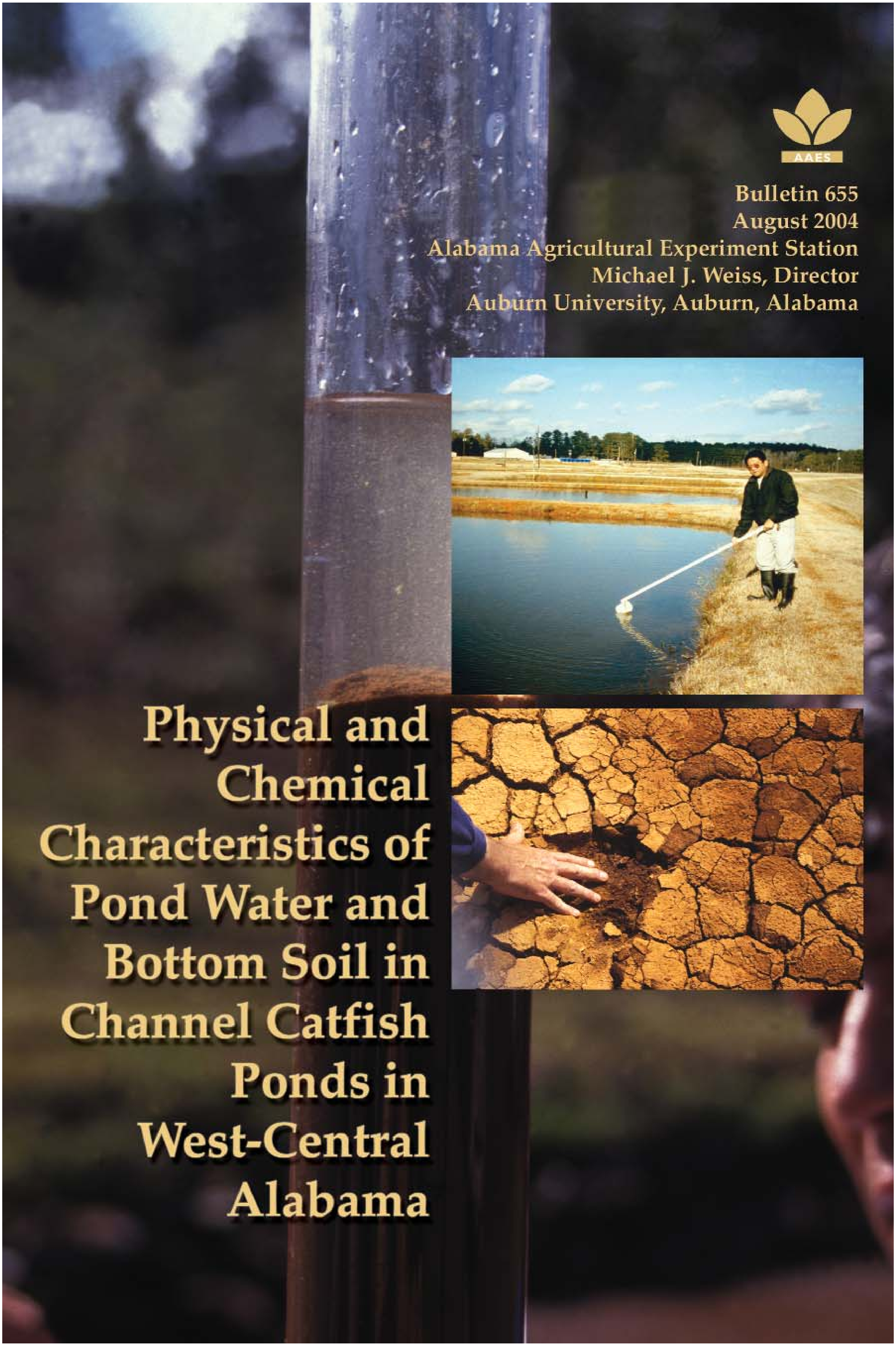

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Michael J. Weiss, Director
Auburn University, Auburn, Alabama

Physical and Chemical Characteristics of Pond Water and Bottom Soil in Channel Catfish Ponds in West-Central Alabama

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PHYSICAL AND CHEMICAL CHARACTERISTICS OF POND WATER AND BOTTOM SOIL IN CHANNEL CATFISH PONDS IN WEST-CENTRAL ALABAMA

Kom Silapajarn, C.E. Boyd, and Orawan Silapajarn

INTRODUCTION

Water quality is important in pond aquaculture because water quality imbalances can cause stress, poor growth, and mortality of culture species *(11)*. Water quality is strongly influenced by feed inputs, and ponds with high feeding rates frequently have more severe problems with low dissolved oxygen concentrations and excessive concentrations of ammonia and nitrite than ponds with low or moderate feeding rates *(39,11)*. Although many water quality problems can be prevented by use of conservative feeding practices and efficient mechanical aeration, there are other water quality concerns in pond aquaculture.

Natural characteristics of pond waters can greatly limit possibilities for fish culture. One naturally occurring water quality imbalance is the case of pond waters with high total alkalinity and low calcium concentration. Such waters often have excessively high pH, which can limit fish culture. Many times, site water quality limitations may be alleviated through management, for example alleviating the problem of high pH and low calcium by applying calcium sulfate (gypsum) to the water to increase calcium concentration. Moreover, some pond water quality variables are strongly influenced by pond bottom soil characteristics. Fish do not grow well in ponds with acidic water, which usually are located on acidic soils, but acidity in ponds can be corrected by liming.

Most channel catfish farms in Alabama are located in the west-central part of the state. Many of these farms were built on soils of the Blackland Prairie. Management procedures for catfish farming in Alabama usually are made with the assumption that ponds have clayey, calcareous bottom soils and waters of high total alkalinity and total hardness because many ponds in the Blackland Prairie have these characteristics.

Investigations of sportfish ponds throughout Alabama *(12,2)* show a wide variety of water quality characteristics. Samples obtained from the west-central part of

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The Silapajarns were graduate students and Boyd is a professor in the Department of Fisheries and Allied Aquacultures.

the state also reveal considerable variation in water quality among ponds. Finally, experience gained by those providing advice on catfish pond management in Alabama also suggests that pond soil and water quality differ over the production area.

The present study provides background information on bottom soil and water quality in catfish ponds in west-central Alabama. The findings reveal that some variables differed enough among ponds to be important considerations in pond management strategies. The data also exhibited relationships among pond soil quality and water quality variables and show how pond water quality is related to soil area.

MATERIALS AND METHODS

Water Samples

Water samples were collected during the period April through October 2000 from 223 ponds on 77 farms in ten counties of west-central Alabama (Figure 1). The number of farms and samples from each county are listed in Table 1. The intensity of sampling was generally proportional to amount of catfish farming in each county.

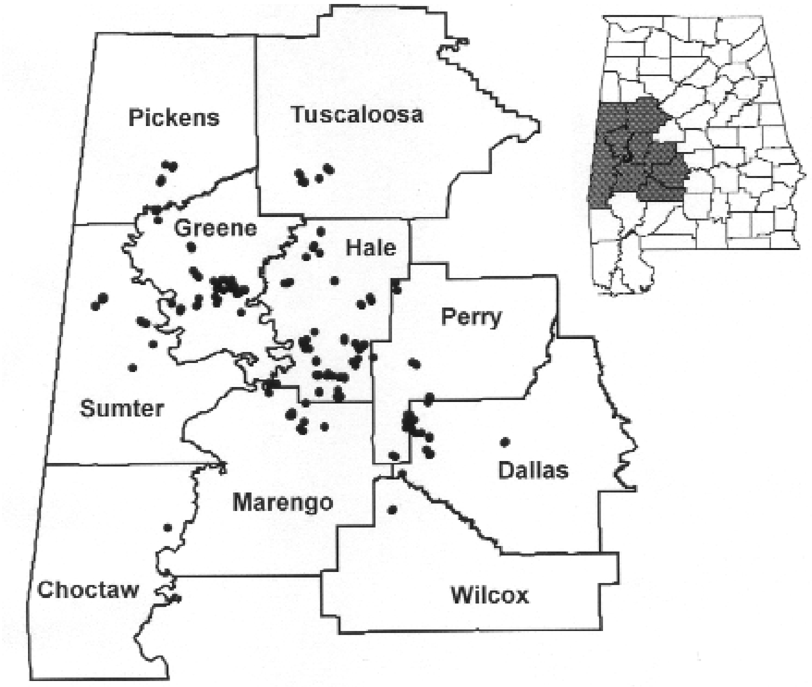
Samples were collected by dipping water from 10-cm beneath the surface and filling a 2-L and a 500-mL polyethylene bottle at each pond. The 500-mL sample was preserved for metal analysis by addition of 1.0 mL of concentrated nitric acid. The location of each pond was determined by global positioning satellite (GPS) using a Garmin Model GPS 12. Water pH was measured with a portable pH meter at time of sample collection. Samples were placed on ice in an insulated chest for transport to Auburn University. Samples were held on ice for 24 to 72 hours before analyses were initiated.

Soil Samples

Soil samples were collected during the period June to September 2001 from 58 of the ponds (Figure 2) from which water samples had been taken. The ponds were selected to include the wide range in water quality documented the previous year. Soil cores were taken from five places in the bottom of each pond with a 5-cm diameter soil corer as described by Munsiri et al. *(25).*The upper 5-cm layer from one core sample from each pond was transferred to a tared soil moisture canister for determination of bulk density later. The 5-cm layers from the other core samples were combined to make a composite sample for each pond. The composite samples

TABLE 1. SAMPLING DATA FOR GENERAL WATER QUALITY CHARACTERISTICS OF CHANNEL CATFISH PONDS IN WEST-CENTRAL ALABAMA

County	Number of farms	Number of ponds
Hale	35	91
Greene	16	52
Dallas	7	25
Pickens	3	7
Sumter	4	12
Marengo	4	9
Tuscaloosa	3	11
Perry	3	11
Choctaw	1	2
Wilcox	1	3
Total	77	223



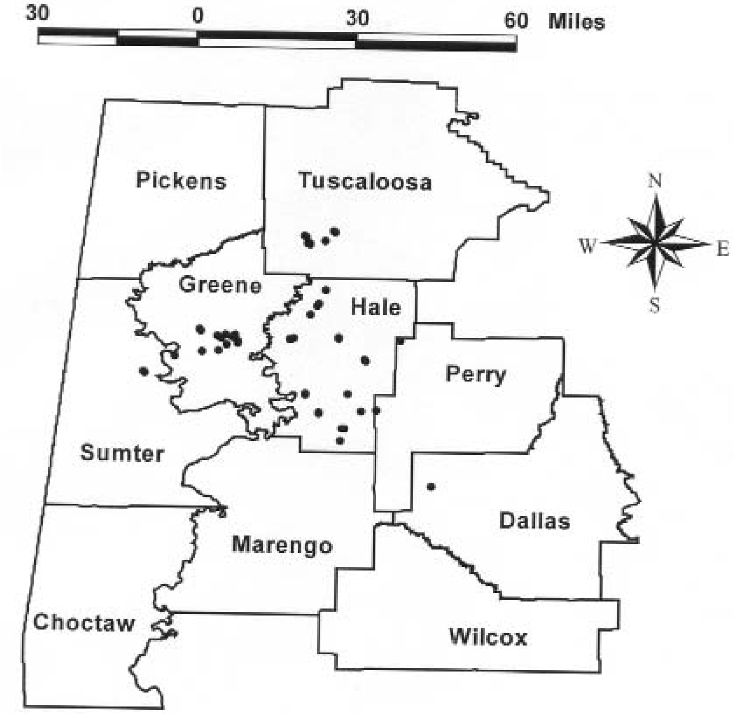


Figure 1 (above). Locations of channel catfish ponds in west-central Alabama for which water quality data were obtained.

