Iso-pH Maps Identify Areas Detrimental to Drainage Structure Performance Life

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• THIS PAPER is a preliminary report of an investigation to determine the hydrogen-ion concentration in natural water throughout Alabama and to map these data. Also reported is a study to show how such data, together with data on the hydrogen-ion concentration and electrical resistivity of various soil types, can be used to construct a map outlining geographic areas that are detrimental to metal highway drainage structures.

During the summer of 1960 it was discovered that two perforated metal pipes on I-65-2, near Jemison, Ala., had been excessively damaged along the flow line by natural elements. This deterioration, or corrosion, of pipe culverts in certain areas of Alabama is not unusual, but the fact that these pipes had been destroyed in less than eight months was unusual.

Investigation showed that the pH of the water passing through these drainage structures was about 2.5, and the nearby soil in places was so acid that no vegetation would grow, also, that the rocks in the immediate vicinity were intensely folded phyllites disseminated with pyrite, an iron-sulfide mineral that upon weathering and contact with the flowing water produced sulfuric acid. Apparently, this acid was produced in enough concentration to severely corrode the lower portion of the existing pipes. The condition was corrected by replacing the damaged pipe with terracotta clay pipe.

The occurrence initiated the idea that it might be possible to predetermine areas within the State where existing soil, rock, or water conditions might be aggressive to certain types of drainage pipe.

Previous experience by the Bureau of Maintenance has developed the fact that metal pipe does not give satisfactory performance life either in the immediate coastal area or in some areas adjacent to coal mining operations in north central Alabama.

PURPOSE AND SCOPE

Zoning the State into areas of high and low pH value seemed the most economical and feasible approach to the problem. Therefore, a review of the literature was begun. This effort, coupled with interviews with pipe manufacturers, maintenance engineers and highway department chemists indicated that not only was the life of a drainage pipe dependent on the pH of its hydraulic traffic, but that some ten to twelve other factors also were believed to have a definite effect on the life of pipe culverts, including:

1. Amount of flowing water.
2. Velocity of flowing water.
3. Content of abrasive sediments.
4. Hydrogen-ion (pH) concentration of the water.
5. Hydrogen-ion (pH) concentration of the in-place soil.
6. Electrical resistivity of the in-place soil.
7. Chemical content of the water with regard to the concentration of calcium carbonate, sulfates, and dissolved solids.
8. Geologic environment from which the water originates.

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9. Presence of organic compounds.
10. Man-made interference of the watershed, such as agriculture and pollution.

It was generally concluded, however, that the major factors affecting the life of pipe culverts are items 4, 5 and 6 in the preceding list. Therefore, it was decided to broaden the scope of this investigation to encompass these three main factors in pipe corrosion and to divide the study into two phases: Phase I was established to be the testing and mapping of hydrogen-ion concentrations in the natural water throughout the State and Phase II was to be a study of the electrical resistivity and hydrogen-ion concentration in the various soil types. The end product of this study is expected to be the construction of a map which would outline geographic areas where no alternates would be carried in the Alabama Highway Department's specifications as to type of drainage pipe.

This paper, then, deals only with the findings on the pH of natural water throughout Alabama. As can be imagined, this project is of considerable magnitude, and although this work has been in progress for approximately two years, certain questionable areas within the State still have not been sampled or the data thoroughly analyzed. Therefore, the current paper is presented as a preliminary report on Phase I.

The remaining field work and final report, for both phases of the study, will be made by the Water Resources Division of the Alabama Geological Survey, through a cooperative research program financed by H.P.S. funds. This agency will undertake an "in-place" water sampling program, in conjunction with an investigation of the related soils conditions. A complete report is expected by the spring of 1965.

GENERAL INFORMATION

To define the limits of the project, and to establish the correct terminology for natural water and corrosional phenomena, the following were adopted:

Hydrogen-Ion Concentration (pH).—The hydrogen-ion concentration indicates how acid or how alkaline a water is. The symbol pH is a much more usable expression and is employed to represent the hydrogen-ion concentration. For example, a water with a pH of 7.0 is said to be neutral—neither acid nor basic. A pH of 6.0 means that the water is ten times more acid than water of pH 7.0; pH 5 means it is 10 times more acid than pH 6 or 100 times more acid than pH 7.

Groundwater.—For the purpose of this study, groundwater is considered to be that water which is contained within its natural geologic environment in a zone of saturation. A spring, for example, is considered to be groundwater until it has migrated one surface foot from the zone of seepage. It then becomes surface water.

