Letters

Acid Rain and Soil Chemistry

In their article "Acid rain on acid soil: A new perspective" (5 Aug. 1983, p. 520) Edward C. Krug and Charles R. Frink highlight the natural processes that govern the chemistry of soil. We agree with their thesis that natural soil formation is a major acidifying process in some environments, including those affected by contemporary acid rain. Yet we disagree sharply with their position that acid rain is not really significant. They argue that some environments that have been affected by acid rain would be acidic naturally, and therefore no chemical changes can be induced by acid rain. These conclusions are misleading or misdirected.

The evidence and arguments used by Krug and Frink revolve around two basic themes: (i) the concept of "total acidity" versus *p*H, and (ii) the role of natural acids, notably organic and carbonic, in acidifying landscapes. Krug and Frink invoke the concept of "total acidity" to purportedly show that acid rain is not much different from natural rain. Total acidity may be a useful parameter in soil chemistry, but is irrelevant for characterizing acid rain (*1*). Because carbon dioxide can be continuously absorbed from the atmosphere, the acid capacity (total acidity) of natural rain is enormous. However, water saturated with atmospheric CO_2 has a relatively low acid *intensity*. For example, natural rain at a *p*H of 5.6 has a hydrogen ion activity (acid intensity) of 2.5 microequivalents per liter. In contrast, acid rain with a *p*H of 4.6 has an acid intensity ten times greater, that is, a hydrogen ion activity of 25 microequivalents per liter. It is true that, if either acid rain or natural rain is titrated with strong bases, their acid capacity would not be greatly different. This phenomenon, however, is not germane to the impact that acid rain may have on a landscape. Total acidity is only a measure of the potentially available hydrogen ions that would be available if certain carefully defined conditions were met. Total acidity is not related at all to *p*H, which is the crucial parameter in deciding whether a given reaction is possible. The heart of the acid rain problem is that rain at *p*H 4.6 can do things chemically that rain at *p*H 5.6 cannot. For example, alumina minerals are essentially insoluble at *p*H 5.6, but are quite soluble at *p*H 4.6 (*2*). Hydrogen ion activity, that is, *p*H, is well known as the "master variable" in solution chemistry (*3*) precisely because it can exert such sensitive control over chemical reactions. The most important aspect of acid rain then is not its "total acidity" but rather its *p*H, that is, its acid intensity. In the thermodynamic consideration of chemical reactions, only *p*H matters; total acidity is of no concern. To contend that somehow acid rain, which may be as acid as *p*H 2.4 (*4*), is as benign as natural rain at *p*H 5.6 is not consistent with chemical theory and ecological understanding.

Table 1. Stream water acidification by natural means (Jamieson Creek) (*5*) and by acid rain (Falls Brook) (*6*). Results of the analysis are given in milligrams per liter. DOC, dissolved organic carbon.

Item	Jamieson Creek 23 July 1982, *p*H, 4.71	Falls Brook 6 March 1979, *p*H 4.75
Ca^{2+}	.29	.72
Na^+	.40	.43
K^+	.13	.11
Mg^{2+}	.05	.19
NH_4^+	.05	.01
SO_4^{2-}	1.0	5.3
NO_3^-	.03	1.56
Cl^-	.42	.62
Al (total)	.30	.61
SiO_2	3.9	2.2
DOC	4.8	~ 2.5

Krug and Frink show how the soil-forming process produces organic acids or carbonic acids, or both. Clearly organic compounds exert a powerful effect on the *p*H and chemistry of podzolic soils. Yet Krug and Frink project the viewpoint that it is not possible for acid rain to affect the chemistry of a podzol soil because ostensibly it is already acid. This view is categorically wrong. The chemical impact of acid rain in a given situation involves not only the *amount* of acid present but also the *kind* of acid anions present. The kind of acid has a profound effect on certain chemical reactions taking place in the soil zone and in the waters draining the soil.

