

The pH values at McClure Pass ranged from 4.85 to 6.85, as seen in Figure 7. The range of values at this site is not too different from the more polluted sites, however, only two samples had pH values which fell lower than 5.0, while eight of the samples had pH values near neutrality or on the alkaline side thereof. The median pH value at this site was 5.35.

At Climax, the samples collected showed the least variability overall. The median value at this site was 5.39. All but three samples had pH values which fell within one quarter of a pH unit from the median. The lowest value at Climax was 5.15 and the highest was 6.75, as seen in Figure 8.

The samples from Guanella Pass ranged from 5.00 to 6.68, with a median value of 5.41. This site was very near to timberline and had undergone much modification from the wind, negating the assumption, valid at the other sites, that it would be a contiguous representation of the precipitation which fell at that site. (Figure 9)

Red Mountain Pass, even though in close proximity to Wolf Creek Pass, was one of the cleaner sites. Here the median pH value was 5.47. The range of pH values is similar to Wolf Creek Pass, 4.7 to 6.63, but there are more alkaline samples at Red Mountain Pass, eight vs. five at Wolf Creek, and eleven samples with pH values less than 5.1 at Wolf Creek, while Red Mountain only shows six. (See Figure 10.)

In addition to the snowpits mentioned above, samples were also collected at Rabbit Ears Pass and Blue Lake in May of 1980 after some melt had taken place (Figures 11 and 12). The most notable feature at both of these samplings is the absence of low pH values as compared with the data obtained earlier in the season (Figures 2 and 4). In the case of Rabbit Ears Pass, only one value falls below 5.0; this is for a sample near the base of the snowpack. Blue Lake now has a low value of only 5.35. The median value at Rabbit Ears Pass was 5.39 and at Blue Lake, 5.55.

Snow samples were again collected during the early spring of 1981 at Wolf Creek Pass, Blue Lake, Rabbit Ears Pass, McClure Pass, and Climax. Only the profiles of pH from Wolf Creek Pass and Rabbit Ears Pass (Figures 13 and 14) are shown for reasons discussed later. The effect of acid precipitation is evident at both of these sites once again. The median values at both sites are similar to the previous year's median. The number of pH values less than 5.0 is reduced, however, there are only five, as compared with nine of the twenty-one samples at Wolf Creek Pass, and only three out of seventeen samples at Rabbit Ears Pass. Wolf Creek's lowest pH value was 4.71 and Rabbit Ears' lowest was only 4.92.

Discussion

From the previous analysis, it can be seen that five of the nine sites discussed show median pH values less than 5.2 while the remaining four have medians higher than this. The difference between these two groups of sites is that the contaminated sites have a local source of acidic pollutant.

The sites at Wolf Creek Pass, Rabbit Ears Pass, Milner and Blue Lake shall be discussed first, since these all seem to have similar sources. Then the clean sites

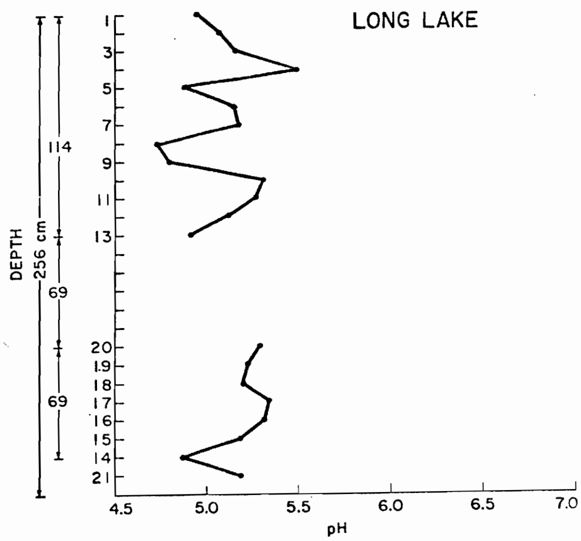


Figure 6. Same as figure 2.

