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Potential Health Implications for Acid Precipitation, Corrosion, and Metals Contamination of Drinking Water

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Potential health effects of drinking water quality changes caused by acid precipitation are presented. Several different types of water supply are discussed and their roles in modifying acid rain impacts on drinking water are explained. Sources of metals contamination in surface water supplies are enumerated. The authors present some results from their research into acid rain impacts on roof-catchment cisterns, small surface water supplies, and lead mobilization in acid soils.

A good correlation was obtained between cistern water corrosivity as measured by the Ryznar Index (RI) values and standing tapwater copper concentrations. However, lead concentrations in tapwater did not correlate well with cistern water RI. A modified linear regression model that accounted for Ryznar Index change during storage in vinyl-lined cisterns was used to predict the Ryznar Index value at a copper concentration of 1000 μg/L. The predicted RI was greater than the RI of precipitation with a pH of 5.3, indicating that anthropogenically acidified precipitation may result in cistern tapwater copper concentrations in excess of the 1000 μg/L suggested drinking water limit.

Good correlations between tapwater Ryznar Index and tapwater copper and lead concentrations were not obtained for the small surface water supply. Aluminum concentrations in reservoir water were similar to those in stream source water. Limited data were also presented that indicated lead was present in acid forest soil leachate and streams draining such soils in relatively small concentrations. Where appropriate, recommendations for future research are included with the discussions of research results.

Introduction

Although acid rain has been recognized as a major environmental problem for many years, very little research has been conducted on its potential health effects. The available literature pertinent to this issue is extremely scant; however, water quality work done to characterize fishery impacts is of relevance. Also of relevance is the considerable body of information on corrosion of water distribution systems by drinking water, and the health effects of toxic heavy metals such as lead in drinking water.

In order to understand the potential impacts of acid rain on drinking water concentrations of toxic heavy metals, a knowledge of water supply sources, types and treatments is required. Water supplies that use deep groundwater as a source are much less likely to be affected by acid precipitation than those that rely on small headwater streams as sources of supply. Watershed and groundwater recharge area factors such as geology, soils and hydrology as well as amounts of acid deposition are also important.

The physical plant of the water supply must also be considered. Reservoir size in relation to water use in the system is particularly important in determining the quality of water entering the distribution system. The larger the reservoir capacity in relation to daily systemwide water use, the smaller the water quality change to be expected at the entry point to the distribution system subsequent to an acid runoff episode affecting the stream source. The makeup and configuration of the distribution system is also of importance in that water may be flushed less frequently from certain parts of the system and piping materials could greatly influence the quality of water at the consumer's tap. Asbestos–cement-lined pipe has the potential to increase the calcium and asbestos concentration of tapwater; iron pipe, the concentration of iron; lead pipe, the concentration of lead; galvanized pipe, the concen-

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tration of zinc and cadmium; and copper pipe, the concentration of copper and lead (from lead solder).

Private water systems serving individual rural dwellings are prevalent in many areas of the country. These systems typically rely on groundwater as a source of water supply, but about 1% of these systems (133,000 systems in the eastern U.S.) use roof-catchment cistern water systems, where precipitation intercepted by the dwelling roof is stored in a cistern for later use. As would be expected, roof-catchment cistern systems are especially vulnerable to acid precipitation.

Water treatment practices are also of great importance. If chlorine gas is used as a disinfectant, corrosivity is likely to be greater following disinfection. If sodium or calcium hypochlorite is used, corrosivity may decrease. The amounts of the chemicals added are also significant. Corrosion control by chemical methods is also important. Chemical corrosion control measures will reduce but not eliminate corrosion. Physical corrosion control such as replacement of easily corroded materials in the distribution system is the only completely effective corrosion control measure.

Although plumbo-solvency has been a problem for mankind since the days of the first advanced water dis-