Figure 2 (below). Locations of channel catfish ponds in west-central Alabama for which soil quality data were obtained.

were dried in a mechanical convection oven at 60°C. One portion of each dry sample was pulverized with a hammer mill-type soil crusher to pass a screen with 0.85-mm openings and stored in plastic bags for chemical analyses to be done later. The other portion was stored in a plastic bag and used later for particle size analysis.

Water and Soil Analyses

Water samples were analyzed according to standard protocol *(15)*. The procedures were as follows: pH (portable meter with glass electrode); total dissolved solids (filtration through Gelman type A/E glass fiber filter, evaporation of filtrate, and gravimetry); specific conductance (portable conductivity meter); total alkalinity (titration with 0.02 N sulfuric acid to methyl orange endpoint); total hardness (titration to Erichrome Black-T endpoint with 0.01 M ethylenediaminetetraacetic acid); calcium hardness (titration to murexide endpoint with 0.01 M ethylenediaminetetraacetic acid); chloride (titration with 0.0141 N mercuric nitrate to diphenylcarbazone endpoint); sulfate (barium chloride tubidimetric technique); total suspended solids (suspended solids removal by filtration through a Gelman type A/E glass fiber filter with gravimetric finish); calcium magnesium, potassium, sodium, iron, manganese, zinc, copper, and boron (plasma spectrophotometer).

Soil color was determined at the time of sampling by comparison with Munsell Soil Color Charts *(23)*. Soil pH was measured by inserting a glass electrode into 1:1 dry, pulverized soil:distilled water mixtures *(37)*. Dry bulk density of soil samples was measured as the weight of solids remaining after drying a specific volume of soil at 102°C *(4)*. For analysis of particles size, soil was gently crushed to pass a 2-mm sieve, water soluble salts were removed by washing with distilled water, and organic matter was destroyed by oxidation with hydrogen peroxide. Soil was dispersed in a solution prepared by dissolving 7.94 g sodium carbonate and 35.7 g sodium metaphosphate per liter of distilled water. Sand was separated and determined by sieving (53 µm screen) and weighing. The dispersed soil suspensions were then placed in 1-L sedimentation cylinders for determination of silt and clay by the pipette method *(18)*. Soil texture names were assigned with aid of a soil triangle *(14)*.

Soil organic carbon analyses were made by the Walkley-Black method of sulfuric acid-potassium dichromate oxidation *(27)*. Soil nitrogen analyses were conducted with a Leco Carbon-Hydrogen-Nitrogen Analyzer CHN 600. Total sulfur was determined by incinerating soil samples in a Leco Induction Sulfur Furnace HP10 and titrating the liberated sulfur with standard KIO_3 using a Leco Sulfur Titrator. Major cations (calcium, magnesium, sodium, and potassium) and trace elements (iron, manganese, zinc, copper, and boron) were extracted from soil samples with dilute, double-acid solution (0.05 N HCl + 0.025 N H_2SO_4) *(20)* and measured with a Jarrel-Ash ICAP 9000 Plasma Spectrophotometer.

In the analysis of cation exchange capacity, soil was saturated with 1.0 N $CaCl_2$ and excess salts were removed by washing with 95 percent ethanol. Calcium was displaced from exchange sites with 1.0 N KCl and measured by titration with standard ethylenediaminetetraacetic acid *(22)*. Free carbonates were analyzed by digesting soil in hydrochloric acid and measuring the amount of carbon dioxide evolved *(22)*. Carbonates were expressed in terms of percentage calcium carbonate equivalent.

RESULTS AND DISCUSSION

Water Quality

pH

It was not possible to sample all ponds at the same time of day, and measurements of pH were made at the time of sampling, which varied from 7:00 A.M. to 6:00 P.M. The average pH was 8.12, but individual values ranged from 5.6 to 10.4 (Table 2). About 90 percent of the samples had pH values between 7 and 9 (Figure 3).

The best pH for pond fish culture is 7 to 9 *(33)*. Brief excursions of afternoon pH to 9.5 or 10 in surface water usually are not detrimental because fish can remain in deeper water where pH is lower. Ponds where waters have pH below 7 usually should be treated with agricultural limestone to increase total alkalinity and pH and improve conditions for fish growth.

A few ponds with water pH below 7 were observed in all three soil areas (Figure 4). Most samples with pH above 9 were from ponds in the Blackland Prairie (Figure 4). Most samples with high pH also were taken in the afternoon from ponds with dense phytoplankton blooms. High pH was the result of high rates of carbon dioxide removal by phytoplankton for use in photosynthesis *(11)*. This is a common phenomenon in aquaculture ponds.

Total dissolved solids

Average concentration of total dissolved solids (TDS) was 521 mg/L, but concentrations ranged from 44 to 5,778 mg/L (Table 2). About 80 percent of samples had TDS

Table 2. Averages, Standard Deviations (SD), and Minimum and Maximum Concentrations for Water Quality Variables in 223 Channel Catfish Ponds in West-Central Alabama

Variable	Average ± SD	Minimum	Maximum
pH	8.1 ± 0.6	5.6	10.4
Total dissolved solids (mg/L)	521 ± 856	44.0	5,778
Specific conductance (μmhos/cm)	740 ± 173	30.0	9,820
Total alkalinity (mg/L as $CaCO_3$)	107 ± 54	2.0	280
Total hardness (mg/L as $CaCO_3$)	103 ± 101	6.8	742
Calcium hardness (mg/L as $CaCO_3$)	86 ± 94	4.0	531
Calcium (mg/L)	34.8 ± 31.2	1.8	212
Magnesium (mg/L)	4.0 ± 6.4	0.34	51
Potassium (mg/L)	13.2 ± 8.2	1.1	50
Sodium (mg/L)	122 ± 252	5.0	1,863
Sulfate (mg/L)	9.8 ± 15.2	0.0	166
Chloride (mg/L)	198 ± 428	1.3	3,087
Iron (mg/L)	0.50 ± 0.54	0.0	3.39
Manganese (mg/L)	0.18 ± 0.29	0.01	3.45
Zinc (mg/L)	0.06 ± 0.11	0.0	1.47
Copper (mg/L)	0.04 ± 0.05	0.0	0.53
Boron (mg/L)	0.19 ± 0.24	0.01	1.46
Total suspended solids (mg/L)	64 ± 52	4.0	340

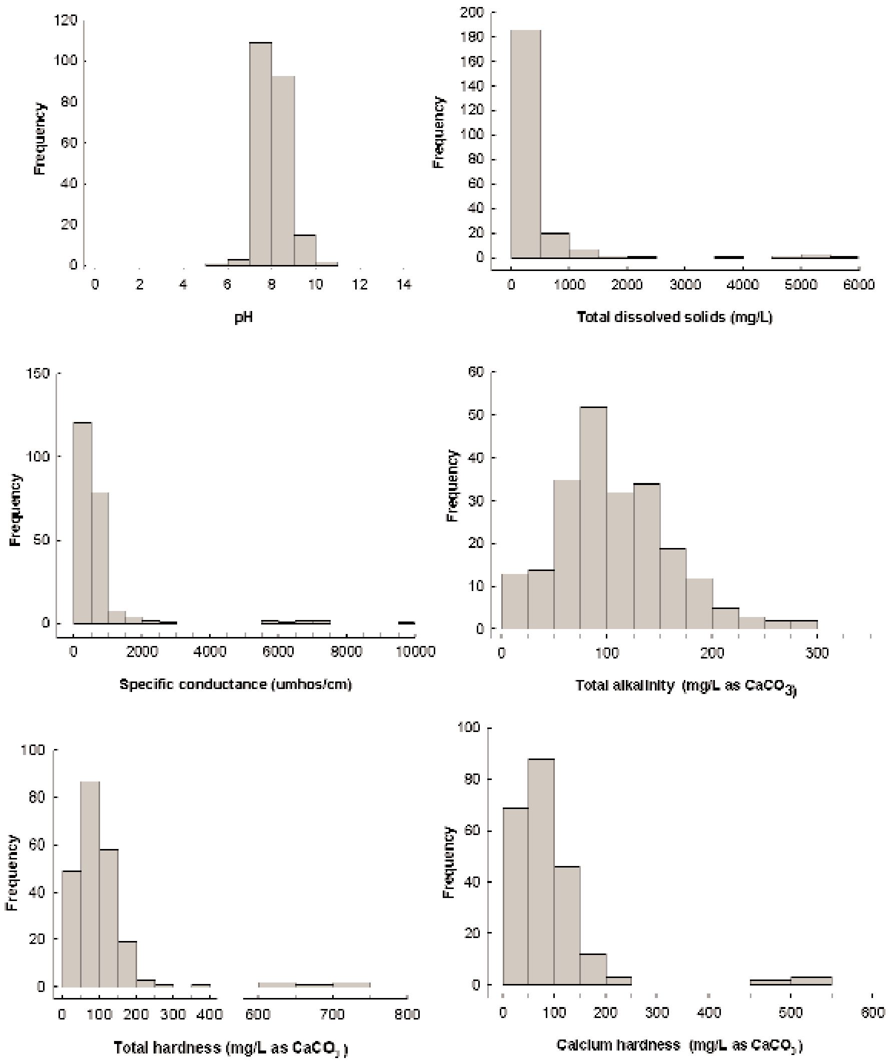


Figure 3. Frequency distribution histograms for concentrations of water quality variables in 223 channel catfish ponds in west-central Alabama.

concentrations below 600 mg/L (Figure 3). There were 17 samples with TDS concentration above 1,000 mg/L. These ponds (Figure 5) were supplied by groundwater from a saline aquifer that extends through parts of Dallas, Greene, Hale, and Perry Counties. Ponds with saline water were found in all three soil areas, but most ponds with waters of over 500 mg/L TDS were located in the Blackland Prairie.