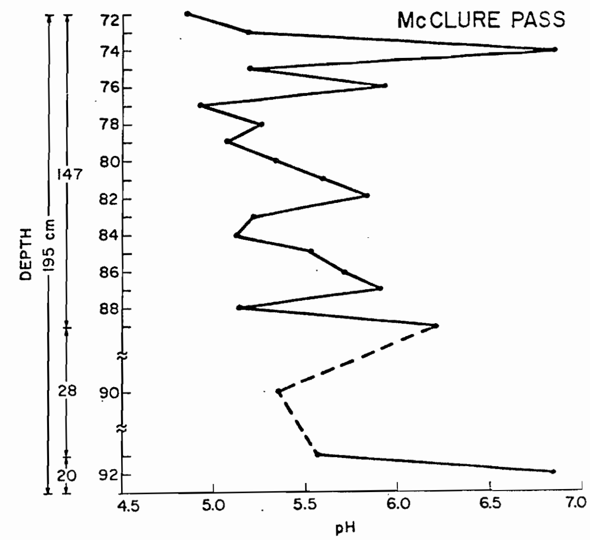


Figure 7. Same as figure 2.

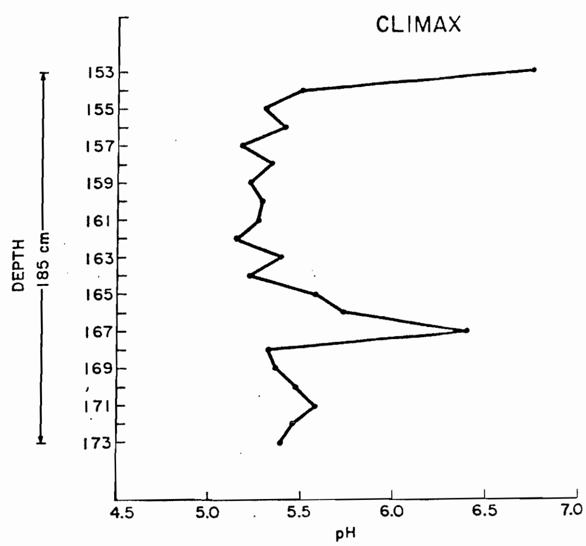


Figure 8. Same as figure 2.

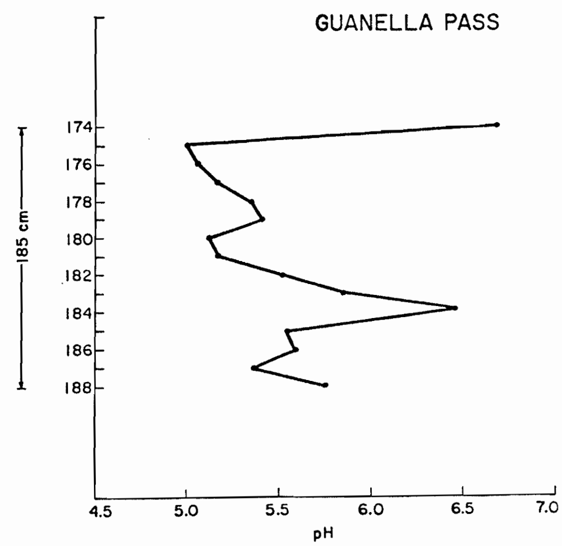
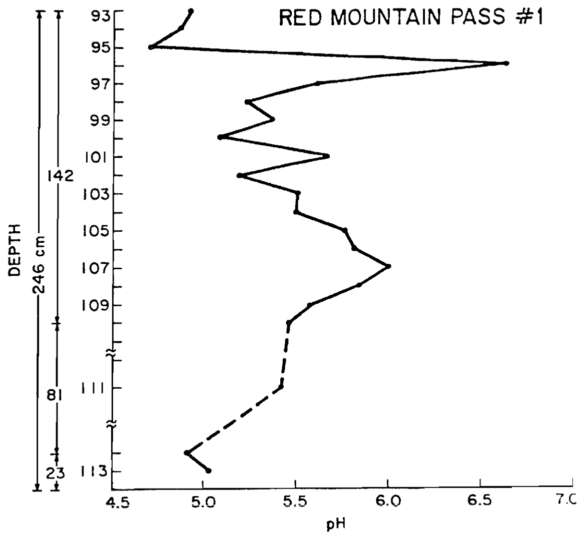
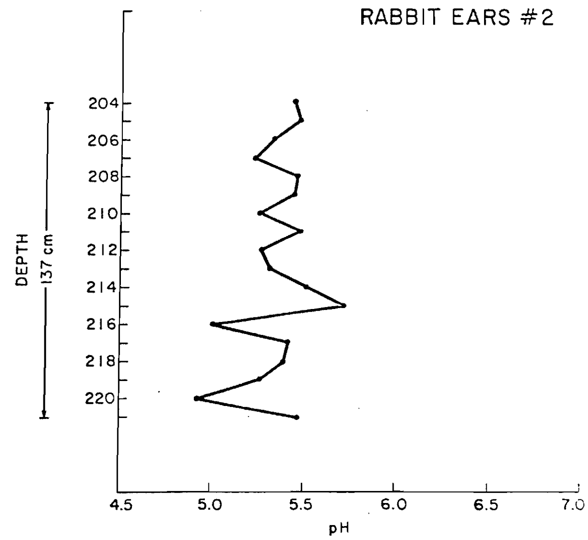