The mineral content and pH of groundwater are directly related to the geologic formations through which it moves. At the outcrop area of a water-bearing stratum the water is generally acidic due to the presence of organic acids derived from the decomposition of vegetation, animal matter, and the weathered soil mantle. As this water moves down within the formation, it tends to collect and become saturated with water-soluble minerals. Generally, groundwater becomes more alkaline as it moves down dip in the Coastal Plain of Alabama.

Surface Water.—Surface water is considered to be that water which is visible on the earth's surface. Examples are puddles, ponds, streams, rivers, and lakes.

The mineral content of surface water is dependent on the character of the soil and the rock through which it flows. It is also influenced by outside contamination with sewage, mine drainage, vegetation, and agricultural components. It is known that the mineral content and pH vary in surface water during periods of heavy rainfall and drought.

In Alabama the pH of surface water, when not affected by unusual conditions, ranges from 6.3 to 7.8.

Theory of Corrosion.—A review of the available literature indicates that corrosion is one of the principal causes of deterioration of metal pipe. Other materials such as concrete and wood are likewise subject to rot and corrosion. It is generally accepted that the corrosion of metal in soil is an electro-chemical process and occurs in the presence of moisture, oxygen, and soil salts.

In fact, the Southern Bell Telephone Company has, for about the last 25 years, routinely conducted electrolysis tests prior to laying underground cables and conduits. These tests are performed in order to combat the electro-chemical action produced by moisture and soils on their cables and conduits. A study of Southern Bell's electrolysis data is scheduled for Phase II of this report by the Geological Survey.

The foregoing deals with corrosion resulting from metal in contact with soil. However, experience with drainage structures is that corrosion of the pipe's exterior is usually of less consequence than that occurring from the hydraulic traffic on the pipe interior.

CHEMICAL CLASSIFICATION OF WATER AS IT AFFECTS DRAINAGE STRUCTURES

Mineral Water.—Sulfur-bearing coal seams, or geologic strata containing sulfide ore deposits (such as the phyllite with disseminated pyrite discussed earlier), produce waters which are corrosive to nearly all materials normally used for drainage structures. This is due to the formation of free acid, originating from acid-forming salts carried in the water.

Every stream in a sulfide mineralogical environment is not necessarily contaminated with chemical constituents that are harmful to structures through which they flow. Other investigations have shown that only the stream that comes in contact with a sulfide-bearing stratum, or issues from an associated mining operation, is contaminated.

For example, in the Brookwood coal mining area of north-central Alabama, only water issuing from mines in or actually cutting certain groups of coal is contaminated. Water issuing from mines developed in some of the other coal beds has a relatively low hydrogen-ion concentration with an almost neutral pH. This occurrence is generally typical for all areas within the Warrior coal field.

Acid Water.—This classification includes many of the conditions previously mentioned. In addition, it refers to aggressive waters caused by contamination with organic acids present in marsh and swamp land, or other areas where considerable quantities of vegetable matter are decaying. Such conditions, often found in conjunction with soft, unstable foundations, tend to increase the difficulty in constructing suitable drainage structures.

Southern Alabama is characterized by many semi-tropical swampy areas where this acid condition is common.

Alkali Water.—"Alkali" is rather a vague term when used to describe certain salts present in many of the arid and semi-arid regions of the western States. This word, it seems, originally was used to describe the soils of these areas in relation to their ability to produce agricultural crops. In general, both concrete and metal pipes fail to provide satisfactory service when associated with an alkaline hydrologic environment.

Drainage structures in Alabama are not seriously affected by this condition.

Salt Water.—The chlorides in sea water are primarily responsible for the corrosion of metal, whereas certain magnesium salts are thought to cause deterioration of concrete. The deterioration resulting from chemical attack by this type of water is accelerated by mechanical disintegration resulting from alternating periods of wetting and drying, as well as frost action. The southwestern tip of Alabama is subject to this corrosional condition.

CONSTRUCTING THE ISO-pH MAP

It has been previously stated that the purpose of Phase I was to develop maps showing the existing pH values for water throughout the State. This was begun by consulting the Groundwater and Surface Water Branches of the U. S. Geological Survey. Both of these agencies had numerous records and publications that listed the location, date of test, and hydrogen-ion concentration value for groundwater and surface water throughout Alabama.

The Public Health Department had also made an extensive study of the surface water in Alabama, and in doing so had recorded the pH at numerous stations along major streams.

It was also found that the Groundwater Branch had recorded numerous pH values for deep water wells. These values were omitted from the current study because they often were taken from bored wells whose depths exceeded 100 feet. It is planned, however, to contour the pH values from these deep water sources. This is expected to have little or no consequence on the study, but merely to provide a comparison with the pH trend for surface water.