A freshwater does not contain more than 1,000 mg/L TDS *(9)*. Thus, in Alabama, channel catfish sometimes are produced in saline water. Channel catfish grow well in moderately saline water *(28),* and farmers report that external bacterial diseases and parasite infestations are much less in saline water than in normal freshwater. Catfish also can be produced efficiently in waters with less than 100 mg/L TDS as has been done for years at the Fisheries Research Unit at Auburn University. Nevertheless, waters with TDS concentrations below 100 mg/L are not as good for fish culture as waters with 250 to 1,000 mg/L TDS. Plankton abundance and water quality tend to be

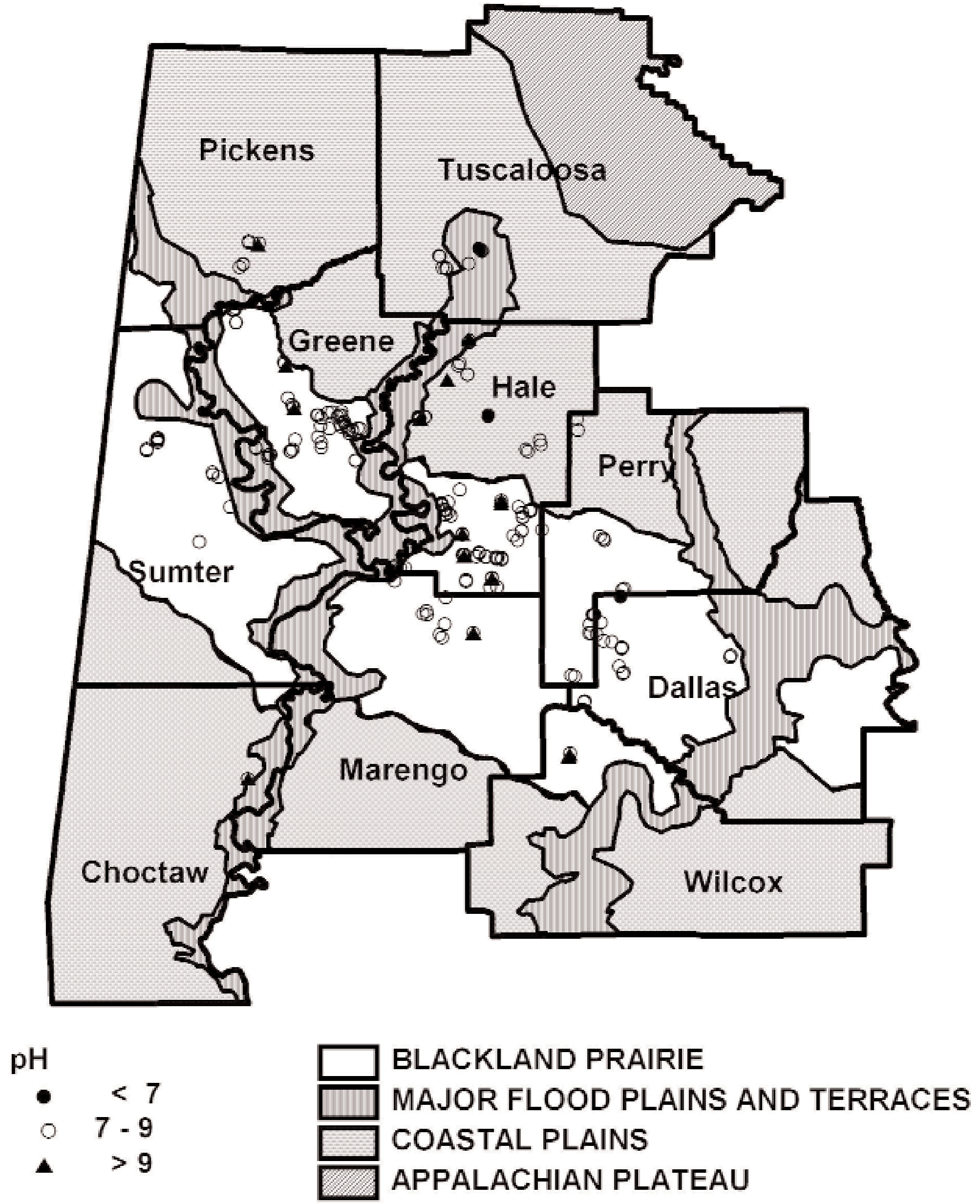


Figure 4. Distribution of pH in waters of channel catfish ponds located on different soil areas in west-central Alabama.

more stable at moderate TDS, and the greater concentration of ions enhances osmoregulation and physiological condition in fish *(11)*.

Specific conductance

The average specific conductance of pond waters was 741µmhos/cm; the minimum was 30 µmhos/cm and the maximum was 9,820 µmhos/cm (Table 2). About 83 percent of values were below 500 µmhos/cm (Figure 3). The distribution across soil areas of specific conductance in pond waters was similar to that of TDS (Figures 5 and 6). There was a strong correlation ($R^2 = 0.939$) between specific conductance and TDS.

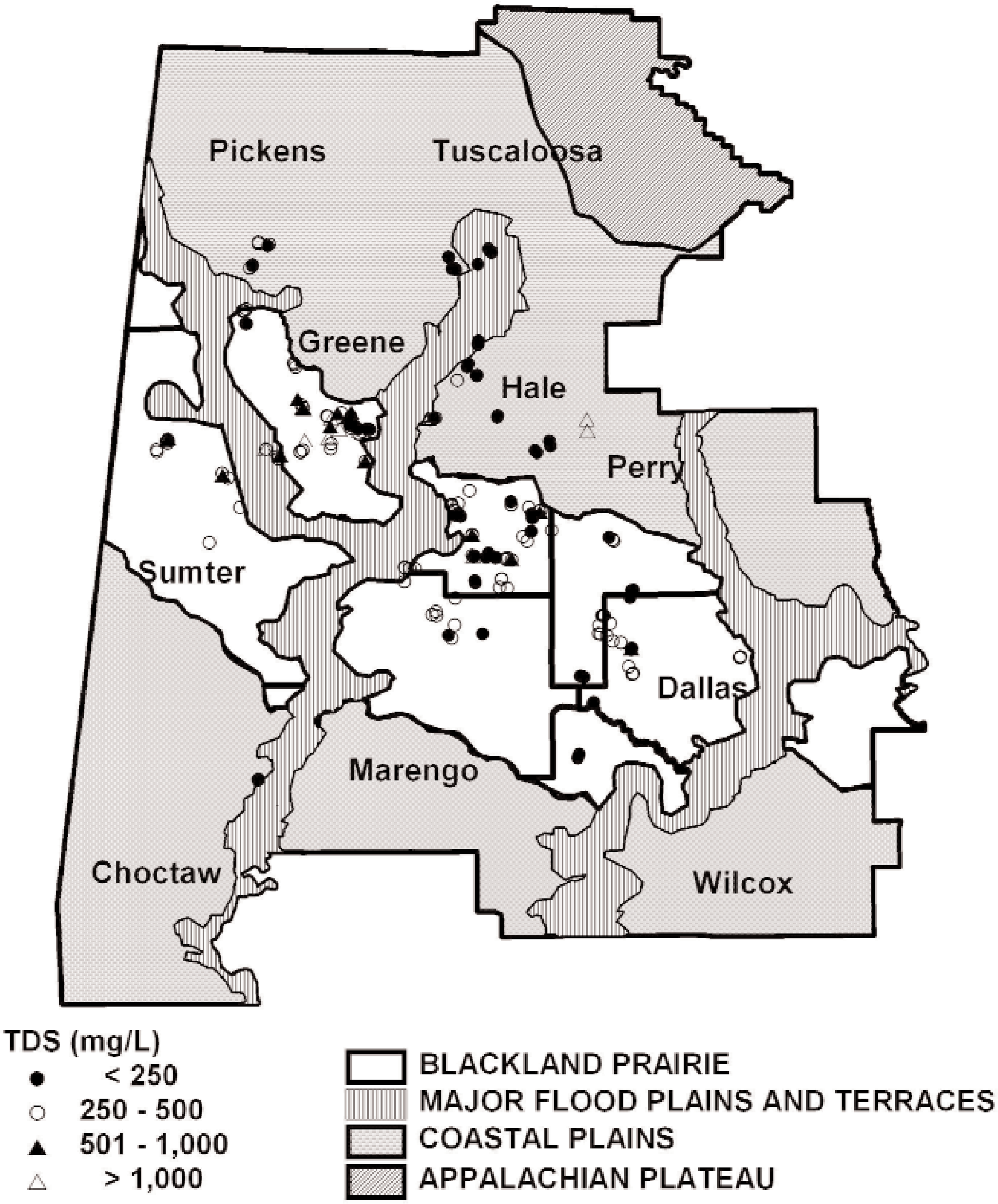


Figure 5. Distribution of total dissolved solids (TDS) concentrations in waters of channel catfish ponds located on different soil areas in west-central Alabama.

The equation for estimating TDS from specific conductance (SC) is

$$\text{TDS (mg/L)} = 42.08 + 0.651 \text{ SC } (\mu\text{mhos/cm}).$$

Specific conductance can be measured *in situ* quickly and easily, while TDS is a tedious, time-consuming analysis that must be done in the laboratory. Freshwaters usually have specific conductance values below 1,500 µmhos/cm *(9).* Using the equation given above, a water sample from a pond in west-central Alabama with a specific conductance of 1,500 µmhos/cm should contain 1,018 mg/L TDS. Thus, catfish pond waters in west-central Alabama conform to the usual relationship between TDS and specific conductance. For practical purposes, specific conductance multiplied by the