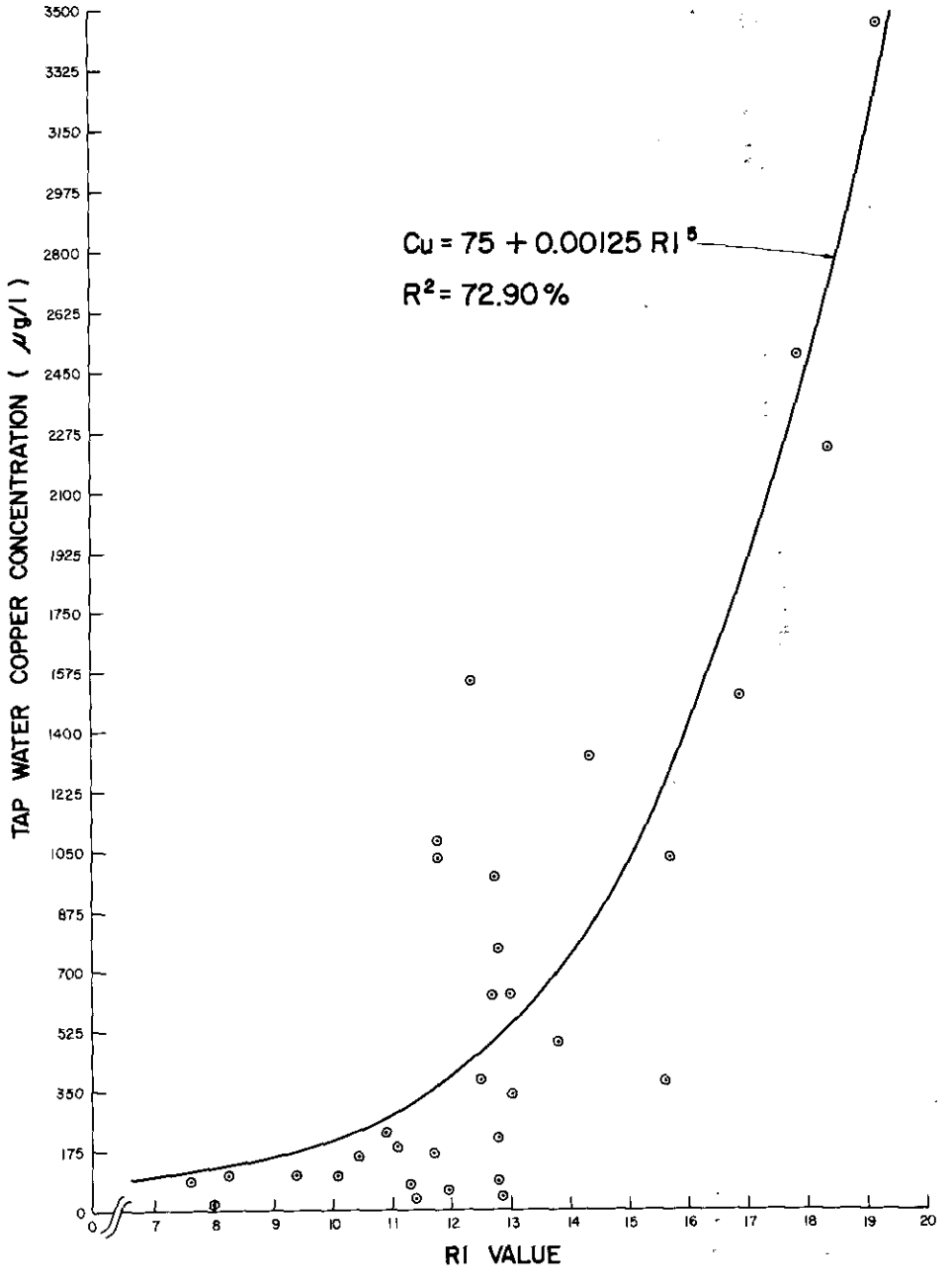

FIGURE 1. Relationship of tapwater copper concentration to cistern water Ryznar Index value for cistern water supplies.