This effect can be illustrated by comparing the chemistry of the waters draining from a natural, unpolluted watershed and a similar one affected by acid rain (Fig. 1). Although both streams are comparably acidified, the cause and consequences of the acidity are entirely different in the two systems. The Jamieson Creek watershed near Vancouver, British Columbia, is a close analog to the Hubbard Brook Experimental Forest in New Hampshire. Both have podzolic soil regimes imposed on a hilly, glaciated, granitic terrane (*5*). A conspicuous difference between the two areas is the general absence of acid rain over the Jamieson Creek catchment and the pervasive presence of acid rain over Hubbard Brook. The headwater streams at Jamieson Creek are acidified by organic acids, as Krug and Frink would predict. A short distance downstream, however, these organic acids are replaced by carbonate alkalinity, again as Krug and

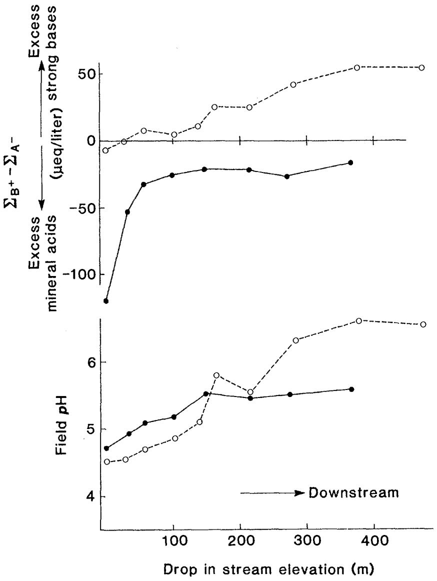

Fig. 1. Chemical differences between natural, podzolic drainage unaffected by acid rain [Jamieson Creek (○) near Vancouver, British Columbia (*5*)] and a system affected by acid rain [Falls Brook (●) within the Hubbard Brook Experimental Forest, New Hampshire (*6*)]. Chemistry is plotted as a function of downstream pathlength, expressed in units of stream drop. In the upper panel ion balance is defined as the sum of the strong bases ($B^+ = Ca^{2+} + Na^+ + Mg^{2+} + K^+$) minus the sum of the strong mineral acids ($A^- = SO_4^{2-} + NO_3^- + Cl^-$). Both streams are acidic in their initial stages and become less so as downstream pathlength increases (lower panel). The *p*H in the stream affected by acid rain (Falls Brook) is clearly controlled by strong mineral acids, while in the natural system *p*H is not controlled by strong mineral acids (upper panel).

Frink would predict. Dissolved aluminum in the Jamieson Creek system is present almost entirely in the form of organo-aluminum complexes. A comparable stream at Hubbard Brook (*6*), an area affected by acid rain, shows that throughout its extent *p*H is controlled by sulfuric and nitric acids, the same acids that characterize acid rain. There is no carbonate alkalinity in the stream system, and dissolved aluminum is largely in the form of inorganic complexes, mostly fluorides and hydroxides (*6*). In the Jamieson Creek watershed, hydrogen ion is supplied to the system entirely from organic and carbonic acids. By comparison, in the Hubbard Brook area at least 50 percent of the hydrogen ion used by the system comes from acid rain (*7*).

Although the concentration of hydrogen ion (*p*H) of these streams is similar, the dominant kinds of acid present are different (Table 1). The ecological consequences of this shift in acid type is exemplified by the behavior of aluminum in both systems. At Jamieson Creek, where *p*H is controlled by weak natural acids, dissolved aluminum in stream water is predominantly all organically complexed. Organically complexed aluminum in solution is essentially nontoxic, and fish can live in such waters (*8*). In marked contrast, inorganic aluminum complexes, which characterize much of the anthropogenically acidified waters of the northeastern United States, are lethal to populations of young fish (*8*). The extent of aluminum toxicity to fish is very much dependent on the speciation of the aluminum, not just the amount (*8*). To infer then that aluminum mobilized by acid rain is the same in every respect as aluminum mobilized by organic acids is misleading.

Finally, Krug and Frink make assertions about land use and its long-term effects on water acidity. The essence of their arguments concerns the accumulation or depletion of organic acids in the soil zone as a function of land use. It is necessary, however, to distinguish between an acid soil and the acidity of waters that drain from it. A watershed with an acid soil is not always associated with acid stream water (Fig. 1). Furthermore, our data from deforestation experiments at Hubbard Brook show that acidity produced by clear-cutting the forest is dominantly nitric acid, not organic acid (*9*). Most important, we have found that the chemical effects of deforestation last only a few years (*10*), not decades, as inferred by Krug and Frink.