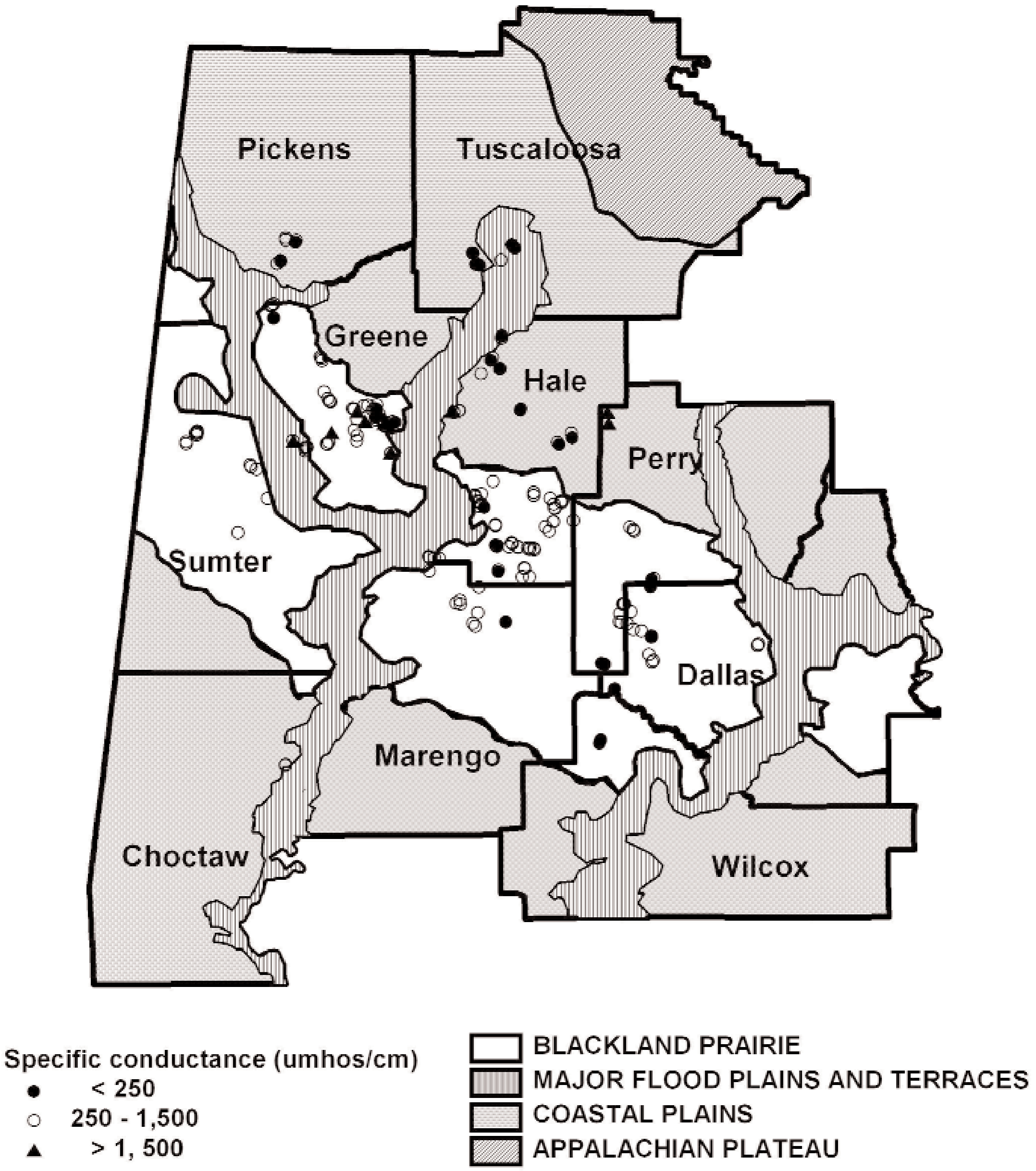


Figure 6. Distribution of specific conductance values in waters of channel catfish ponds located on different soil areas in west-central Alabama.

factor 0.7 will provide an estimate of TDS that agrees well with estimates made by the equation above.

Total alkalinity

Total alkalinity ranged from 2 to 280 mg/L and averaged 107 mg/L (Table 2). About 88 percent of samples had total alkalinity concentrations greater than 50 mg/L, and about 66 percent had between 50 and 150 mg/L total alkalinity (Figure 3). Most samples with less than 50 mg/L total alkalinity were from ponds located in the Coastal Plain and Major Flood Plains and Terraces, but a few ponds in the Blackland Prairie also had total alkalinity below 50 mg/L (Figure 7). Thus, it is not possible to

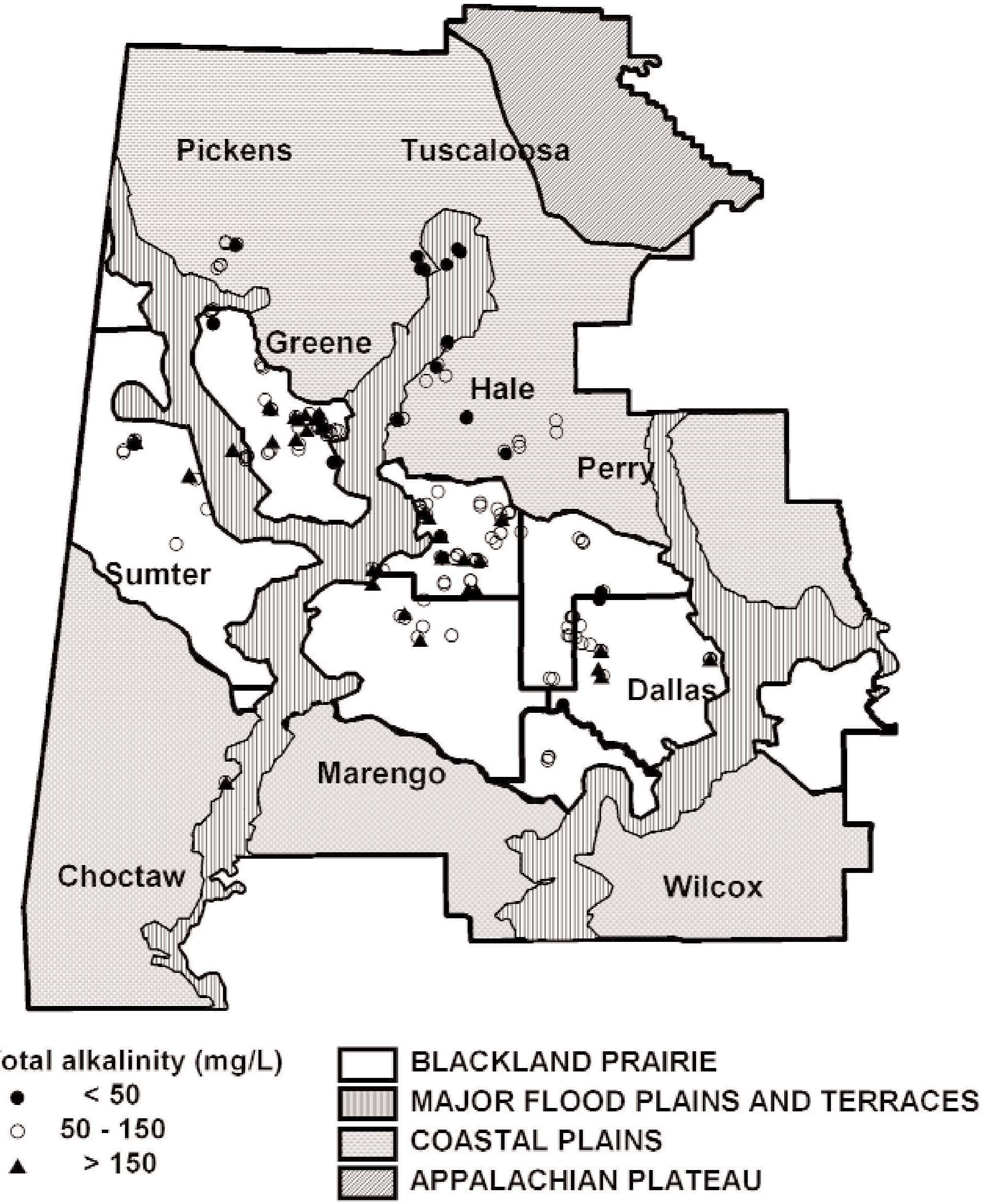


Figure 7. Distribution of total alkalinity concentrations in waters of channel catfish ponds located on different soil areas in west-central Alabama.

rely on soil area alone in predicting the occurrence of ponds with low alkalinity water. Of course, most ponds in the Blackland Prairie had a high total alkalinity because soils in the area were developed on limestone formations *(21)*.

Channel catfish can be cultured in water with total alkalinities as low as 5 to 10 mg/L *(26)*. Nevertheless, pond waters with less than 20 mg/L total alkalinity often have low abundance of phytoplankton because of low availability of carbon dioxide and removal of phosphate from water by acidic bottom soils *(35)*. In ponds with moderate alkalinities (20 to 50 mg/L), the buffering capacity of the water is not great enough to prevent wide diurnal shifts in pH in response to phytoplankton photosynthesis. Moreover, catfish farmers often apply copper sulfate to ponds to control algal species responsible for off-flavor in fish *(38)*. Copper sulfate applications in low alkalinity water must be measured carefully to avoid fish toxicity, for copper is much more toxic to fish in acidic, low alkalinity water than in waters of moderate or high alkalinity *(32)*.

High total alkalinity is not harmful to fish, but waters with alkalinities above 150 or 200 mg/L naturally have higher pH values than lower alkalinity waters. Blue-green algae tend to dominate phytoplankton communities in nutrient-rich, high-pH water *(30)*.

Total alkalinity tended to increase with increasing specific conductance. The relationship for ponds in the present study can be expressed by the following equation:

$$TA = 29.19 + 0.171\ SC \qquad R^2 = 0.482$$

where: TA = total alkalinity (mg/L),
SC = specific conductance (µmhos/cm).

Total hardness

Concentrations of total hardness were between 7 and 742 mg/L with an average of 103 mg/L (Table 2). About 80 percent of samples had hardness values above 50 mg/L, and almost 60 percent of concentrations were between 50 and 150 mg/L (Figure 3). Both concentration frequency (Figure 3) and distribution of concentrations across soil areas for total hardness and total alkalinity were similar (Figures 7 and 8). The waters with total hardness above 250 mg/L were from seven of the 17 ponds filled with saline groundwater. These waters tended to have greater total hardness than total alkalinity. A number of other ponds supplied mainly by well water tended to have higher alkalinity than hardness. The ratio of total alkalinity:total hardness ranged from 0.08 to 8.79, but the average was 1.42. Nevertheless, the correlation between total alkalinity and total hardness was weak ($R^2 = 0.219$). Specific conductance was strongly correlated with total hardness:

$$TH = 56.1 + 0.064\ SC \qquad R^2 = 0.653$$

where: TH = total hardness (mg/L),
SC = specific conductance (µmhos/cm).

The calcium hardness ranged from 4 to 531 mg/L and averaged 86 mg/L (Table 2). Nearly all samples (about 95 percent) had calcium hardness values less than 200 mg/L, and around 65 percent of values were below 100 mg/L (Figure 3). Based on averages, calcium hardness was 0.84 total hardness (Table 2), so magnesium hardness usually was a minor component of total hardness. When all samples were considered, the ratio of total alkalinity:calcium hardness was 1.76, but the minimum was 0.12 and the maximum was 12.20.

