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  13. I thank W. W. Murdoch, A. Stewart-Oaten, A. Kuris, J. T. Gray, M. A. Scott, S. Rothstein, R. Dean, and an anonymous reviewer for helpful comments on earlier versions of this report. Supported by NSF grant DEB 79-22131 to W. W. Murdoch.

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## Effect of Urban Sources on Acid Precipitation in the Western United States

In their report of acid precipitation near the Continental Divide, Lewis and Grant state (1, p. 176) that they expect the air at their measurement site "to receive only sporadic and limited contamination from nearby urban sources of pollution." Although we agree that the movement of air from the Denver front range metropolitan area into the mountains may be termed sporadic, our observations of such upslope episodes indicate that they may have a determining effect on the results of Lewis and Grant, especially since Lewis and Grant collected the sum of dry and wet deposition.

We have made continuous measurements of gas-phase  $\text{NO}$ ,  $\text{NO}_2$ , and  $\text{HNO}_3$  in the same area of the Como Creek watershed as that used by Lewis and Grant, from January to July 1979 (2). We find that the concentrations of these pollutants are up to 100 times higher in periods of upslope air movement from the east than during periods of clean air movement from the west. Over a sampling period of a week, the interval at which Lewis and Grant emptied their precipitation collectors, we find that the average concentrations of  $\text{NO}$ ,  $\text{NO}_2$ , and  $\text{HNO}_3$  are determined by their high concentrations in upslope periods. This result was also found by Noxon in his study of  $\text{NO}_2$  concentrations near the Divide (3).

Lewis and Grant state (1, p. 177) that "no local, sizable sources of pollutants are properly situated" to account for their observed pH trend. Their only apparent support for this conclusion is the meteorological study by Barry (4). Because of the long sampling interval used by Lewis and Grant, it is vital that they consider not only the probable frequency of pollution episodes, based on the local meteorology, but also the severity of

such pollution relative to the clean air which they purport to study. Our observations indicate that the average pollutant concentrations at their sampling site are so dominated by intermittent transport from urban sources that their measurements cannot be the basis for generalizations about precipitation in the western United States as a whole.

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We look forward to the publication of the  $\text{NO}_x$  observations alluded to by Kelly and Stedman; such data will provide a welcome addition to our knowledge of materials transport in the vicinity of the Continental Divide in Colorado.

Kelly and Stedman are mistaken in their implication that their observations of eastward upslope air movement contradict some aspects of our recent report of acid rain near the Continental Divide (1). We have not promoted the idea of long-distance transport from the west of the Divide but merely urge that it be considered as a contributor, possibly even a major one, of acidic materials to the Como Creek watershed. Even in view of Kelly and Stedman's observations, we must remain skeptical that the acid precipitation phenomenon can be essentially accounted for by upslope move-

ment of air from the east until this has been demonstrated quantitatively on an annual basis. The seasonal pattern of storms in this area is such that the frequency of upslope air movements is highest during the fraction of the year (January through July) studied by Kelly and Stedman.

By selecting for quotation from our report portions of sentences without the accompanying qualifiers, Kelly and Stedman have unfortunately made our comments on sources of acidity appear more tendentious than they were intended to be. Our report did not purport to be a summary of the condition of bulk precipitation for the entire western United States, nor does it deny the possibility of significant westward-moving upslope contributions to acidity in the Colorado Rockies. In fact, in our report we explicitly stated that regional urban sources to the east of the Divide (Denver) are one possible source. We view the study of Kelly and Stedman as providing useful information verifying the potential importance of sources to the east of the Divide.

As we now see it, the evidence could be summarized as follows. (i) Contrary to expectations prior to the publication of our report, bulk precipitation in the Como Creek watershed (6 km east of the Continental Divide) is affected by substantial amounts of strong mineral acids almost all weeks of the year. (ii) Urban pollution from Denver is one potential source of the mineral acids in precipitation near the Continental Divide, but very forceful and frequent year-round upslope movements are required, against strong prevailing weather patterns in certain months, in order to account fully for the acidity. (iii) Upslope movement definitely does occur at some times of the year and is perhaps more important in transport than previously suspected if the patterns observed by Kelly and Stedman are typical. (iv) A quantitative balance sheet for the sources of the strong mineral acids at the Como Creek site cannot be drawn as yet, and any conclusion that the acidity is principally from the east or the west would be premature.

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