Figure 9. Same as figure 2.



gure 10. Same as figure 2.



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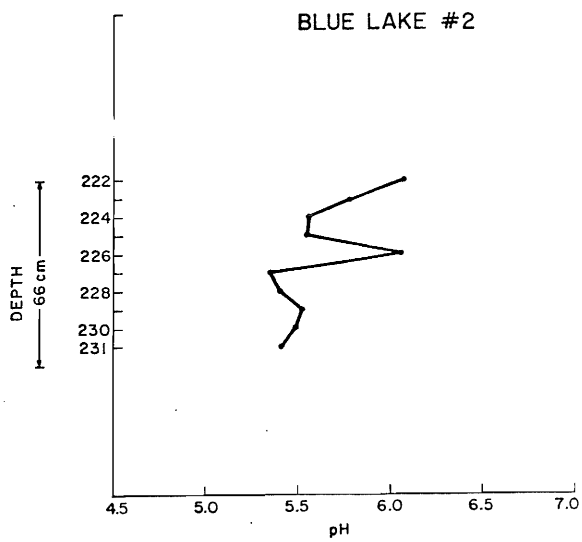

Figure 12. Same as figure 2.

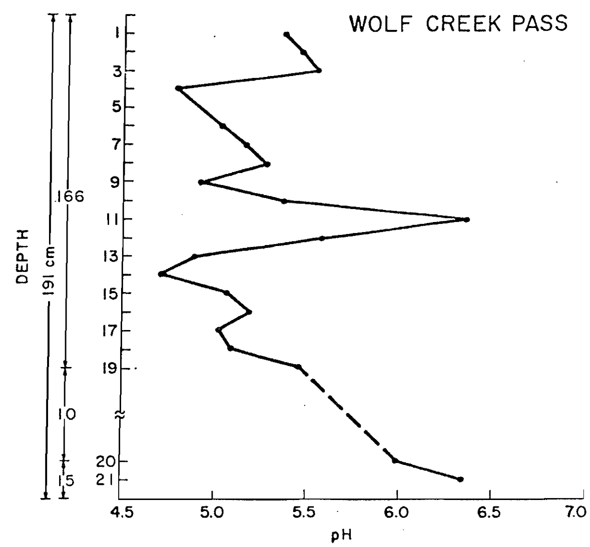

Figure 13. Same as figure 2.

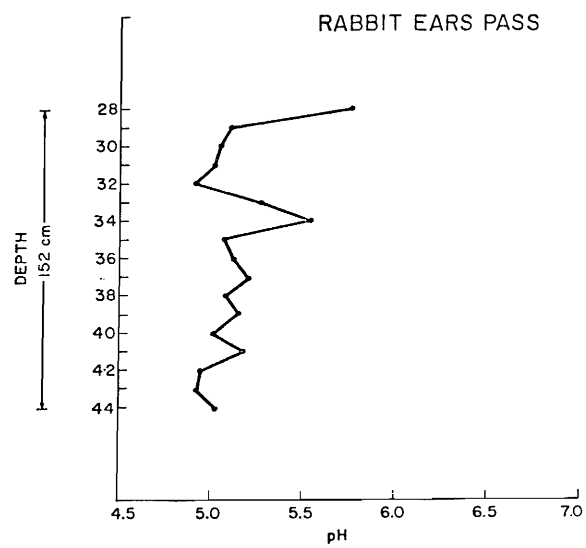

Figure 14. Same as figure 2.

will be examined. Finally, the precipitation acidity at Long Lake is analyzed using the perspective gained from the other sites.