Boyd and Brown *(10)* reported that some well waters in west-central Alabama had much higher total alkalinity than calcium hardness and total hardness. Ponds with large total alkalinity concentrations and low calcium or total hardness concentrations apparently were supplied water from such wells. The occurrence of waters with high alkalinity and low total hardness is common where surface soils contain limestone

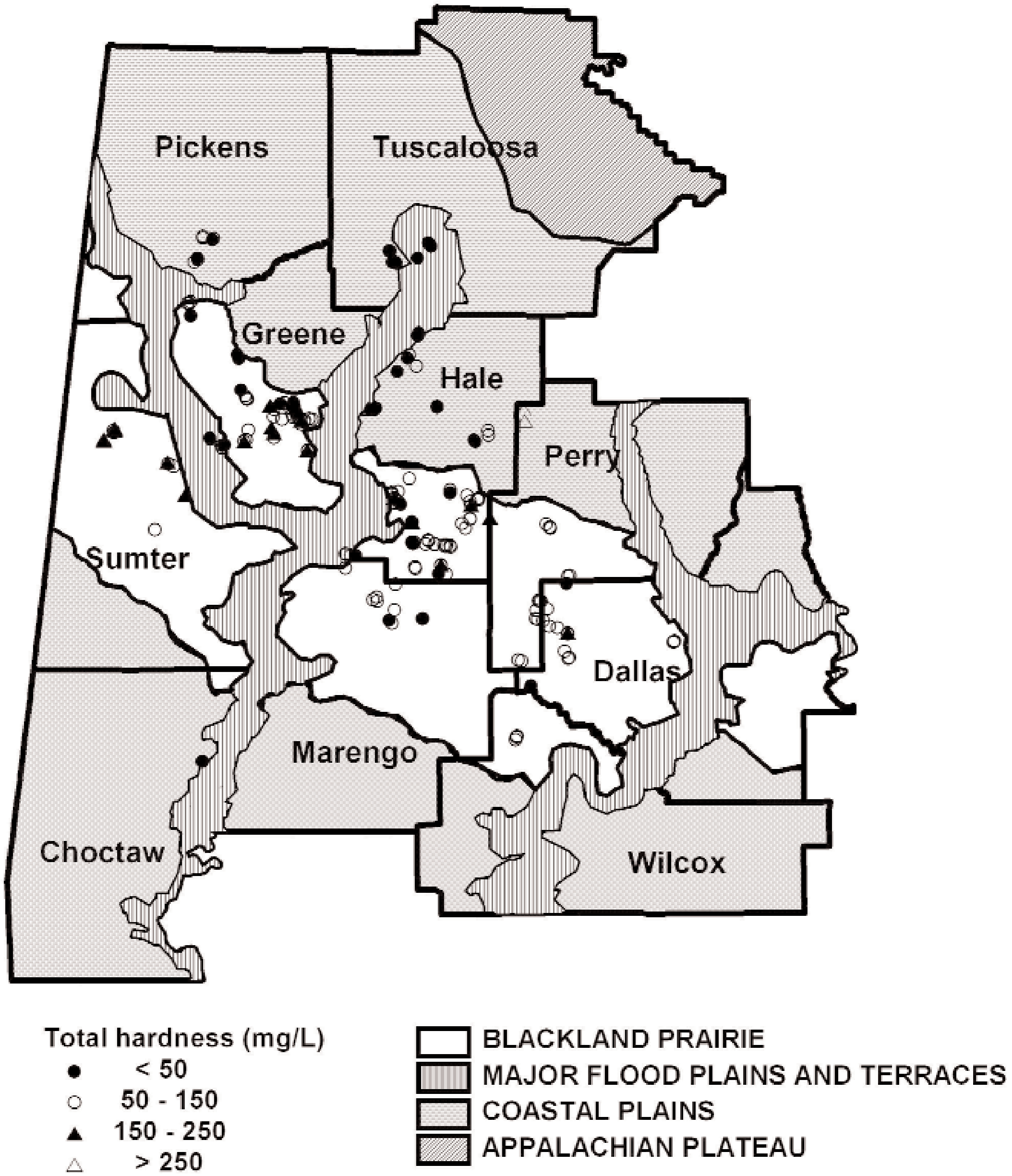


Figure 8. Distribution of total hardness concentrations in waters of channel catfish ponds located on different soil areas in west-central Alabama.

and solids in underlying aquifers have absorbed large amounts of sodium through ion exchange. Sodium entered the aquifers in earlier geologic periods when aquifers contained seawater. Over time, seawater was replaced by freshwater as uplifting of the land occurred. Water infiltrating into the aquifer following precipitation on the land above has large concentrations of calcium, magnesium, and alkalinity from dissolution of limestone. Upon entering the aquifer, calcium and magnesium in water are exchanged for sodium adsorbed on the solids. This process is called natural softening of groundwater *(19)*. When naturally-softened groundwaters are used in aquaculture, they commonly have afternoon pH above 10, because there is insufficient calcium to precipitate much of the carbonate generated by carbon removal by phytoplankton *(6)*.

Waters with total alkalinity at least twice the concentration of total hardness are most likely to have excessive pH *(6)*. Thirty-two of 223 samples had total alkalinity twice total hardness. All but four of these samples were from the Blackland Prairie (Figure 9).

The regression between total alkalinity and calcium hardness was weak ($R^2 = 0.029$). Specific conductance was strongly correlated with calcium hardness:

$$\mathrm{CaH} = 52.9 + 0.046\ \mathrm{SC} \qquad R^2 = 0.574$$

where: CaH = calcium hardness (mg/L),
SC = specific conductance (µmhos/cm).

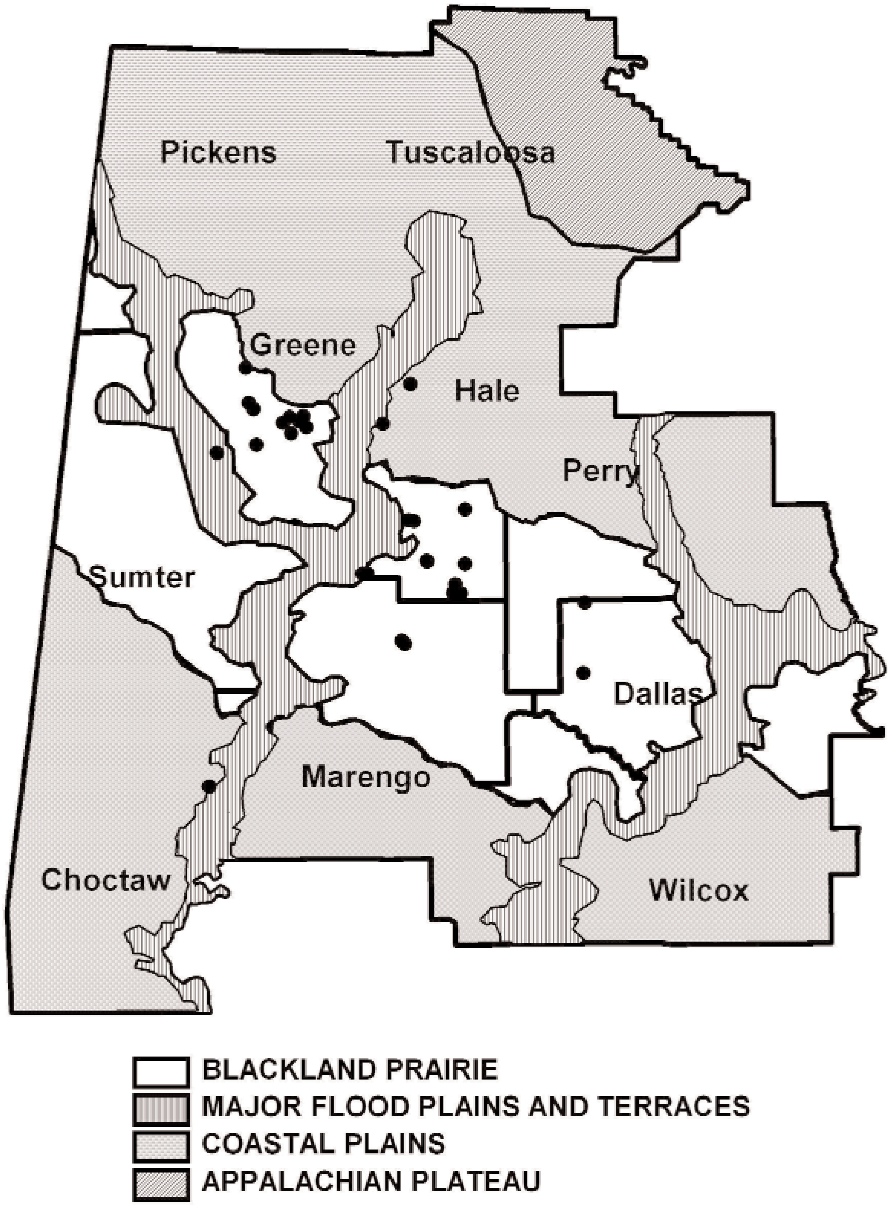


Figure 9. Locations of channel catfish ponds in west-central Alabama that had total alkalinity concentrations twice or greater than total hardness concentrations.

Major cations

Calcium concentration averaged 35 mg/L and ranged between 2 and 212 mg/L (Table 2). About 75 percent of samples contained less than 50 mg/L calcium (Figure 10), and samples containing more than 75 mg/L calcium were from ponds supplied saline groundwater from wells. The average magnesium concentration was 4 mg/L, and minimum and maximum concentrations were 0.34 mg/L and 51 mg/L, respectively (Table 2). Nearly all samples contained less than 5 mg/L magnesium (Figure 10). Samples with more than 15 mg/L were from ponds filled by saline well water. These waters contain almost nine times more calcium than magnesium.

There are not specific recommendations for optimum calcium and magnesium concentrations or calcium:magnesium ratios for pond fish culture. The two ions are the source of water hardness, and it usually is recommended that water for food fish production should contain at least 50 mg/L total hardness *(11),* but the optimum ratio of calcium hardness:magnesium hardness has never been considered.

Potassium concentration averaged 13 mg/L with a range of 1 to 50 mg/L (Table 2). About 75 percent of samples contained less than 20 mg/L potassium (Figure 10). Earlier studies of pond waters *(2)* and well waters *(10)* in west-central Alabama revealed that potassium concentrations were seldom above 5 mg/L. The comparatively high potassium concentrations found in this investigation were unexpected. The likely explanation is that rock salt ($NaCl$) added to almost all catfish ponds in annual doses of 50 to 100 mg/L contains potassium as an impurity.

Sodium concentrations were between 5 and 1,863 mg/L with an average of 122 mg/L (Table 2). Salt routinely is added to channel catfish ponds as mentioned above to increase chloride concentrations. The freshwater ponds contained considerable sodium, usually more than 50 mg/L. Nevertheless, 90 percent of samples contained less than 200 mg/L sodium (Figure 10). Ponds with the greatest sodium concentrations were supplied with saline groundwater from wells.

No specific upper or lower limits for sodium and potassium concentrations have been recommended for fish culture. These ions contribute to osmotic pressure and they have important physiological functions. Experience suggests that freshwater pond fish grow quite well at sodium and potassium concentrations of 1 or 2 mg/L in waters where TDS concentrations are high enough to allow satisfactory osmoregulation.

The distributions of concentrations of major cations related to soil areas are shown in Figures 11 to 14.

There was a weak correlation between total alkalinity and calcium concentration ($R^2 = 0.150$), but alkalinity and other major cations were not correlated. There were fairly strong correlations between specific conductance and calcium, magnesium, and sodium as follows:

$$Ca = 21.2 + 0.018\ SC \qquad R^2 = 0.576$$

$$Mg = 0.78 + 0.004\ SC \qquad R^2 = 0.754$$

$$Na = -76.5 + 0.302\ SC \qquad R^2 = 0.752$$

where: Ca, Mg, and Na = calcium, magnesium, and sodium, respectively (mg/L),
SC = specific conductance (µmhos/cm).