In summary, Krug and Frink ignore the substance of published chemical data from Scandinavia, Canada, and the United States which show that stream and lake acidification over large regions are due to sulfuric and nitric acids, not organic acids (*11*). Instead, they concentrate on selected, anecdotal evidence or hypothetical scenarios to make a case that acid rain hardly matters, when in fact the evidence is overwhelmingly to the contrary (*12*). Discussions about a largely peripheral concept such as "total acidity" or generalizations about natural acids do not enrich or advance the present debate about the acid rain problem (*13*).

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13. Contribution of the Hubbard Brook Ecosystem Study. Financial support provided by the National Science Foundation and the Andrew W. Mellon Foundation. Hubbard Brook is operated by the Forest Service, U.S. Department of Agriculture, Broomall, Pa. The help of the Greater Vancouver Water District is gratefully acknowledged.

Krug and Frink present some interesting arguments but do not give a balanced view of the importance of various causes of acidification of freshwaters. Moreover, it seems inappropriate to say that they present a new perspective. Important arguments on this topic were raised by Rosenqvist (*1*) several years ago, and they have since been under continuous discussion. The mechanisms involved in freshwater acidification are certainly complicated (*2*), but very likely acidic precipitation plays an important role in most cases (*2, 3*).

Krug and Frink discuss a number of studies carried out in Norway, but often their description is incomplete. They say, for example, that runoff from minicatchments that received acidic deposition was twice as acidic as that in the rain. Although this is correct for the period they mention (an event in November 1977), it is an incomplete representation. The final report from the Norwegian project on "Acid Precipitation—Effects on Forests and Fish" (the SNSF project) (*3*) states, "It is seen that the runoff is, in general, more acid than the precipitation [during the event]. However, there is apparently a wash-out of sulphate in the same period. The sulphate may originate from an accumulation of air-borne sulphate or oxidation of sulphur compounds during summer." The SNSF project final report also shows that accumulation of airborne sulphate does, in fact, occur during summer and early fall.

Krug and Frink suggest that the "mobile anion" concept (*2, 4*), that is, that sulfuric acid falling on soils may move through the soils "causing increased cation leaching proportional to the increased flux of SO_4^{2-}" has a "major flaw" because organic anions tend to decrease as other anions increase. They hypothesize that the concurrent increase in SO_4^{2-} flux will balance the decrease in organic anion flux, resulting in little or no change in pH of runoff water. Such a trend may occur, but a number of lysimeter studies show that increased concentrations of SO_4^{2-} do increase leaching of cations from acid soils (*3*). Furthermore, models of stream water chemistry based on the mobile anion concept have proved useful in predicting stream water chemistry (*5*). In addition, Krug and Frink argue that acidic precipitation affects water pH only slightly. In the section on anion leaching they state, however, that "the added H^+ in acid rain hinders their [humic acids] dissociation and decreases their solubility." This does not appear to be consistent.

If one accepts Krug and Frink's arguments, a decrease in the input of H_2SO_4 should not result in a change (increase) in water pH. Long-term trends in lake and stream chemistry in sensitive areas in both Scandinavia and North America do not always unequivocally support the contention that acidification of freshwaters has occurred (the period of data collection is usually short relative to changes in deposition of strong acids). However, changes in freshwater chemistry resulting from a decrease in H_2SO_4 deposition have, in fact, been recorded.

The emission of SO_2 from the ore smelters at Sudbury, Ontario, declined from an average of 3900 metric tons per day in 1973 through 1977 to approximately 1800 metric tons per day in 1978 through 1982, a drop of approximately 54 percent (*6*). We studied several lakes in the Sudbury area during this decade (*7*); two (Clearwater and Swan) were not manipulated by any chemical technique. The mean annual pH of Clearwater Lake fluctuated from 4.10 to 4.32 between 1973 and 1977; it began to increase systematically in 1978 and by 1982 averaged 4.6. The SO_4^{2-} levels dropped from an average of 545 microequivalents per liter (μeq/liter) (1973 to 1977) to 380 μeq/liter (and are still declining). Swan Lake was studied less intensively. In 1977, its pH averaged 3.96, and its SO_4^{2-} concentration was 580 μeq/liter; by 1982, its pH had risen to 4.8 and its SO_4^{2-} concentration was 220 μeq/liter. These results clearly demonstrate that a reduction in sulfuric acid deposition can result in not only a decrease in SO_4^{2-} levels in freshwater but a substantial change in pH.