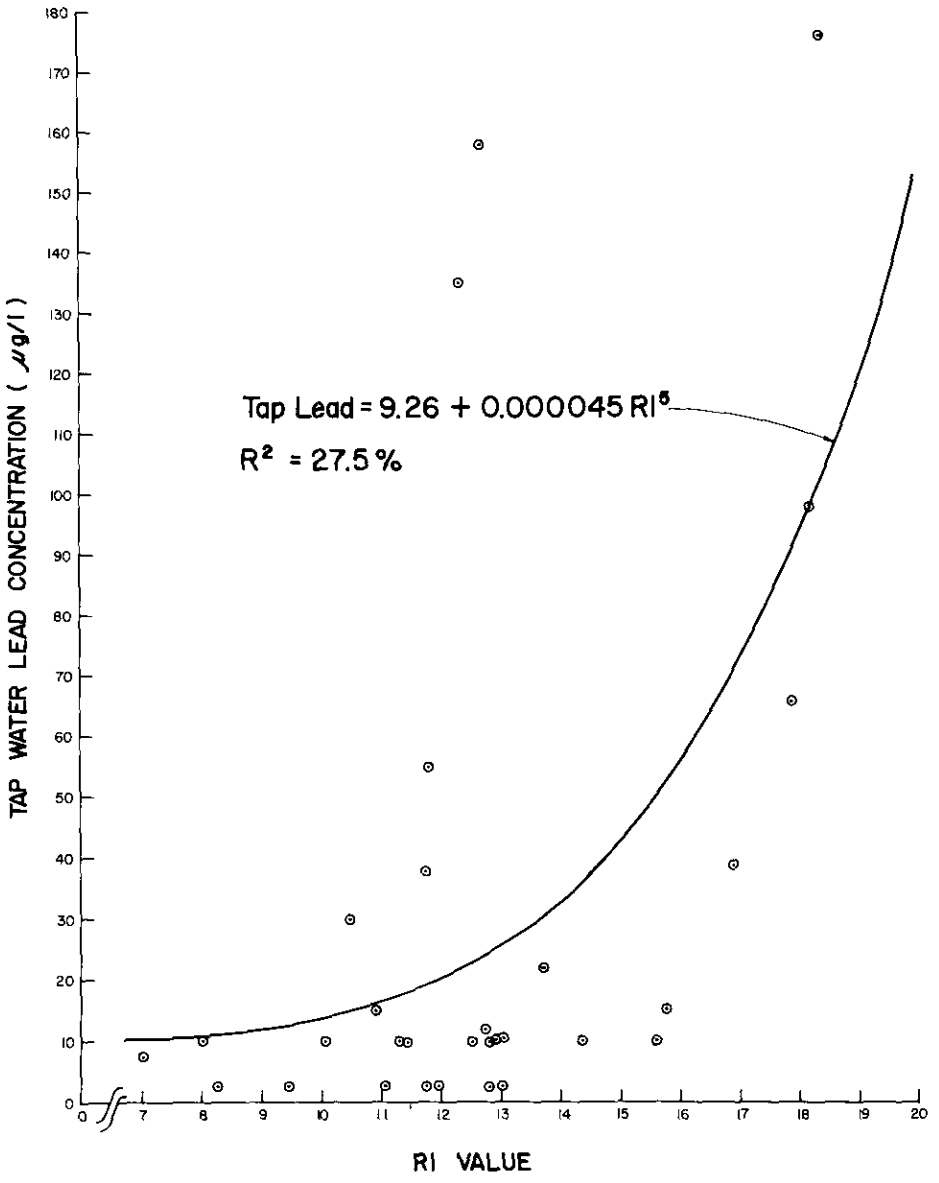

FIGURE 2. Relationship of tapwater lead concentration to cistern water Rynzar Index value for cistern water supplies.

tribution systems built by the Romans, it is still a poorly understood phenomenon. The standard method for evaluating the corrosivity of water remains the Langelier Saturation Index (*1*). However, numerous articles in the literature are critical of this index, and a large number of others have been proposed that have likewise been criticized. Very few of the corrosion indices appearing in the literature have been related quantitatively to corrosion products or rates. One author (*2*) related his Ryznar Stability Index subjectively to corrosion rates observed in water distribution systems. The Ryznar Stability Index (RI) was chosen for the corrosivity estimates in this report.

There are four main sources of toxic metals in any water supply system. These are: sediments deposited in the distribution system, the water conveyance system, water treatment chemicals, and the source water. Apart from unusual natural situations and cases of pollution by industry, the conveyance system has historically been of the greatest importance and because of the corrosivity of acid precipitation, of interest in the determination of the health effects of acid rain. However, recent interest in the toxicity of aluminum may indicate a greater importance for the source water in cases of drinking water quality problems caused by acid rain.