What the sites at Wolf Creek Pass, Rabbit Ears Pass, Milner, and Blue Lake have in common is that they are all downwind from large, coal-fired power plants. Wolf Creek Pass is northeast of the Four Corners Power Plant in Farmington, New Mexico, while the remaining three are at varying distances downwind from the power plants at Hayden and Craig in the Yampa River valley of northwestern Colorado.

The Four Corners Power Plant has a generating capacity of 2100 megawatts and is located approximately 150 km. southwest of Wolf Creek Pass. Wolf Creek Pass also has the distinction of being the area of highest snowfall in the state of Colorado. The tie between these two facts in relation to this study is that the heaviest snowfall events at Wolf Creek Pass occur when the 700 mb. air flow is from a southwesterly direction, that is a direction which would allow pollutants from the Four Corners plant to be directly transported to the Wolf Creek Pass area. This phenomenon can be seen in precipitation patterns from an orographic precipitation model (Rhea, 1978). A maximum in orographic precipitation enhancement at Wolf Creek Pass occurs with a southwesterly flow direction. Since southwesterly flow leads to such high snowfall amounts at this site, and since this is the first major barrier northeast of the Four Corners plant, the effects of pollutants from the plant will be increased due to the orographic enhancement of precipitation here.* Southwesterly flow does not provide the only precipitation at this site. Orographic precipitation occurs from most wind directions, but the enhancement is not as great from other directions as with southwesterly flow. As was noted in the previous section, the pH profile at Wolf Creek Pass has wide variability. It would be expected that the lowest pH values would occur during southwesterly flow, while the higher values would occur from precipitation from other wind directions.

The Hayden and Craig Power Plants are located due west of the Milner, Rabbit Ears Pass and Blue Lake sampling sites. Maxima in the orographic snowfall pattern occur with westerly flow at Rabbit Ears and the Blue Lake area, indicating the likelihood of a high degree of pollutant being incorporated in the heavy snowfall episodes.

The Rabbit Ears Pass site is located on the western edge of the Park Range, due west of Hayden and Craig. Rabbit Ears Pass is also the first barrier downwind from these plants during westerly flow. During northwesterly and southwesterly flow this site is in the precipitation shadow of other barriers. Being the first barrier to westerly flow, and receiving its highest amount of precipitation from westerly flow events, will enhance the effects of pollutants from the local upwind sources at this site. These two effects explain why the Rabbit Ears Pass site was the most consistently contaminated.

The site at Milner was interesting for several reasons. One, its highest pH value was only 5.18. Secondly, the bottom six samples had essentially the same value. The generally low values were due to the close proximity of the Hayden plant and a coal mine. The uniformity of the values of the lower samples is due to the elevation of the site. The previously mentioned sites are all at elevations greater than 2700 m.; this site, however, is in the Yampa River valley at an elevation of around 1800 m. This leads to less snow on the ground and warmer ambient air temperatures. The combination of these factors leads to some melt in the lower, older layers of the snowpack, allowing some percolation of liquid water, which yields a more homogeneous distribution of hydrogen ions. The top four samples were from more recent snowfalls which had not yet undergone any melt.

The Rabbit Ears Pass and Milner sites are in fairly close proximity to the power plants in the Yampa River valley, and the power plants would appear to be the obvious sources for acidic pollutants. The Blue Lake site, however, is 105 km to the west. The Blue Lake site had an acidic pH profile, the source of which cannot be readily explained in terms of a source in close proximity. Orographic events which have the

*Previous studies have shown that orographic precipitation enhancement will increase the effects of acid precipitation (Likens et al., 1979).

largest snowfall amounts at this site can come from the west, northwest, north or east. In terms of sources of acidic pollutants, the westerly or the easterly flow would be the most likely direction of transport. The westerly flow would carry acidic pollutants from the Yampa River valley to this area from the high stacks there. With easterly flow, the nearest source of any acidic pollutants at the present time would be the Fort Collins area. The only source in Fort Collins would be automobile emissions. The site at Guanella Pass, which is in a similar geographic situation in relation to the Front Range Urban Corridor, has high pH values in relation to the other sites and has no source of acidic pollutants to the west. The sources to the west should dominate the Blue Lake profile.