Potassium concentration and specific conductance were not correlated.

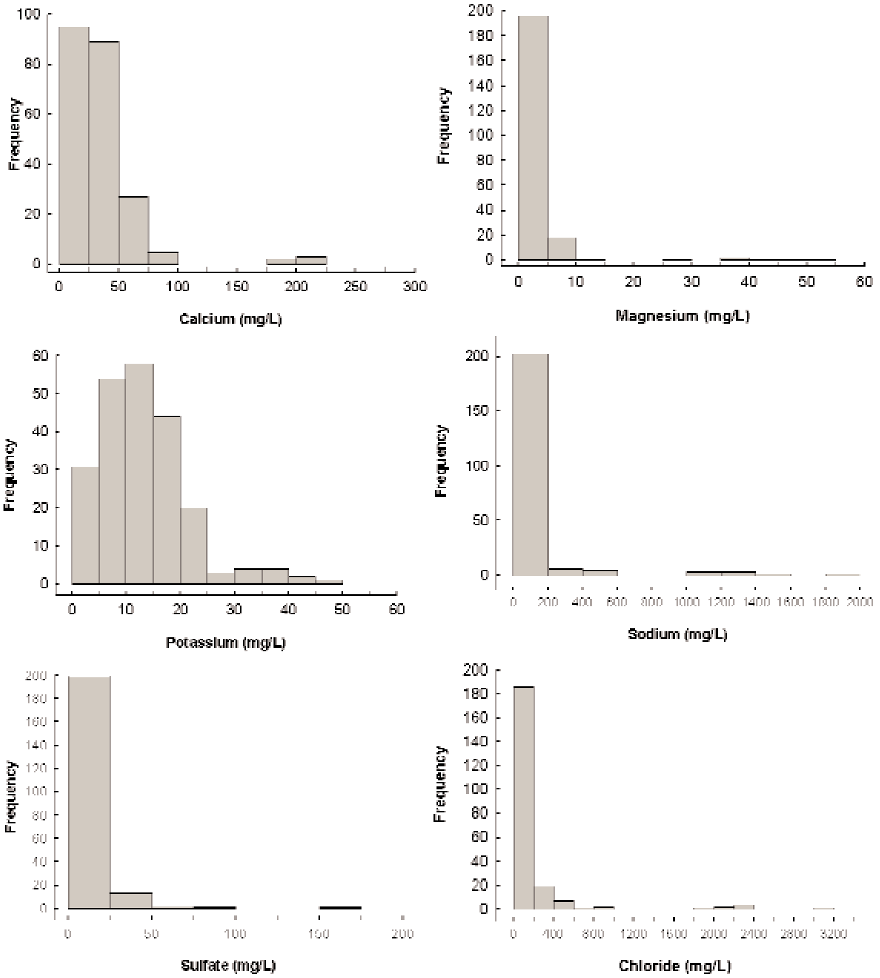


Figure 10. Frequency distribution histograms for concentrations of water quality variables in 223 channel catfish ponds in west-central Alabama.

Major anions

Bicarbonate and carbonate are the source of alkalinity in pond waters, and it is traditional to report total alkalinity concentration rather than the concentrations of these two ions *(8)*.

Sulfate concentration ranged from 0 to 166 mg/L; the average was 10 mg/L, and more than 80 percent of samples contained less than 25 mg/L (Table 2, Figure 10). Sulfate contributes to osmotic pressure, and sulfur is a component of protein. However, freshwater fish apparently do not have a specific requirement for dissolved sulfate in water and obtain sulfur mainly from their food.

Chloride is added in rock salt to almost all channel catfish ponds in Alabama in an effort to maintain chloride concentrations 10 to 20 times greater than nitrite concentrations and prevent nitrite toxicity *(11)*. Thus, chloride concentrations in catfish ponds in west-central Alabama were much greater than those reported for sportfish ponds by Arce and Boyd *(2)*. The average chloride concentration was 198 mg/L, and

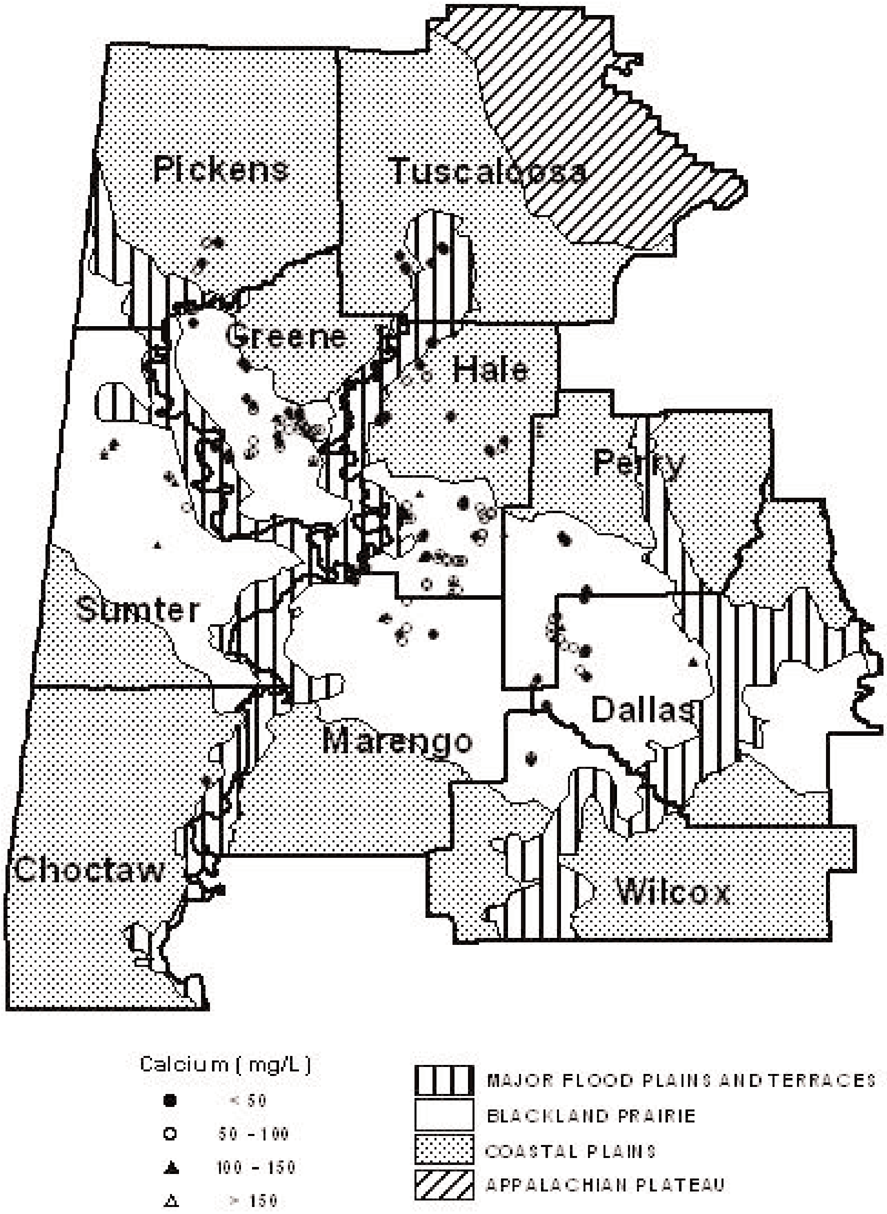


Figure 11. Distribution of calcium concentrations in waters of channel catfish ponds located on different soil areas in west-central Alabama.

individual samples had a range of 1 mg/L to 3,087 mg/L (Table 2). Only 37 samples, or roughly 16 percent, exceeded 200 mg/L chloride (Figure 10). Although chloride concentrations differed greatly among ponds, there were no clear trends in concentration related to soil areas (Figure 15).

There are no specific minimum chloride concentrations for waters used to culture freshwater fish. Many species of pond fish have been cultured successfully at the Auburn University Fisheries Research Unit where pond waters contain less than 5 mg/L chloride.

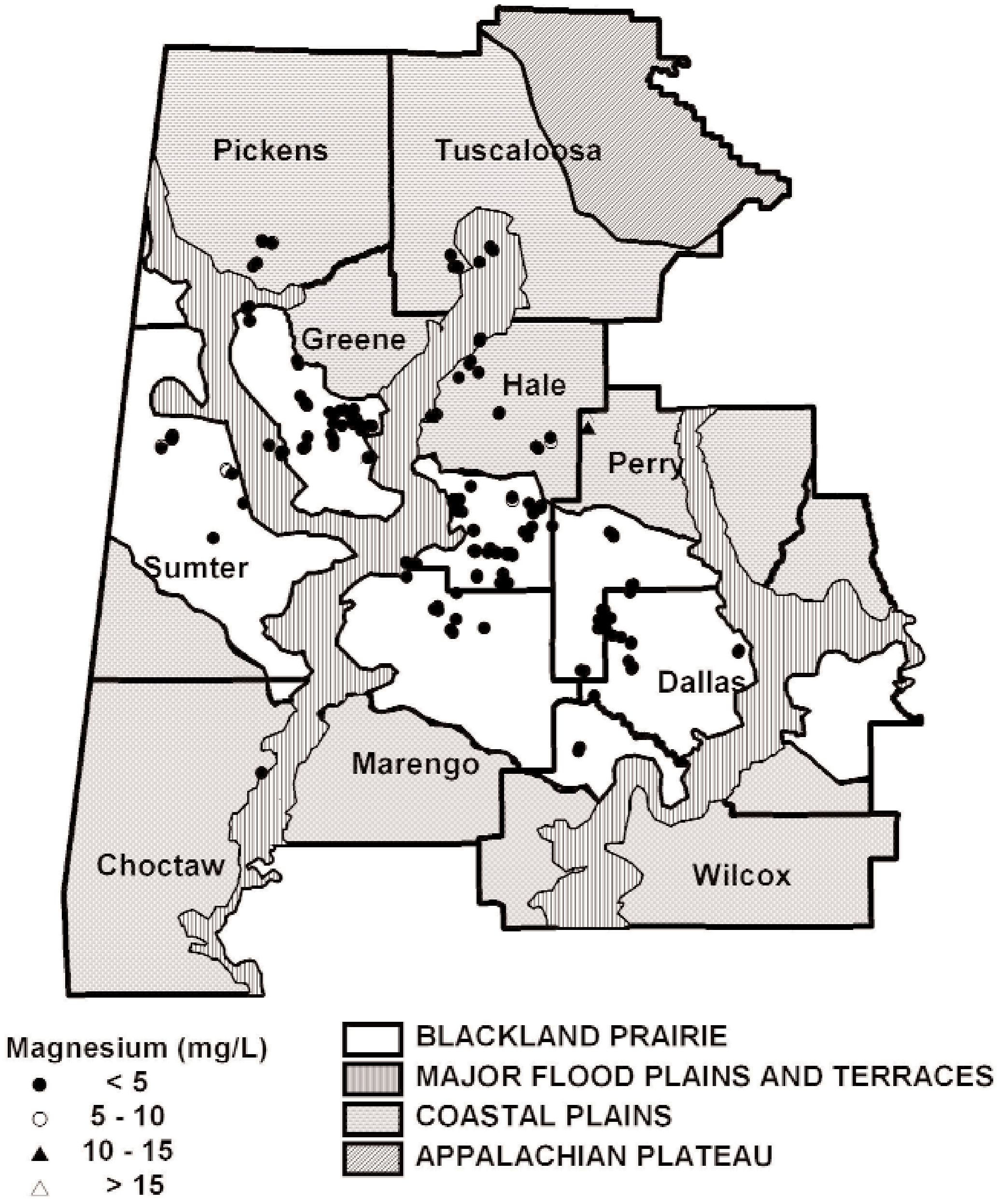


Figure 12. Distribution of magnesium concentrations in waters of channel catfish ponds located on different soil areas in west-central Alabama.