In undisturbed watersheds, the origins of metals in source water may be atmospheric or as a consequence of the water's contact with soil and/or rock containing metals. The solubility of metals in water varies but generally increases with decreasing pH. As a consequence there is much concern over the potential role of acid

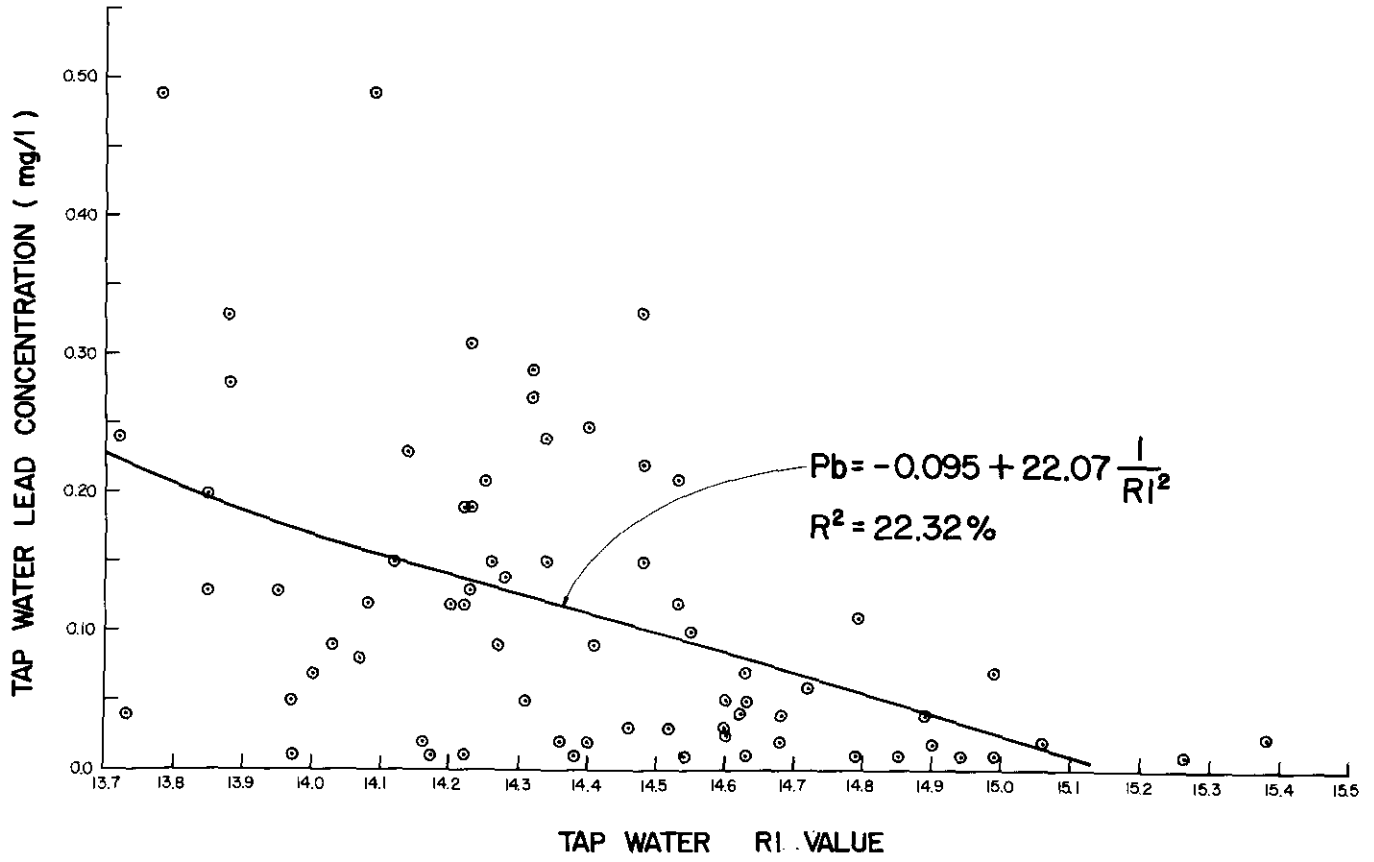

FIGURE 3. Relationship of tapwater lead concentration to tapwater Ryznar Index value for a small surface water supply.

rain in the accelerated leaching of metals from soil and rock. Aluminum leaching is hypothesized to have increased as a consequence of acid rain and there is concern over the potential leaching of other metals such as lead and cadmium.

The toxicity of most of the heavy metals is well known and well documented in the literature; consequently, further iteration would be superfluous. However, the literature with respect to the impact of acid rain on toxic metal availability to man or man's food chain is sparse. It is not yet possible to link acid rain directly to any observed drinking water related health effects in man.

Results reported in this paper attempt to indicate the relationships between drinking water corrosivity and concentrations of toxic heavy metals in tapwater for roof catchment and small surface water supplies. Data are also presented on the mobilization of lead in acidified soils receiving high rates of acid precipitation. Some suggestions for research on acid rain, drinking water quality, and human health effects are also included.