The actual construction of the iso-pH map was done by plotting each pH value, as to date, and the location from which it was recorded on a State map, scaled 1 in. to 8 mi. That is, all values recorded during seasons of heavy rainfall were plotted and contoured on one map, and the pH values for dry seasons were plotted and contoured on a second map.

It was necessary in contouring the pH's to set all values in the range of 6.7 to 7.3 as neutral. This was done not only to facilitate the actual contouring, but also to take care of the variation in pH values produced by temperature and atmospheric pressure.

High-Water Iso-pH Map.—Figure 1 shows the iso-pH map constructed with pH values taken during the high-water months of December to April since 1955. The "low" areas in north-central Alabama are produced by acid water from the coal mining area. Also worthy of note are the slightly acidic values in the extreme south, and the alkaline trend in the central belt of the State. The alkaline trend generally follows the strike of calcareous sediments in the coastal plain formations.

This map is considered to be of a more general nature than those shown in Figures 2 and 3 because of the limited number of available pH data.

Low-Water Iso-pH Map.—Figure 2 shows the iso-pH map constructed with pH values recorded during low-water periods in the months of July to October since 1955.

This map also shows low values in the coal mining region and a definite acidic condition existing along the southern part of the State.

It can also be noted that the pH trend in the east-central part of the State is most irregular. This is probably due to the complex geologic and soil conditions that exist in this section of the State. Parent material found in this area consists of igneous and metamorphic rocks, which include slates, schists, phyllites, quartzites, granites, gneiss, and marble. Sulfide minerals are also known to be common to many of the watersheds in this vicinity.

Contours drawn from pH values taken in the east-central part of Alabama, therefore, are presumably less accurate than for any other area due to the variable nature of these soils and rocks. The Geological Survey is presently conducting a close-knit sampling program in this area with the hopes of analyzing the pH trend more precisely.

Iso-pH Check Map.—Figure 3 shows the iso-pH map constructed with pH values determined by the Alabama Highway Department. These data were obtained by having the seven divisional offices take samples from designated sources within the counties in their respective areas. This sampling was conducted during the months of September and October 1962.

Samples were collected in 6-oz pharmaceutical bottles. Each bottle was thoroughly rinsed with the water that was to be sampled, and then tightly capped, numbered, and sent to the chemical laboratory in Montgomery. Care was taken to get these water samples to the laboratory as soon as was practical so as to obtain as accurate an in-place pH reading as possible. The readings were made with a Beckman ZeroMatic pH meter.

In all, more than 700 pH readings were made from springs, branches, and creeks in almost every township in Alabama. This resulted in coverage of the out-of-the-way sources heretofore untested. In this way, many of the unexpectedly high and low values caused by pollution were accounted for.

As shown in Figure 3, the map produced is somewhat comparable to the maps made from government data.

Zone Map of Corrosive Areas.—Figure 4 shows the final interpretation of the iso-pH maps. It is a map which outlines the areas where deleterious water conditions were found to exist. In drafting this map, the "lows" were marked off in rectangular-type patterns roughly conforming to the pH contours of that particular area.

The acidic area in north-central Alabama that results from the presence of coal deposits was studied in detail. It was decided to establish the outer limits of these ag-