In contrast to the four previous sites, the four sites at McClure Pass, Climax, Guanella Pass and Red Mountain Pass have no local sources which could affect them. They all, however, have a few low pH values and all have median pH values which are slightly acidic.

McClure Pass is on the western side of the Rockies and essentially is on the first barrier to westerly flow. The only major population center near this site is Grand Junction, to the west. This has no industries or activities which are likely to contribute acidic pollutants to this site, other than automobile emissions.

The site at Climax is in the interior of the state. From any direction of air flow, this site will have numerous mountain barriers upwind of it, allowing most any acidic contaminants to be washed out before they reach this site. This is evidenced by the fact that this was the cleanest site overall, having no pH values less than 5.15.

The site at Guanella Pass is geographically similar to Blue Lake, as mentioned earlier. There are about 65 km. of foothills and mountains between this site and the extensive urbanization at the base of the mountains. Any pollutants moving upslope, from the east, would be washed out before this site.

Red Mountain Pass is in close proximity to Wolf Creek Pass. Even though this site is to the NE of the Four Corners Power Plant, it does not have the markedly acidic profile that Wolf Creek Pass has. This is because this site is in the precipitation shadow of the southern San Juan Mountains during a southwesterly flow pattern. This site will receive most of its snow from flow with a northerly component of flow which has no consistant sources of acid pollutants.

Finally, in a category of its own, is Long Lake. There are no coal-fired power plants in the vicinity to affect it, yet it still has an acidic pH profile. The Front Range Urban Corridor appears to be the source. The primary pollution problem in this area is not automobile emissions, which could lead to nitric acid formation in precipitation. This site is near to the Como Creek site used in the studies of Lewis and Grant and Kelly and Stedman. As indicated by Kelly and Stedman, concentrations of NO, NO_2, and HNO_3 were up to 100 times higher in periods of upslope air movement from the east, than clean air movement from the west. Long Lake differs from Guanella Pass and Blue Lake in that it is much closer to the urbanized areas with fewer topographic features in between, hence is affected by pollutant transport from the east. Sources to the west would be similar to Guanella Pass. These facts support the urbanization to the east as the source of acidic precipitation found at this site.

The snowpit samples obtained in May, 1980 at Rabbit Ears Pass and Blue Lake show the effect of the spring melt on the ionic content of the Colorado snowpack (Figures 11 and 12). The difference in these two sites is the depth of the snowpack and hence, the relative amount of melt which has taken place. Both profiles show some variability in the hydrogen ion concentration. The variability at the Rabbit Ears Site (Figure 11) extends throughout the depth of the snowpack, while the Blue Lake profile (Figure 12) shows variability near the top of the snowpack and fairly uniform pH values in the lower two-fifths of the snowpack, a feature similar to the snowpit at Milner (Figure 5) taken in March. The difference between Milner and Blue Lake, however, is that the upper layers of the Milner site were fresh snow, with an acidic component deposited on acidic snow which had undergone periods of melt during the daytime. This allowed some percolation of liquid water to adjacent layers in the snowpack, spreading hydrogen ions uniformly.

The Blue Lake site is all aged snow, so this process had already occurred and the hydrogen ions had already been removed into the runoff, leaving a relatively neutral profile.

The Blue Lake #2 snowpit, Figure 12, exhibited an interesting feature. When compared with the Blue Lake #1 profile, Figure 4, there remains a spike in pH which is on the alkaline side of equilibrium with atmospheric CO_2, while all low pH values are absent. It is suggested that this feature is due to aerosols originating in alkaline soils and that these aerosols are not as water soluble as the acidic components in the snowpack. Hence, they remain in the snowpack well past the initial runoff, and are not available in the initial runoff to neutralize the acidic components. The high surface pH value in the Blue Lake #2 profile is probably due to dry deposition of dust during the springtime fair weather.