Procedure

Selected results from three separate studies are reported in this paper. The first of these studies involved the evaluation of water quality in 40 roof-catchment cistern systems in western Pennsylvania. Bulk precipitation, water in cistern storage, water and sediment at the sediment-water interface at the bottom of the cistern, and tapwater were sampled on two occasions at each location. The Ryznar Stability Index (RI) was calculated for cistern water at the point of entry to the household plumbing system and correlated by linear regression techniques to the measured concentrations of lead and copper in tapwater that was stored in the plumbing system overnight. A more detailed report of this study has been given elsewhere (*3*).

The second study attempted to correlate tapwater quality in two private homes served by a small publicly owned water utility with changes in source water quality and with the RI of tapwater. Two cold water taps in each of the two residences were monitored through two periods of acid runoff episodes on the system's watershed in 1984. Linear regression analysis was used to correlate the variables. A more complete description of this study is presented in Spangenburg (*4*).

The third area of study involved observations of lead mobility in acidified forest soils in an area of high acid precipitation and atmospheric deposition of lead. Lead concentrations in bulk precipitation, precipitation falling through trees, soil water and stream water were determined. The objective of this study was to determine the extent to which lead was being mobilized in

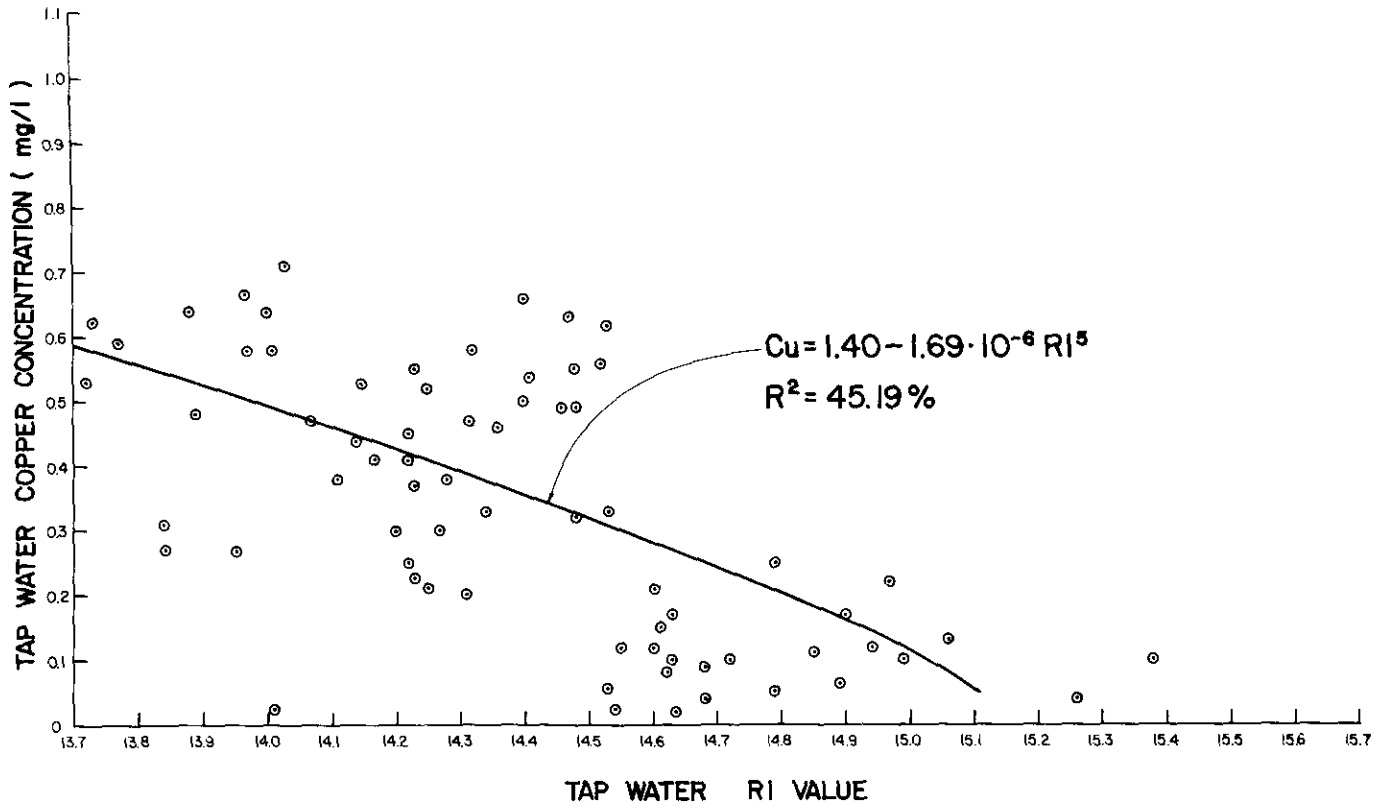

FIGURE 4. Relationship of tapwater copper concentration to tapwater Ryznar Index value for a small surface water supply.

