# Map Supplement

# Total Alkalinity of Surface Waters—A National Map

James M. Omernik and Charles F. Powers

Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, OR 97333

**Abstract.** This map illustrates the regional patterns of mean annual alkalinity of surface water in the conterminous United States. As such, it affords a qualitative graphic overview to the sensitivity of surface waters to acidification. The map is based on data from approximately 2,500 streams and lakes and apparent spatial correlations between these data and macrowatershed characteristics, especially land use.

**Key Words:** surface-water alkalinity, sensitivity to acidification, water quality.

THE accompanying map represents the first step in a comprehensive project to identify general patterns of surface-water sensitivity to acidification. The map results from the growing demand for accurate identification of acid-sensitive aquatic areas of the conterminous United States and is part of a continuing program to (1) inventory and synthesize, state-by-state, the vast quantities of relevant water quality data; (2) conduct general field surveys to fill data gaps; (3) prepare detailed regional maps and update national maps; and, finally, (4) conduct extensive field surveys (including biological parameters) of critically sensitive areas.

The map was developed from mean annual total alkalinity values of approximately 2,500 streams and lakes and from the apparent relationships of these data with land use and other macro-watershed characteristics, such as soil type and geology. Total alkalinity is used as an index of sensitivity because it expresses the acid-neutralizing capacity of water bodies and thus their relative sensitivity or tolerance to acid inputs. The ranges of our six map units were chosen to illustrate patterns of relative sensitivity on a national scale. Although there is general agreement that total alkalinity expresses acid sensitivity of surface water, there is lack of agreement on exactly where the breaking points exist between sensitive, moderately sensitive, and insensitive waters. Hendry et al. (1980) considered waters not sensitive to acidification when alkalinities exceeded 500 $\mu$eq/l and of high sensitivity when alkalinities were less than 200 $\mu$eq/l. The Ontario Ministry of the Environment (1981) proposed that alkalinities between 0 and 40 $\mu$eq/l indicate extreme sensitivity and those between 40 and 200 $\mu$eq/l moderate sensitivity. Zimmerman and Harvey (1979–1980) have suggested a triad of parameters to define acid sensitivity in surface waters: pH $<$ 6.3–6.7, conductivity $<$ 30–40 $\mu$mho/cm, and alkalinity $<$ 300 $\mu$eq/l.

General patterns of average sensitivities of surface waters to acidification are depicted by this map, not worst-case or best-case conditions. Our intent is to show what one might expect to find in most surface waters most of the time. Subsequent larger-scale maps of the more sensitive areas will address worst-case conditions, ranges of conditions, and significant regional and (to the extent possible) local relationships between alkalinity and geology; soils; and climatic, physiographic, and human-use factors. Confidence limits for areas of greatest sensitivity will also be pro-

*Annals of the Association of American Geographers*, 73(1), 1983, pp. 133–136

vided. These maps will be compiled as detailed information is gathered and analyzed.

For the present, however, there is an urgent need to understand the relative sensitivity of surface waters in different parts of the country in order to (1) provide a national perspective on the extent of the problem, (2) provide logic or rationale for selecting geographic areas for more detailed studies, and (3) allow more accurate regional economic assessments of acid-precipitation impacts on aquatic resources.

## Map Development

The data used to compile this map were selected and mapped according to several categories. Stream sites were listed separately from lakes, natural lakes were distinguished from impoundments, and both stream sites and lakes were separated into two groups—those associated with watersheds of less than 260 sq km (100 sq mi) and those associated with watershed areas of between 260 and 2,600 sq km (100 and 1,000 sq mi). Except in areas that were very similar in land use, physiography, and soils (e.g., the Great Plains), data associated with watersheds larger than 2,600 sq km (1,000 sq mi) were excluded. As might be expected, we found that the patterns of alkalinity values in streams were quite similar to those of lakes in the same area. As the data were being gathered and plotted, and geographical patterns of high and low alkalinities developed, collection efforts tended to concentrate on these apparent areas of greatest sensitivity.

Most of the data were obtained from the U.S. Geological Survey via STORET, an EPA computer-based water quality data storage and retrieval system. The remainder came from varied sources, principally the National Eutrophication Survey (U.S. Environmental Protection Agency 1974, 1978a, 1978b, 1978c), the Pennsylvania Cooperative Fishery Research Unit (D. E. Arnold, personal communication, 1981), and the Tennessee Valley Authority (Meinert and Miller 1981). Although various analytical procedures were used by the various agencies [U.S. Geological Survey and the Tennessee Valley Authority, single endpoint titration to pH 4.5; National Eutrophication Survey, colorometric endpoint (methyl orange); and Pennsylvania Cooperative Fishery Research Unit, double endpoint titration], the alkalinity values obtained are reasonably equivalent and, we feel, comparable for our scale of spatial analysis.