Krug and Frink state that "rates of cation export from watersheds in the northeastern United States, Canada, and Norway which are thought to be sensitive to acid rain are remarkably low." However, comparison of cation yield (*8*) from areas with different deposition of sulfuric acid but similar soils indicates that cation yield is relatively high in areas with substantial sulfuric acid deposition. For example, in southern Ontario (deposition of strong acid averages approximately 70 to 100 milliequivalents per square meter per year), net yield of cations ($Ca^{2+} + Mg^{2+} + Na^+ + K^+$) from several catchments averaged 95 meqm^{-2}year^{-1}, but in northwestern Ontario, where deposition of strong acid averages 8 to 10 meqm^{-2}year^{-1}, the yield of cations was approximately 30 meqm^{-2}year^{-1}, although the organic content (as dissolved organic carbon) of streams was as great or greater.

We agree with Krug and Frink that land-use changes may be of importance (*3*), although it is difficult to quantify the effects on water chemistry. The published material referred to by Krug and Frink seems, however, to be selective. They refer to Rosenqvist's estimate of increase in standing biomass in Norwegian forests, but many more detailed studies (*3, 9, 10*) are not mentioned. Tveite (*3*, p. 102) found that, for large areas of southernmost Norway, the sum of the annual cation export by removal of timber plus the accumulation of cations in trees was much smaller than the atmospheric H^+ deposition. The effect of forest growth on soil acidity should therefore be small compared to that of acidic precipitation. Other studies by Drabløs and co-workers (*9*) in areas with acidification problems did not show land-use changes expected to cause acidification. Such studies are difficult to execute, and details may certainly be criticized, but they should be mentioned.

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Krug and Frink contend that studies conducted in southern Norway support their conclusion that natural soil formation is often more important than acid rain in determining the acidity of lakes and streams. They also resurrect the hypothesis that changes in land use have caused changes in soils and vegetation that in turn are responsible for the acidification of surface waters. This is surprising because this hypothesis has been tested and faulted as a result of several independent studies, including the final report of the SNSF project (*1*) and reports presented at the 1980 Sandefjord Conference (*2*), both cited by Krug and Frink.

With respect to lake and stream acidification and damage to fish populations, Krug and Frink do not address the empirical data at hand. Whereas land-use changes and podzolic soils are found over all of Norway, the acidified lakes and streams with extinct or damaged fish populations are located only in areas in which the weighted-average pH of precipitation is 4.7 or lower. These fish populations have been lost during the past 40 years, the same period in which emissions of sulfur dioxide in Europe (and deposition of acidifying compounds) have doubled. Acidification of freshwaters and loss of fish populations coincide in time and space with the occurrence of acid rain (pH <4.7). The empirical data from Norway show that acid rain is a necessary but not sufficient condition for freshwater acidification (*3*).

How then do we explain the fact that, in areas not receiving acid rain, podzolic soils are often highly acidic (pH <5) and yet surface waters are typically bicarbonate with a pH greater than 5.5 (*4*)? In such areas organic and bicarbonate anions predominate in soil solutions. Soil respiration causes elevated levels of carbon dioxide; the CO_2 dissolves and hydrolyzes to form carbonic acid. Base cations enter solution by hydrogen-cation exchange with the soil exchange complex (*5*). The organic anions are typically removed from solution in the lower soil horizons. When the solution leaves the soil, degassing occurs and CO_2 is lost. The *p*H increases, and the result is a Na^+, K^+, Ca^{2+}, Mg^{2+} bicarbonate stream water with a *p*H greater than 5.5. Krug and Frink do not give sufficient attention to the effect of CO_2 pressure on soil solution and stream water chemistry.

Acid rain adds the additional mobile anions SO_4^{2-}, and often NO_3^- to this system. These are strong-acid anions. The increased concentration of anions in soil solution causes increased concentrations of cations, again regulated by exchange with the soil exchange complex. As the soil solution leaves the soil, degassing of CO_2 occurs, but the water may contain sufficient H^+ to give the H^+, base cation, SO_4^{2-} stream water observed in acidified regions of both Europe and North America (*6*).