Table 1. Mean concentrations of copper and lead at various points in the water system.

Location	Cu, μg/L	Pb, μg/L
Source water (Galbraith Gap Run)	<20[a]	<1[a]
Reservoir	<20	<1
DI tapwater	539	4
HI tapwater	496	24

[a] Detection limit.

acidified forest soils and to determine its presence in waters exhibiting varying degrees of acidification.

Results

Roof-Catchment Cisterns

Initial attempts at correlating the tapwater concentrations of lead and copper to cistern water RI values were disappointing (*5*). Linear regression analysis with polynomially transformed data yielded poor correlation coefficients in both cases. However, subsequent reanalysis of the data in which temperature differences that had previously been thought to be minor were taken into account and where disinfected (chlorine additions) systems were removed from the data set, yielded a satisfactory correlation for copper (Fig. 1). The correlation of lead concentration in tapwater with cistern water RI remained poor (Fig. 2).

Demonstrating a relationship between the corrosivity of cistern water and tapwater copper concentration does not go far enough to link acid precipitation to the problem of drinking water quality impairment. In an attempt to establish such a linkage, Sharpe and Young (*5*) adjusted the RI of the acid precipitation collected in their study to reflect changes that they observed occurring during storage in vinyl-lined cisterns. If the adjusted RI's based on this regression model [$Cu = 75 + 0.00125(0.95\ RI^5)$] are used, the potential effect of acid precipitation on tapwater copper concentration can be predicted for precipitation of varying RI. It can be seen from this exercise that precipitation with an RI of 15.7 or greater will result in a predicted copper concentration that exceeds the drinking water standard for copper. Since the RI of precipitation with a pH of 5.3 collected in the Sharpe and Young study was 14.7, one might conclude that rainwater not strongly acidified by sulfuric and nitric acids would result in vinyl-lined cistern water that would produce an acceptable tapwater copper concentration. A more complete determination of the role cisterns play in modifying precipitation is necessary before a conclusive statement to this effect can be made.