Each data point was scrutinized to insure representativeness. To accomplish this, it was necessary to keep the watershed size consistent with the relative homogeneity of major watershed features, such as physiography and land use. In areas of relative heterogeneity, most of the data were associated with small watersheds (less than 260 sq km). Representativeness of the data was imperative for detection of spatial patterns of alkalinity, possible correlations with patterns of other characteristics, and ultimately, extrapolation of the data. To include data from sites having large watersheds of widely differing characteristics (e.g., the Willamette River at Salem, Oregon, the watershed of which includes vast contrasts in soils, geology, climate, and land use), or data downstream from major industrial or municipal waste discharges, would mask these spatial patterns.

The data were plotted on a 1:3,168,000-scale base map of the United States. Each site was represented by a small circle color-coded to approximate value. The exact value of the site was noted beside the circle, together with a designation for lake or stream. The spatial patterns of alkalinity were then compared with maps showing characteristics that are believed to be driving or integrating factors affecting alkalinity. Driving factors, as used in this paper, refer to those that directly affect alkalinity (e.g., geology and soils). Integrating factors, on the other hand, are considered those that reflect combinations of driving factors; for example, land use and potential natural vegetation reflect regional combinations (or an integration) of driving factors such as soils, land surface form, climate, and geology. We believe that the importance of each of these driving factors, and the hierarchy of importance relative to the combinations of factors, varies from one region to another. Clarifying these regionalities is a major goal of our overall synoptic analyses; they will be addressed in the text accompanying the subsequent larger-scale maps.

It became apparent early in this study that land use generally correlated with alkalinity throughout much of the United States, and particularly in the West. In general, surface-water alkalinity was low in areas of ungrazed forest and high where cropland predominated. In-between types of land use generally reflected alkalinity values that corresponded to the degree of agricultural use. However, the apparent relationship between land use and alkalinity varied considerably; in some areas, particularly in the Southeast, the relationship was poorly defined or nonexistent.

Except for some localized situations, we were not able to relate geographical patterns of surface-water alkalinity with geological sensitivity as depicted by bedrock or soil types. Recent studies by Kaplan, Thode, and Protas (1981), McFee (1980), and Hendrey et al. (1980), based on county-by-county average values, have demonstrated such correlations. Because alkalinity, in large part, is a function of the nature of the rock and soil makeup of a drainage basin (Cole 1975), it did not appear unreasonable to expect similar results in this mapping study. The lack of correlation is probably in large part a function of study scale. Had our focus not been on the nation, but rather on a small region or state, possible surface-water alkalinity/geology and soil-type relationships might have been more perceptible. However, this lack of correlation may be due to one or more of several other factors. First, inconsistencies and inaccuracies in rock- and soil-type maps are common between, and even within, regions and between states. Second, the alkalinity in a lake or stream reflects the characteristics of both rocks and soils in the watershed. Even in small watersheds, large spatial variations in rock and soil types and depths can be found. Another confounding factor is that surface and subsurface watersheds frequently are difficult or impossible to define, particularly in areas of karst or continential glacial topography (Hughes and Omernik 1981). Apparent surface watersheds of streams and lakes in such areas often differ greatly in area from the even more-difficult-to-define ground watersheds.

Because of the general correlation of land use with alkalinity, the 1:3,168,000-scale base map with alkalinity values was overlaid onto a color enlargement of Anderson's Major Land Uses map (U.S. Geological Survey 1970). When viewed on a light table, the general land-use patterns and spatial relationships of surface-water alkalinity to land use could be visualized. By studying these relationships and patterns, along with apparent local relationships with geologic and soil characteristics, interpretations were made and map units drawn to reflect these regional relationships.