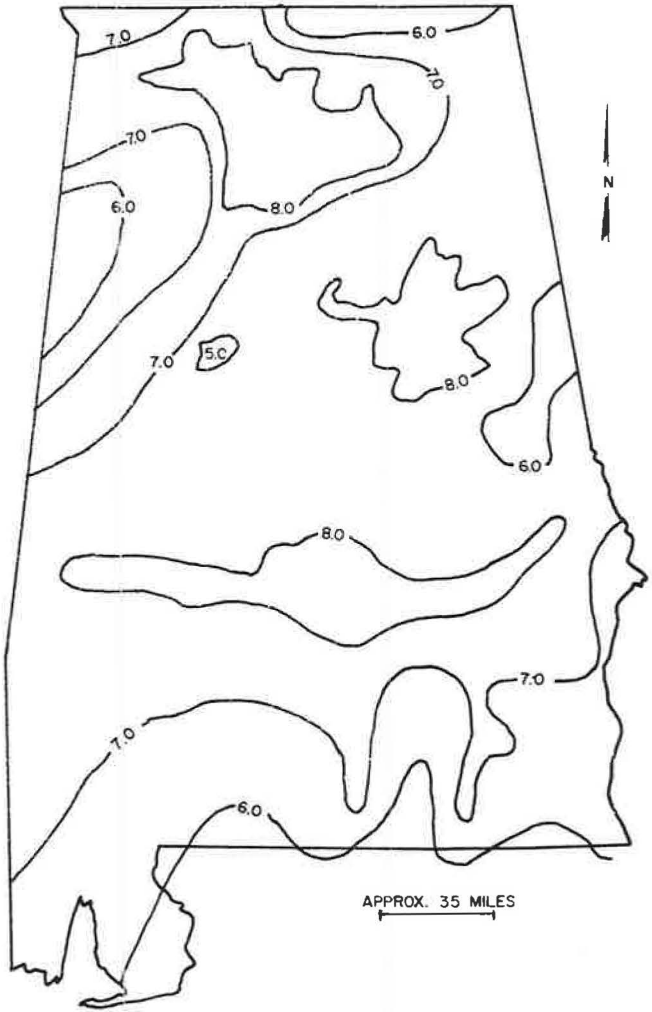

Figure 1. Iso-pH map of Alabama surface waters constructed on pH values recorded during high-water periods (December to April) since 1955.

Figure 2. Iso-pH map of Alabama surface waters constructed on pH values recorded during low-water periods (August to October) since 1955.

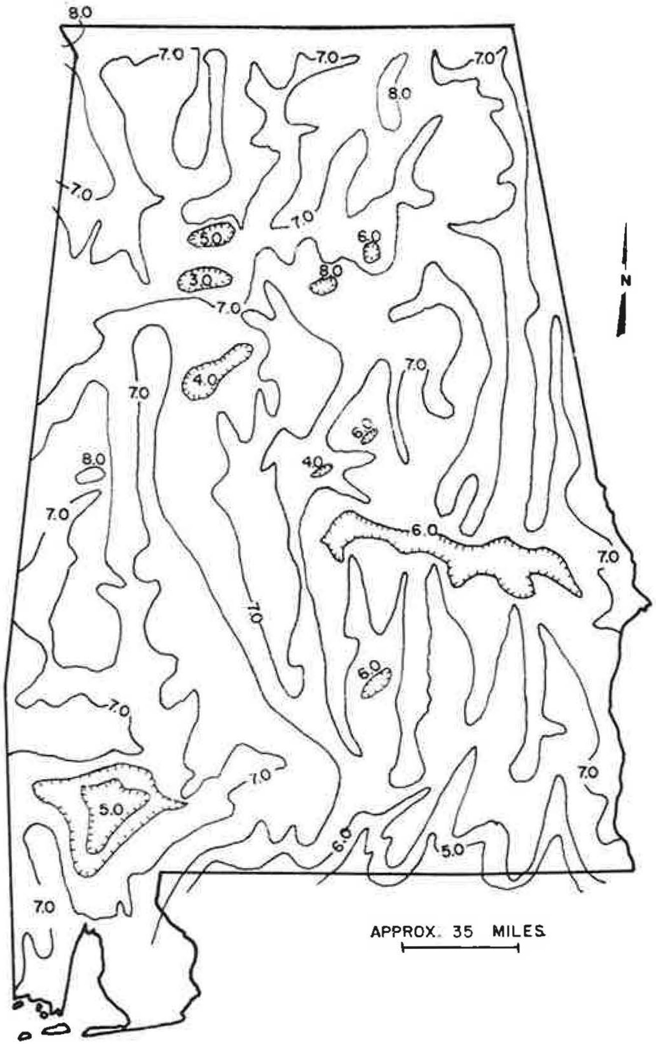

Figure 3. Iso-pH map of Alabama surface waters constructed on pH values recorded in field survey of September-October 1962.

Figure 4. Pipe zoning map of Alabama showing areas where specific types of drainage pipe are recommended to provide longer performance life.

gressive zones to be compatible with the margin of the areas that are underlain by coal seams known to contain excessive amounts of sulfides. Alabama Geological Survey publications on the coal in this region served as a guide to the location and content of these seams. Previous experience and records on the coal beds in this area were also utilized.

Figure 4 shows the recommendation for areas where specific types of drainage pipe should be used.

In summary it can be said that chemical, soil, and rock conditions, in addition to the pH of water, influence the service life of pipe culverts. Some of these phenomena are as yet not fully understood. Therefore, because the major portion of damage to drainage pipe is believed to result from its hydraulic traffic, a study of the surface water pH value is the most reasonable approach to identifying areas where water may be corrosive to pipe culverts. Although the scope of this type investigation is of a general nature, it does reduce the magnitude of the area of study, by isolating those areas where detailed study should be made.