It is recommended that additional work be done in

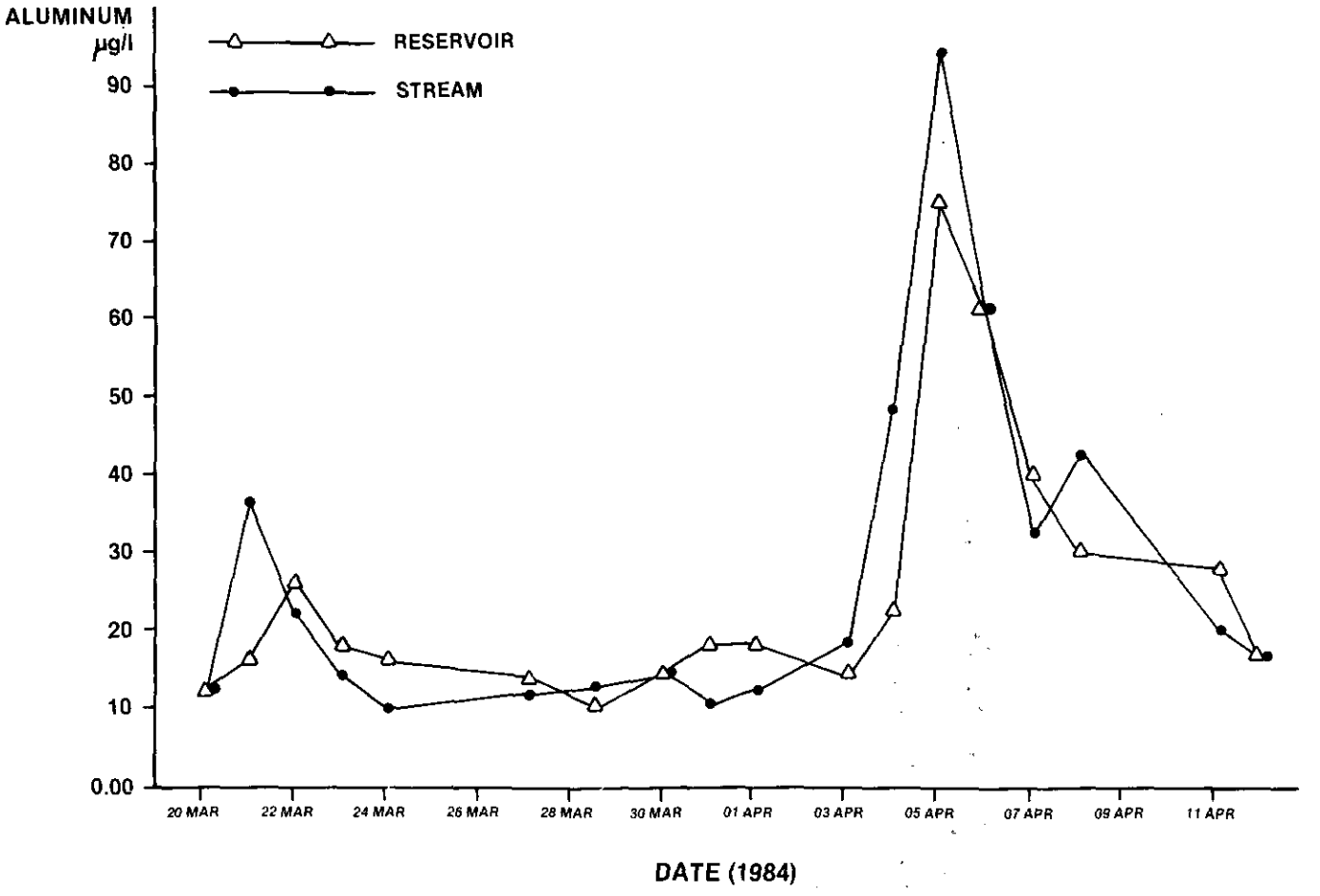

FIGURE 5. Temporal changes in the aluminum concentrations of Galbraith Gap Run and the water supply reservoir during an acid runoff episode.

an attempt to establish a cause and effect link between acid rain and the presence of corrosion products in cistern tapwater. In addition, cistern systems should be monitored to determine if additional heavy metals such as arsenic and selenium may also constitute potential health risks.

Small Surface Water Supplies

Researchers have demonstrated acidification of headwater streams during acid runoff episodes (*6–8*). The work of Leibfried et al. (*8*) reports a similar problem in the source water for two public water supplies in Pennsylvania. The work reported here is a continuation of that reported by Leibfried et al. for Galbraith Gap Watershed. A strong relationship was shown for a number of water quality parameters, including RI, between the source water and reservoir water at the distribution system intake, linking acid runoff episodes on the study stream (Galbraith Gap Run) to acidification of the water entering the water distribution system.

An attempt was made to link tapwater RI in this system with tapwater copper concentration at two residences in the system. As indicated in Figures 3 and 4, linear regression analysis failed to demonstrate a strong relationship between these two variables. Two reasons for the lack of correlation between these variables appeared to be sodium hypochlorite additions to the water for control of bacteria, and corrosion of asbestos-cement pipe located in the distribution system. Further work will be required to explain these results. Additional studies are required to ascertain the potential hazards of asbestos-cement pipe in systems subjected to acid precipitation.

The data presented in Figures 3 and 4 indicated that the water in the system was definitely corrosive. Although copper and lead concentrations in standing tapwater were not in excess of drinking water standards, the levels observed were appreciable, especially for lead. The lack of these metals in the source water (Table 1) indicated that they were corrosion products of the distribution system.

Aluminum concentrations in reservoir water are shown torise in concert with aluminum concentrations in the source water, Galbraith Gap Run (Figure 5). Mann-Whitney tests reveal no difference between the median Al concentrations in stream water and the reservoir ($\alpha = 0.05$).