Minor elements

Data on concentrations of iron, manganese, zinc, copper, and boron are summarized in Table 2 and Figure 16. Some waters had relative high concentrations of iron (up to 3.39 mg/L) and manganese (up to 3.4 mg/L). Naturally occurring compounds of these two metals are highly insoluble in oxygenated water of pH 5 or greater. It must be assumed that the high iron and manganese concentrations in some ponds resulted from chelation of iron by fulvic and humic acids *(8)*.

Zinc and copper concentrations tended to be quite low, but a few samples had concentrations above 0.3 mg/L. The high concentrations of zinc in a few ponds can-

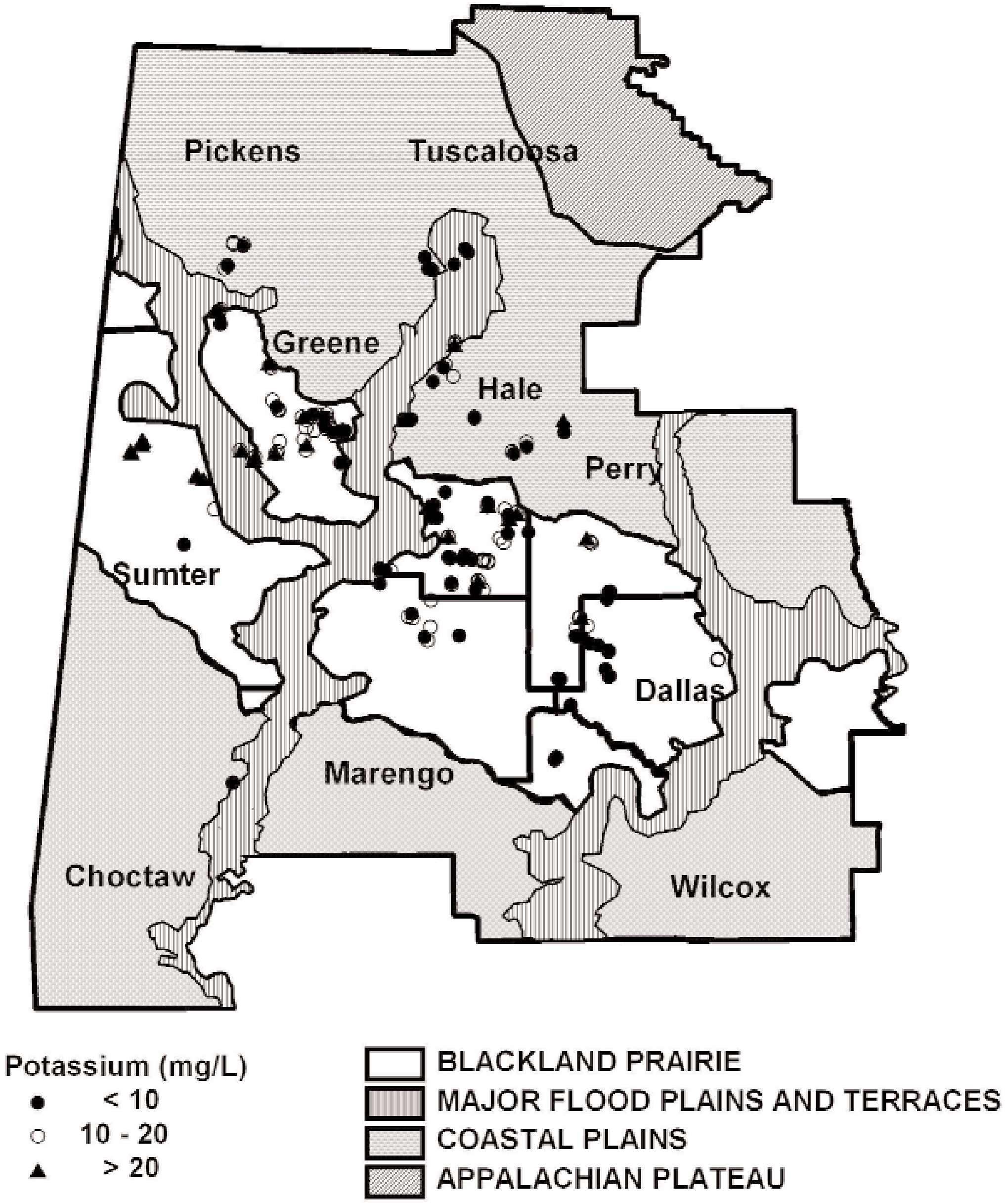


Figure 13. Distribution of potassium concentrations in waters of channel catfish ponds located on different soil areas in west-central Alabama.

not be explained. The high copper concentrations were not unexpected, because copper sulfate often is applied to catfish ponds as an algicide and a method for controlling off-flavor in fish.

Fish have no specific requirements for particular concentrations of minor elements in water. Thus, no further discussion of minor elements will be provided.

Total suspended solids

Concentrations of total suspended solids (TSS) ranged from 4 to 340 mg/L. The average concentration was 64 mg/L (Table 2). About 50 percent of samples contained

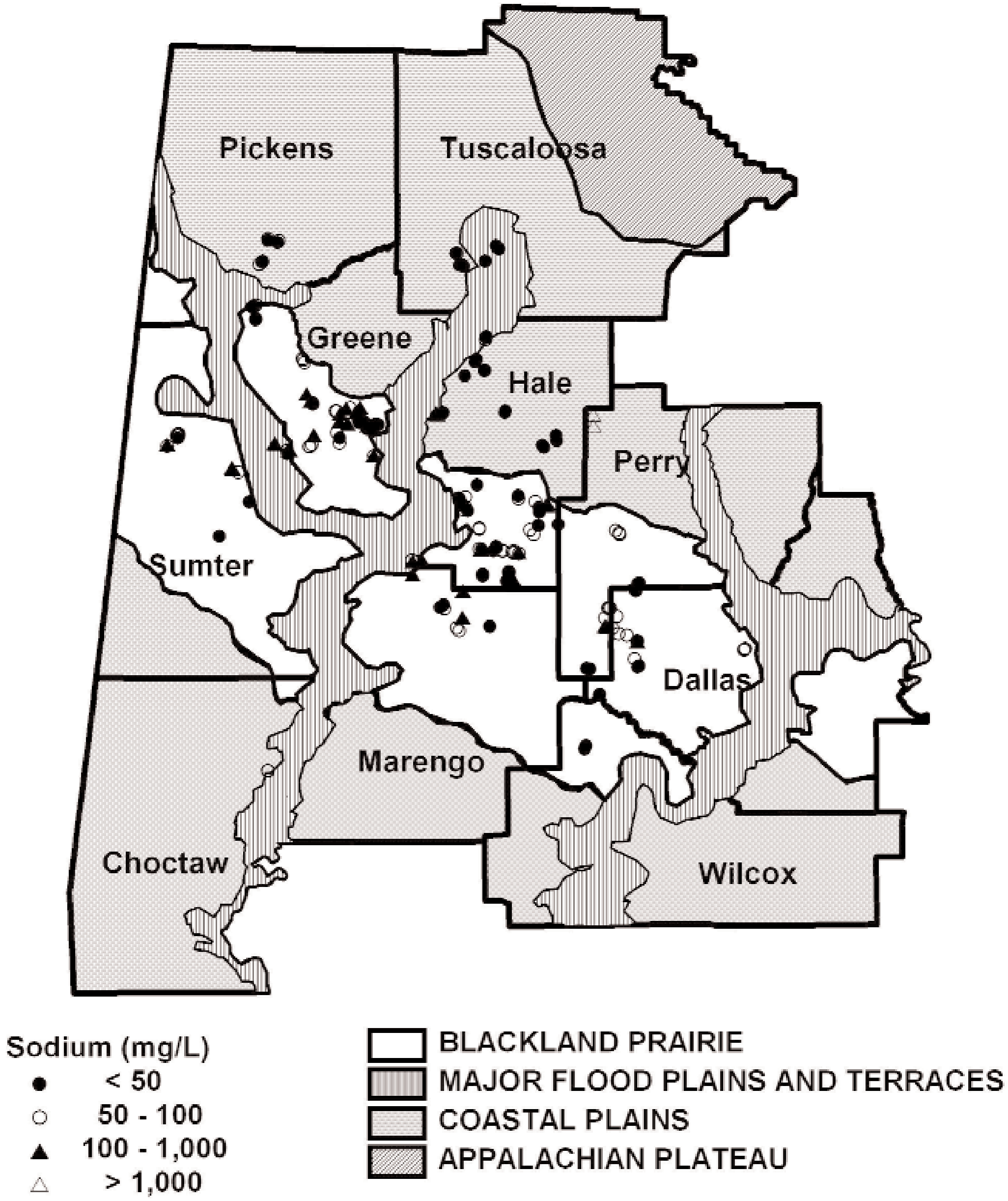


Figure 14. Distribution of sodium concentrations in waters of channel catfish ponds located on different soil areas in west-central Alabama.

less than 50 mg/L and around 75 percent were below 100 mg/L (Figure 16). Ponds in west-central Alabama have concentrations of TSS typical of those found in aquaculture ponds throughout the world *(11)*.