## Use of the Map

The development and usefulness of this map can best be illustrated by comparison with a more familiar graphic—an isometric map of mean annual precipitation.[1] One should not use a precipitation map to predict the precipitation that will occur during a particular year at a given location. Rather, the map illustrates patterns of long-term conditions. Few parts of the United States typically experience a truly "normal year" climatically. Generally, precipitation totals are somewhat higher or somewhat lower than the mean; occasionally, total deviation from the mean is extreme. Admittedly, precipitation maps may provide a more accurate indicator of their subject than the alkalinity map because of their more extensive data base (particularly from the temporal standpoint). However, precipitation maps are compiled using data from different geographical locations together with knowledge of apparent associations of these data with physiographic characteristics, water bodies, ocean currents, latitude, and other environmental factors. For example, precipitation patterns in mountainous areas, where data are scarce or lacking, are drawn to reflect the expected orographic effects of elevation and exposure to weather systems. Much the same kind of qualitative analysis was used to compile the alkalinity map. It is based on values from more than 2,500 stream sites and lakes throughout the United States, as well as on knowledge of the apparent associations between the alkalinity data and other spatial phenomena, particularly land use.

As with a precipitation map, one should exercise caution when using this alkalinity map. In many parts of the nation, nearly all of the surface waters have mean annual alkalinity values within the range illustrated in the map. In other areas—particularly where there are complex variations in geology and soil types, and other factors affecting acid sensitivity—there are wide spatial and temporal variances in alkalinity. For these types of areas, at this scale of mapping, we were able to estimate only the mean annual alkalinity of most surface waters; many may reflect higher or lower values.

## Acknowledgments

Many people contributed to the development of this map. Especially deserving of recognition is Andrew J. Kinney for his help in gathering, scrutinizing, and plotting the data.

## Note

1. McDowell and Omernik (1979) used this comparison to clarify the utility of a set of national maps of nutrient concentrations in streams from nonpoint sources (Omernik 1977). The total alkalinity map was compiled in a similar fashion to the nutrient maps but with more than two and one-half times as many data points.

## References

**Cole, G. E.** 1975. *Textbook of limnology*. St. Louis, Mo.: The C. V. Mosby Company.

**Hendrey, G. R., Galloway, J. N., Norton, S. A., Schofield, C. L., Shaffer, P. W., and Burns, D. A.** 1980. *Geological and hydrochemical sensitivity of the eastern United States to acid precipitation.* EPA-600/3-80-024. Corvallis Environmental Research Laboratory. U.S. Environmental Protection Agency, Corvallis, Ore.

**Hughes, R. M., and Omernik, J. M.** 1981. Use and misuse of the terms watershed and stream order. In *Proceedings of the Warmwater Streams Symposium*, pp. 320–26. Southern Division, American Fisheries Society.

**Kaplan, E., Thode, H. C., Jr., and Protas, A.** 1981. Rocks, soils, and water quality. Relationships and implications for effects of acidification on surface water in the northeastern United States. *Environmental Science and Technology* 15:534–44.

**McDowell, T. R., and Omernik, J. M.** 1979. *Nonpoint source—stream nutrient relationships: A nationwide study. Supplement 1: Nutrient map reliability*. EPA-600/3-79-103. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Ore.

**McFee, W. W. 1980.** *Sensitivity of soil regions to acid precipitation*. EPA-600/3-80-013. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Ore.

**Meinert, D. L., and Miller, F. A. III.** 1981. *A review of water quality data in acid sensitive watersheds within the Tennessee Valley—Volume 1*. Tennessee Valley Authority, Chattanooga, Tenn. Prepared for the U.S. Environmental Protection Agency.

**Omernik, J. M.** 1977. *Nonpoint source—stream nutrient level relationships: A nationwide study.* EPA-600/3-77-105. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Ore.

**Ontario Ministry of the Environment.** 1981. *Acid sensitivity survey of lakes. Acidic precipitation in Ontario study*. (APIOS) Report No. AP1 002/81, Toronto.

**U.S. Environmental Protection Agency.** 1974. A compendium of lake and reservoir data collected by the National Eutrophication Survey in the northeast and northcentral United States. *National Eutrophication Survey Working Paper No. 474.* Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Ore.

———. 1978a. A compendium of lake and reservoir data collected by the National Eutrophication Survey in the eastern, northcentral, and southeastern United States. *National Eutrophication Survey Working Paper No. 475*. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Ore.

———. 1978b. A compendium of lake and reservoir data collected by the National Eutrophication Survey in the central United States. *National Eutrophication Survey Working Paper No. 476*. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Ore.

———. 1978c. A compendium of lake and reservoir data collected by the National Eutrophication Survey in the western United States. *National Eutrophication Survey Working Paper No. 477.* Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Ore.

**U.S. Geological Survey.** 1970. *The national atlas of The United States.* Washington: U.S. Government Printing Office.

**Zimmerman, A. P., and Harvey, H. H.** 1979–1980. *Sensitivity to acidification of waters of Ontario and neighboring states.* Final Report for Ontario Hydro. Univ. of Toronto.