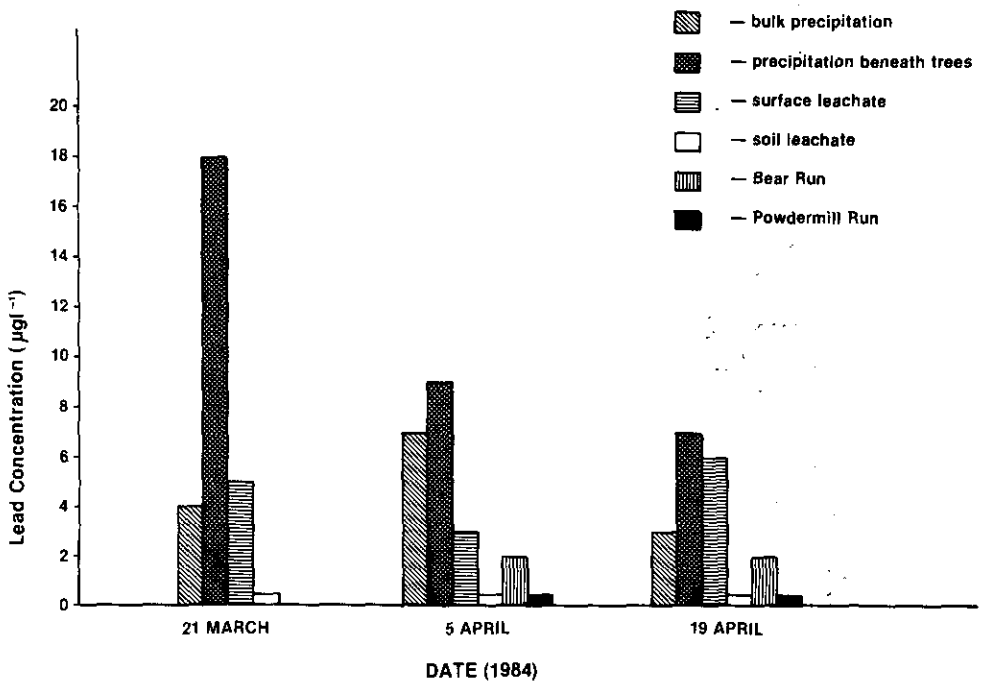

FIGURE 6. Lead concentrations at several locations on Pennsylvania's Laurel Hill.

A more thorough study of tapwater metals concentrations in areas of high acid deposition is clearly needed. Such a study should be conducted on a water system with small reservoir storage capacity, lead and copper service lines and where corrosion control treatment is not provided. Systems of this type are numerous in the Appalachian Mountains. The study should attempt to link changes in source water quality to changes in tapwater quality. The influence of water treatment chemicals and presence of concrete-lined pipe should be determined. In addition, a study of the impact of acid deposition on the release of asbestos-cement fibers where asbestos-cement water distribution pipe is used should be initiated.

Lead Mobilization from Acidifed Soil

Data were collected in the summer of 1984 on Pennsylvania's Laurel Hill to determine the potential for lead mobilization from acidified soils receiving large amounts of acid deposition. The Laurel Hill is located in an area of high atmospheric lead deposition (*3,9,10*). Soil leachate and stream water were sampled during an acid runoff episode to determine the presence of lead in soil water and subsequently in stream water. Streams of varying responses to acidification (Bear Run, severely acidified; Powdermill Run, moderately acidified) were selected, and an acidified (pH 4.3) forest soil was studied. The summarized data are presented in Figure 6.

The results presented in Figure 6 indicate that the concentration of lead in soil leachate is low—well below drinking water standards. Leachate collected at lower levels in the soil contained less lead than leachate collected near the surface. In all cases there was a higher concentration of lead in water reaching the soil than in the soil leachate. The small concentrations of lead found in two streams in the area during an acid runoff episode that occurred during this time period are further indication that the acidified forest soils on these watersheds are retaining lead.

A study of heavy metals mobility on acidified watersheds being utilized for public water supply in an area of high acid deposition is indicated. Such a study would use mass balance techniques to determine the input and output of metals to the watershed over time. Concentrations of metals at various locations on the watershed should be identified along with the sources and sinks of such metals. Experiments should be conducted to produce estimates of change in metals exposure to consumers of drinking water obtained from these watersheds under a scenario of increased acid deposition.

Summary and Conclusions

Very little information is currently available on the drinking water quality impacts of acid precipitation. A great deal of research is necessary before conclusive statements can be made, but it is clear that measurable adverse impacts are taking place in small surface water supplies and roof-catchment cistern systems. It is equally clear that impacts to drinking water quality will be negative rather than positive; however, it is as yet difficult to quantify these impacts precisely. Until these impacts are quantified, it will remain impossible to link acid precipitation caused drinking water quality

changes to human health effects. More research on the question of acid precipitation caused drinking water quality changes and human health effects is clearly indicated.

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