Krug and Frink's hypothesis of land-use change does not explain the observed acidification of lakes and streams and loss of fish populations. Apart from natural sea spray chloride in coastal regions, sulfate and nitrate are the dominant anions in these acidified waters. Acid precipitation supplies both. Land-use change in the absence of acid rain can only affect the concentration of the weak-acid anion bicarbonate and organic acids. The concentration of organic anions is negligible in clear waters. Surface waters with appreciable bicarbonate have a *p*H greater than 5.5. Thus land-use changes can affect surface waters only in the *p*H range down to 5.5. Acid rain or some other source of strong acids is necessary to acidify surface waters to a *p*H below 5.5 and to cause the resulting damage to fish populations.

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We are pleased that Johnson *et al.* agree that soil formation is a strongly acidifying process that can contribute to the acidification of landscapes, including those receiving acid rain. This was the major point of our article. Also, Seip and Dillon agree that changes in land use may be important, although Wright argues that such changes cannot acidify surface waters below about *p*H 5.5.

However, there are differences of opinion about the importance of soil organic matter in buffering acidity, as well as the effects of deposition of atmospheric sulfate, and the impact of historical or naturally occurring changes in the landscape. In addition, there are some misinterpretations of our statements or their emphasis. We welcome the opportunity to clarify these issues.

We agree with Johnson *et al.* that the *p*H of a system is an important thermodynamic parameter. The heart of the matter, however, is not the *p*H of the rain, as Johnson *et al.* contend. Rather, the question is, how much does the rain change the *p*H of the soil? Any thermodynamic treatment must include the total acids and bases present in the system because these capacity factors also influence *p*H. As Johnson himself noted earlier (*1*), the potential acid neutralizing capacity of the geologic materials present in the average landscape is enormous. Clearly, this is the most important process controlling the acidity of water, even in areas where acid rain is believed to have a great impact: the majority of waters in these areas are bicarbonate with a *p*H greater than 5.5 (*2–6*) (Table 1). Even most headwaters in sensitive regions are not critically acidified at a *p*H less than 5 (Table 1).

Johnson (*1*) also noted that the rate at which minerals can react with acid rain is critical. We agree. In addition, we emphasized in our article that, in sensitive areas, the buffering capacity of the thin and rocky soils is greatly augmented by the humus that typically develops on such landscapes. While it was generally thought that soil organic matter buffers against additions of strong acids only by cation exchange, it is increasingly recognized that the complex solubility properties of organic matter intimately influence acid buffering capacity both in the soil and in water (*7–10*). The importance of organic matter is illustrated by the high proportion of humic-colored waters in sensitive regions of eastern North America and Scandinavia (*4, 5, 8, 11, 12*). The proportions are even higher for acid lakes: 88 percent of the Norwegian lakes with *p*H less than 5 in Table 1 are humic colored. None are blue waters with high transparency (*5, 9*).

We pointed out that great quantities of acids accumulate naturally in surficial soil horizons, which can be reflected by the extreme acidity of soil and soil solution *p*H, and which can also mobilize ionized aluminum (*7*). We also noted that not all aluminum is complexed by organic matter. We do not agree with statements by Johnson and others (*13*) that *p*H 5 throughfall or *p*H 4.6 snowmelt at Hubbard Brook (*12*) is dissolving aluminum from soils whose mean *p*H ranges from 3.4 to 3.9 (*14*). However, we did note that acid rain may mobilize ionic aluminum indirectly through ion exchange.

While it is apparently true that ionic aluminum is more toxic to fish than complexed aluminum, Johnson *et al.* do not provide convincing evidence that ionic aluminum and fish kills can be attributed solely to acid rain. Adirondack and inland New England waters have had failures of natural fish populations and stocking programs since the turn of the century (*15, 16*). Sixty years ago, the "natural pollution problem" of acidity was considered an important factor, with water from sphagnum bogs and floods after drought or snowmelts being especially acid and said to cause coagulation of the mucus in fish (*16*).