CONCLUSIONS

1. Measuring the pH of surface water throughout an area is a fast, relatively inexpensive means of identifying areas that may affect the performance life of highway drainage structures.
2. The accuracy of an iso-pH map is based on taking a sufficiently large number of readings, in enough locations, to insure thorough coverage of the area.
3. In areas of questionable pH values a check sampling program should be conducted. This is necessary to confirm the presence of organic compounds originating from pollution and agricultural products.
4. Separate test programs and maps should be made for seasons during heavy rainfall, and light rainfall. A third map should be constructed as a check against the season producing the most aggressive condition.
5. The variable nature of in-place pH values taken in surface water will result in a general pH trend; that is, iso-pH lines are not conclusive, but averages, and should be considered as such.

REFERENCES

1. Baker, J., "Geology and Ground Water Resources of the Piedmont Area." Spec. Rpt. 23, Alabama Geological Survey, University, Ala. (1957).
2. Beaton, J. L., and Stratfull, R. F., "Corrosion of Corrugated Metal Culverts in California." HRB Bull. 223, p. 1 (1959).
3. Beaton, J. L., and Stratfull, R. F., "Field Test for Estimating the Service Life of Corrugated Metal Pipe Culverts." Bur. Materials and Research, Div. of Highways, State of California (Jan. 1962).
4. Carlston, C. W., "Ground Water Resources of the Cretaceous Area of Alabama." Spec. Rpt. 18, Alabama Geological Survey (1944).
5. Caroon, L., Personal Discussion and Interview, District Engineer, Surface Water Branch, U. S. Geological Survey, University, Ala. (Nov. 1961).
6. Cook, J. D., and Scott, R. G., "Sewer Facts." Clay Products Assoc.
7. Gill, D. G. (Chairman), "Studies of Pollution in Streams of Alabama." State of Alabama, Water Improvement Advisory Commission (1949).
8. LaMoreaux, P. E., "Fluoride in the Ground Water of the Tertiary Area of Alabama." Bull. 59, Alabama Geological Survey, University, Ala. (1948).
9. LaMoreaux, P. E., Personal Discussion and Interview, State Geologist, Alabama Geological Survey, University, Ala. (Nov. 1961).
10. Langbein, W. B., and Iseri, K. T., "General Introduction and Hydrologic Definitions." Manual of Hydrology. Part I, Water Supply Paper 1541-A, U. S. Geological Survey.
11. Leopole, L. B., and Langbein, W. B., "A Primer of Water." U. S. Geological Survey.

12. Manson, P. W., "Drain Tile Characteristics That Determine the Durability of Concrete Drain Tile When Exposed to Acid Waters." Tech. Memo., Amer. Conc. Pipe Assoc. (Oct. 1, 1960).
13. Manson, P. W., and Miller, D. G., "Essential Characteristics of Durable Concrete Draintile for Alkali Soils." Tech. Memo., University of Minn.
14. McCalley, H., "Warrior Coal Basin." Spec. Rpt. 10, Alabama Geological Survey, University, Ala. (1900).
15. McCalley, H., "Map of the Warrior Coal Basin." Alabama Geological Survey, University, Ala. (1898).
16. Miller, D. G., "Basic Requirements for Sulphate Resistant Draintile with Particular Reference to the Cement." Tech. Memo., Am. Conc. Pipe Assoc. (Nov. 1, 1958).
17. Miller, D. G., and Manson, P. W., "Long-Time Tests of Concretes and Mortars Exposed to Sulphate Waters." Tech. Bull. 194, Univ. of Minnesota Agric. Exper. Sta. (May 1951).
18. Peckworth, H. F., "Concrete Pipe Field Manual." Managing Director, Amer. Conc. Pipe Assoc.
19. Pierce, L. B., "Hydrology and Surface Water Resources of East Central Alabama." Spec. Rpt. 22, Alabama Geological Survey, University, Ala. (1955).
20. Pierce, L. B., "Surface Water Resources and Hydrology of West Central Alabama." Spec. Rpt. 24, Alabama Geological Survey, University, Ala. (1959).
21. Powell, W. J., Personal Discussion and Interview, District Geologist, Ground Water Branch, U. S. Geological Survey, University, Ala. (Nov. 1961).
22. Prouty, W. F., "Map of Coosa Coal Field." Alabama Geological Survey, University, Ala. (1912).
23. Prouty, W. F., "Geology of Clay County." County Report No. 1, Alabama Geological Survey, University, Ala. (1923).
24. Squire, J., "Map of Cahaba Coal Field." Alabama Geological Survey, University, Ala. (1905).
25. Spindler, W. H., "Handbook of Drainage and Construction Products." Mark Development Division, Armco Steel Corp.
26. Watkins, R. K., "Influence of Soil Characteristics on the Deformation of Embedded Flexible Pipe Culverts." HRB Bull. 223, p. 14 (1959).