While the 1979-80 winter season was an ideal year for snowpack sampling in Colorado, 1980-81 was not. The 1980-81 winter season produced less than the normal snowpack. Temperatures were well above normal, which lead to frequent melting episodes throughout much of the winter at many of the sites. Sites where this occurred will not be representative of the chemical makeup of the precipitation which fell. Because of this, only the profiles of the sites at Wolf Creek Pass and Rabbit Ears Pass taken in the spring of 1981 are shown (Figures 13 and 14), since the snowpack was deep enough at each of these sites to withstand any warm periods. As was mentioned earlier, each of these sites showed similar characteristics to the data taken the previous winter.

The feature that was different about the Wolf Creek and Rabbit Ears sites is that at the sampling time of the second data set, melt had started to occur in the upper layers, evidenced by the snowpack structure. The topmost layers at Wolf Creek Pass were samples 1, 2 and 3 in Figure 16. These pH values were around 5.4. Sample 4, taken in the unmelted snow just below sample 3, drops to a pH of 4.8. As well as this, the specific conductivity jumps from 5.9 μmhos cm^{-1} to 13.2 μmhos cm^{-1}. Then, as can be seen in Figure 16, the pH rises steadily in the next several samples, but still is fairly acidic. A similar situation occurs at Rabbit Ears Pass. Here the upper layers were not quite as melted, so they retained more of their acid content. However, there is once again a minimum in pH just below the melted upper layers. These phenomena indicated a buildup of acidic components within the snowpack from the melting process.

<u>Conclusions</u>

The pH values obtained from the Colorado snowpack are, in general, larger than the pH values found in areas strongly affected by acid precipitation such as Scandinavia, where some snowfalls have actually been grey in color and had pH values falling as low as 3.8 (Elgmork, et al., 1973). They are, however, consistent with the results of studies of the acidity of the snowpack from similar geographic situations in other parts of the world. In the French Alps, pH values in the snow ranged from 4.4 to [illegible].0 with most falling around 5.4 (Clement and Vaudour, 1967), similar to the study at hand. Snow has also been sampled in the mountains of northern Africa, since this region should be free from the effects of anthropogenic acidic pollutants. Two sites were used. One had pH values between 5.2 and 5.7, while the other's values fell between 5.9 and 6.7 (Brimblecomb, 1980). Both of these sites were cleaner in terms of acidic components than Colorado, except for the interior mountain sites, which had similar values. A study of the effects of volcanic eruptions, the most dramatic natural producer of acidic components, on the acidity of Greenland ice cores, showed pH values ranging between 4.64 and 5.3 (Hammer, 1980).

In this study, only snowpack sampling sites with a local source of acidic pollutants showed significantly acid profiles. The sites at Wolf Creek Pass and Rabbit Ears Pass showed the greatest effect from acid precipitation. Their acid sources would appear to be coal-fired power plants within 150 km. Orographic precipitation enhancement, when the air flow direction is from the direction of the acid source, seems to be a major contributor to acidic precipitation in the Colorado mountains. The sites at Red Mountain Pass and McClure Pass are representative of the flux of acidic precipitation into the state from the west, since both ot these sites are on the western edge of the Colorado Rockies and receive their maximum snowfalls when the air flow would have a trajectory free from local sources of acidic pollutants. Both of these sites show a few low pH values but the majority are near the values expected in precipitation, unaltered by anthropogenic constituents. The pH profile of the Climax snowpit is typical of what one would find in the interior of the mountains away from any industrialization or major urbanization. Long Lake shows an acidic profile. It, however, does not indicate any pH values as low as some of those found by Lewis and Grant in the Como Creek watershed nearby. The most likely source of acidic contaminants to this site, as indicated by this study and that of Kelly and Stedman, is the Front Range Urban Corridor to the east. In lieu of the fact that only snowpack sampling sites near localized sources of acidic components showed acidic pH profiles, and since the Long Lake site has as its acid pollutant source the Front Range Urban Corridor, the hypothesis of widespread acidification of precipitation in the Western United States, put forth by Lewis and Grant, is apparently invalid.

At the present time there seems to be no major threat from acid precipitation in Colorado. The economy of the state is, however, expanding. People are constantly moving into the Front Range area because of employment opportunities and the pleasant climate, leading to further pollution in this area. Large deposits of fossil fuels are presently being exploited for energy development in western Colorado. The combination of these two things can lead to the extension of what is now a minor problem. Pristine areas downwind from future development could well be significantly affected. This study has indicated a need for future monitoring and provided a baseline of data for comparison with future studies of this nature.

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