The comparison of Jamieson Creek in British Columbia with Falls Brook in New Hampshire is uncertain. Jamieson Creek drains a coniferous watershed receiving about 370 centimeters of rain annually, while Falls Brook drains a northern hardwood forest receiving only about 130 centimeters of rain annually. Consequently, the two streams have vastly different seasonal chemical and hydrologic budgets (*17, 18*). Indeed, parallel streams at Hubbard Brook separated by only a few hundred meters display twofold differences in cation yields (*19*).

All three letters continue the assumption that nitrate and sulfate in acid waters come from acid rain. However, the presence of considerable sulfate in acid runoff and leachate from soils and peats in "clean" environments has been known since the early 1930's when mineral acids rather than organic acids were thought by some to be the principal acidifying component of soil (*20*). Similarly, the mere presence of nitrate in acid runoff is not proof of acidification by acid rain. Watershed studies with acid soils in "clean" environments in the Northwest show pulses of acidity in runoff that are associated with nitrate (*21*).

Table 1. Regional watershed surveys from the Adirondacks (*2*), New England (*3*), and southern Norway (*4*).

Survey	Number	
	Total	*p*H < 5
Adirondack Lakes and ponds	2877	212
New England Headwater lakes and streams	226	19
Southern Norway Small headwater lakes	155	28

Silicate rocks rich in sulfides underlie much of New England (*22*). Although the bedrock at Hubbard Brook is said to be very low in sulfur (*17*), its actual concentration was not given (*23*). Petrographic analyses of the two types of bedrock found at Hubbard Brook show that both contain pyrite (FeS) with up to 2.2 percent sulfur by weight (*24*). The fact that concentrations of sulfate in runoff are correlated with products of mineral weathering such as silica and bases (*17*) suggests that the estimate that 96 percent of all sulfur at Hubbard Brook comes from atmospheric deposition should be reexamined. Similar observations have been made for Adirondack waters (*5*).

The authors of all three letters also assume that acid waters with little or no anion deficit are unnaturally acidified, presumably by the strong acids in acid rain. However, waters can be acidified by strong acids produced by ion exchange with electrolytes in rain or from weathering, as well as by weak organic acids. In these mixed acid systems, estimates of weak acidity by anion deficit can be obscured by suppression of dissociation of weak acids by strong acids (*9*), by complexation of cations and anions with organic matter (*25*), and by analytical errors inherent in determinations by difference. For example, a series of 19 Australian lakes with a mean *p*H of 4.65 and 15.7 milligrams per liter of dissolved organic matter have little or no anion deficit. The strong acids apparently came from ion exchange with sea salts in rain (*8, 26*). Similar acidification has been observed in Tasmanian lakes (*27*) and Norwegian watersheds (*28, 29*).

Seip and Dillon state that we misrepresented the findings of the SNSF project on acidification of runoff. We said that runoff from a minicatchment was twice as acid as the rain. The *p*H of runoff was correlated with soil *p*H for two events in November 1977 as well as for an unspecified number of events from May to September 1978. While Seip and Dillon concentrate on washout of sulfate assumed to be from dry deposition, the data show that only about one-third of the cations were charge-balanced by sulfate from all sources (*25, 29*). Thus we believe that we have accurately represented the results of this and many other SNSF studies which show that electrolyte content of rain is often more important than its acidity, and that soil *p*H has even a greater effect on the *p*H of runoff than does total electrolyte in rain.

The effect of soil *p*H on runoff is further illustrated by a study showing that the composition of snowmelt had relatively little effect on the *p*H of runoff when compared with the effect of soil *p*H, even though the soil was frozen. Runoff from acid humus with heather was *p*H 4, while loam had runoff of *p*H 6 (*29*). Furthermore, we showed in our article that recovery of hardwood forests in Connecticut can acidify soil from *p*H 5.5 to 3.9 in 50 years. Conifers in Massachusetts acidified soil to *p*H 3.0 to 3.2 following disturbance 140 years ago, and a thick forest floor developed that restricts percolation into underlying mineral soil (*30*). Thus we agree with Rosenqvist that even small changes in vegetation and humus production can overwhelm the effects of regionally acidified precipitation (*31*).

Acidification of leachate and runoff by sulfuric acid in rain is difficult to measure in complex and variable watersheds. Thus, we wrote that sulfate leaching will increase with little or no *measurable* change in *p*H. Seip's minicatchment studies were designed to eliminate such complications (*25*). As we noted, even here the measurable effects of acid rain of runoff were subtle (*25*). While the mobile anion concept is useful, increases in cation leaching will not be as great as those of sulfate because of organic buffering.

Undoubtedly, lakes downwind from the Sudbury smelter were considerably acidified by sulfuric acid. When these studies began, emissions of sulfur dioxide from this one point source at Sudbury were estimated to be 10 percent of the total emissions in North America. Apollo astronauts used the barren landscape to simulate walking on the moon. On the other hand, these extreme-case studies together with many years of experience in reclaiming acid sulfate soils (*32*) show that the effects of acidification are not irreversible. Thus, the concerns of many that our landscapes will be sterile forever unless immediate action is taken are unwarranted.

Seip and Dillon agree that changes in land use may be important and that the effects on water chemistry are hard to quantify. Norwegian research cited by Wright as disproving the effects of changing land use leaves something to be desired. For example, there is no explanation in the report of data showing that (i) in the watersheds studied that lacked dairy farming, 78 percent of the lakes were fishless; (ii) in watersheds with abandoned dairy farms, 60 percent of the lakes had no fish; and (iii) in watersheds with active farming, only 30 percent were fishless (*33*). Furthermore, acidification predates the occurrence of acid rain with a *p*H less than 4.7, or the 40 years mentioned by Wright. Acidification and loss of fish from mountain lakes in Norway dates back to at least 1900 (*29, 34*). Where losses of salmon have been reported in rivers of southern Norway, most of the decline occurred between 1910 and 1920, with great fish kills after heavy rains and snowmelts (*35*). Acidification and fishing losses were public concerns in Norway by the 1920's (*35*).

Despite Wright's assertion, soils are not uniform over all of Norway. Soils in southernmost Norway are generally more acid, thinner and rockier than those further north (*36, 37*). Thus, edaphic and hydrologic conditions are more favorable for acidification of runoff and surface waters in the south of Norway (*38*). Careful examination of maps of soil, *p*H of rainfall, and acidity of surface waters clearly show that the distribution of acid waters (*4*) is much better correlated with the distribution of acid podzols, peats, and thin lithic associations (*37*) than with the distribution of acid rain (*4*).

The comment by Johnson *et al.* that deforestation produces nitric acids, not organic acids, misses the point. First, foresters did not follow clear-cutting with herbicides as was done at Hubbard Park: they wanted vegetation to return. It is the recovery of the forest that results in the gradual acidification of soil by the accumulation of acid humus, a process that requires many years. We used Rosenqvist's biomass data to illustrate the accumulation of organic acids, but we criticized estimates of net cation uptake in biomass as being incomplete estimates of mineral weathering. Although it is necessary to distinguish between acid soil and the acidity that drains from it, we believe that there is now more than sufficient evidence that water draining from acid soils will be acid.

The recognition that naturally occurring acid soils can contribute to the acidification of lakes and streams represents a significant advance in our understanding of this serious environmental problem which heretofore has been attributed to acid rain. It is clear, however, that the relative roles of acid soil and acid rain need closer scrutiny. We hope that some of the resources now devoted to documenting the extent of the problem can be redirected toward determining its cause.

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Boiling Drinking Water

The timely and important letter by P. J. Isaacson, L. Hankin, and C. R. Frink (17 Aug., p. 672) showing that boiling drinking water removes ethylene dibromide residues comes as no surprise to knowledgeable Washingtonians. Our public water supply, consisting at times of much of the flow of the Potomac River, contains many elements that can be significantly reduced by boiling. Volatile halogenated hydrocarbons, the result of either pollution or de novo synthesis upstream are efficiently removed by boiling, as judged by samples spiked with ethylene dichloride (*1*). Chlorine, sometimes approaching breakpoint concentrations, is effectively decreased by boiling, at least by organoleptic test. In many ground waters, seasonal blooms of algae produce peculiar flavors that may be partially eliminated by boiling. Finally, boiling may reduce the risk from infectious contaminants that have escaped treatment.

Most carcinogens are unaffected by simple boiling of ground water, but as an alternative to home filtration systems, distilled or deionized drinking water, or imported mineral water, boiling is the most cost-effective and pragmatic step the individual can take to avoid the effects of at least a few of the environmental insults with which one is faced.

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