Bottom Soil Quality

Color

Soil color was highly variable with hues of red, brown, gray, and black (Table 3). Grayish and black soils were dominant in southern Hale County and in Greene and

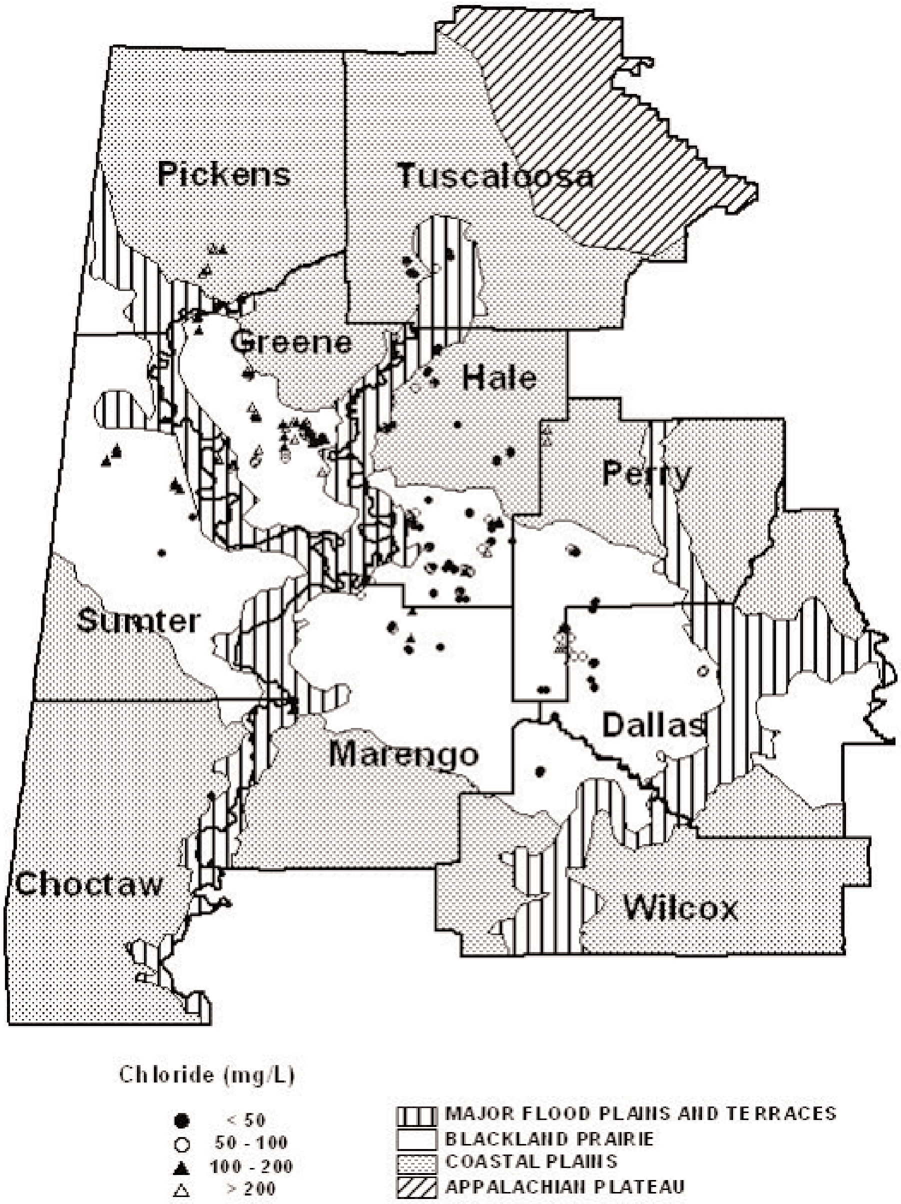


Figure 15. Distribution of chloride concentrations in waters of channel catfish ponds located on different soil areas in west-central Alabama.

Dallas Counties. Red and brown soils were more common in northern Hale County and in Tuscaloosa County. Color is an important indicator of soil condition. The lighter colors, red and brown, suggest that a soil contains iron oxide and is aerobic. Darker colors suggest a higher organic matter content or anaerobic conditions *(7,17)*.

Dry bulk density

The bulk density of soils ranged from 0.17 to 1.55 g/cm^3 and averaged 0.92 g/cm^3 (Table 4). Sediment with a bulk density less than 0.5 or 0.6 g/m^3 is very soft and more likely to be in poor condition than a soil of greater bulk density. Where sediment is soft, there is a greater tendency for anaerobic conditions to develop.

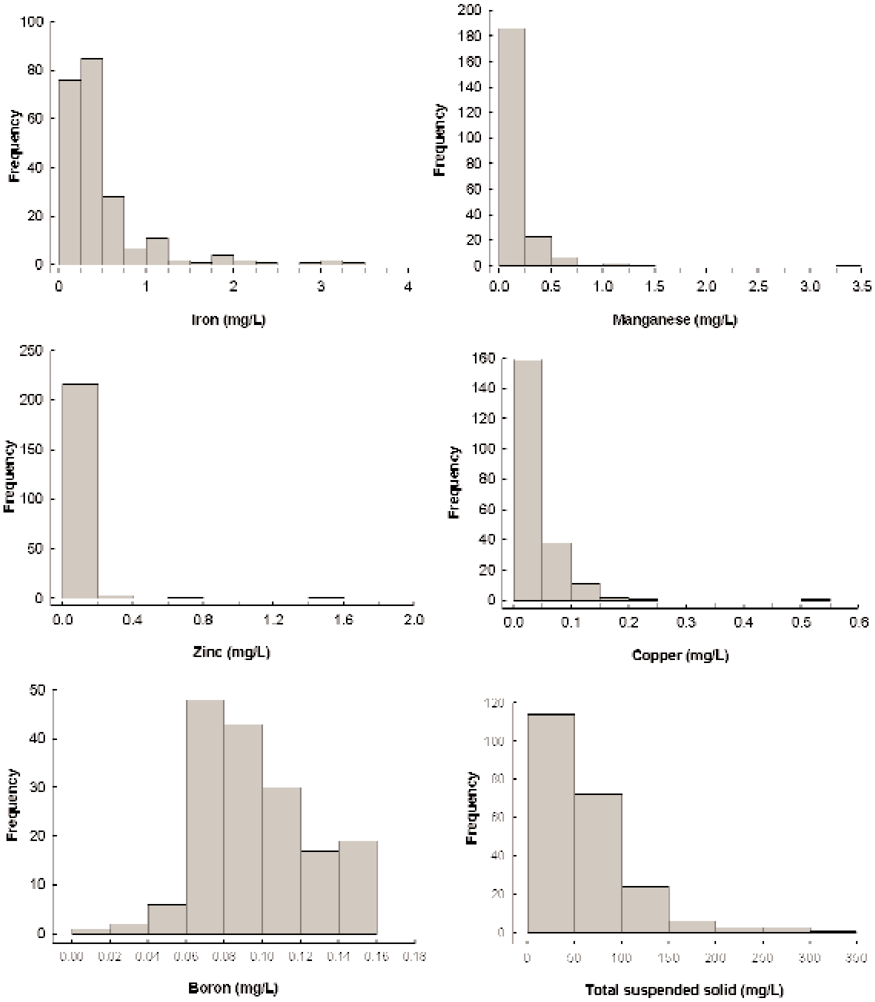


Figure 16. Frequency distribution histograms for concentrations of water quality variables in 223 channel catfish ponds in west-central Alabama.

Dissolved oxygen cannot diffuse into the soft material as rapidly as into firmer sediment. Soft sediment interferes with fish harvest by seining. It is suspended easily by mechanical aeration. It fills in the deeper areas of ponds, contributes large amounts of suspended solids to effluent when ponds are drained, and does not completely dry after ponds are drained. Only eleven of 58 samples had bulk densities lower than 0.5 g/cm^3 (Figure 17).

Texture

The sediment samples had a wide range in percentages of sand, silt, and clay particles (Table 5). Twelve soil texture names can be assigned with a soil triangle *(14)*. The ponds in this study were from a relatively small geographic area, but 10 soil texture names were assigned within the series of samples (Table 6). The heavier textured soils, those with clay in the texture name, tended to occur in the Blackland Prairie and the other soils of lighter texture tended to occur in the Coastal Plain. Nevertheless, light textured soils were found in some ponds in the Blackland Prairie.

TABLE 3. THE COLOR OF CATFISH POND SOILS FROM VARIOUS COUNTIES IN ALABAMA

Soil area[1]	Soil color	Munsell color notation
Dallas County		
BP	Dark greenish gray	1G 4/10Y
BP	Very dark gray	5Y3/1
Greene County		
BP	Brown	7.5YR 5/3
BP	Dark grayish brown	2.5Y4/2
BP	Olive brown	2.5Y4/4
FP	Light olive brown	2.5Y5/4
BP &FP	Olive gray	5Y4/2
BP	Olive	5Y4/3
BP	Olive	5Y5/4
BP	Dark greenish gray	1G 4/5 GY
BP	Dark greenish gray	1G 4/10 GY
BP	Very dark greenish gray	1G 3/5 GY
BP	Very dark greenish	1G 3/10Y
BP	Very dark greenish gray	2G 3/5BG
Hale County		
CP	Dusky red	2.5YR3/2
CP	Dark reddish brown	2.5YR3/3
BP	Reddish brown	5YR4/3
CP	Reddish brown	5YR4/4
BP	Brown	7.5YR 5/2
BP	Very dark gray	10YR 3/1
CP	Very dark grayish brown	10YR3/2
Hale County, continued		
FP	Dark grayish brown	2.5Y4/2
BP	Very dark grayish brown	2.5Y3/2
CP	Olive brown	2.5Y4/3
CP	Olive Brown	2.5Y4/4
BP	Black	5Y2.5/2
CP &BP	Olive gray	5Y4/2
BP	Very dark greenish gray	1G 3/10y
BP	Dark greenish gray	1G 4/10Y
BP	Very dark greenish gray	1G 3/5G
	Very dark greenish gray	1G 3/10BG
Sumter County		
BP	Olive gray	5Y4/2
BP	Olive	5Y4/3
Tuscaloosa County		
CP	Very dark grayish brown	2.5Y3/2
FP	Dark olive brown	2.5Y3/3
FP	Dark grayish brown	2.5Y4/2
CP	Olive brown	2.5Y4/3
CP	Olive brown	2.5Y4/4
CP	Brown	10Y4/3
CP &FP	Reddish brown	2.5YR4/4
FP	Red	2.5YR5/6

[1] BP = Blackland Prairie; CP = Coastal Plain; FP = Major Flood Plains and Terraces

Water-tight ponds can be constructed in soils that have 5 to 10 percent clay and a mixture of sand and silt particles. It is not necessary to have 20 to 30 percent clay particles in soil for ponds as often recommended, but soils containing mostly sand or silt-sized particles are not good for pond construction. The effect of bottom soil texture on the suitability of a pond for fish production has never been properly evaluated.

pH

Soil pH averaged 7.15, but the minimum value was 5.05 and the maximum was 8.10 (Table 4). The best pH for pond soils is considered to be 6.5 to 7.5, and pH 5.5 to 8.5 is considered acceptable *(3)*. Based on Banerjea's scale *(3),* all but two of the soils had acceptable pH (Figure 17). Boyd *(7)* argued that aquaculture pond soil should not have pH below 7, and 19 (32.8 percent) of the samples had pH below 7. Acidic soils were found in both Coastal Plain and Blackland Prairie (Figure 18).

TABLE 4. AVERAGES, STANDARD DEVIATIONS (SD), AND MINIMUM AND MAXIMUM CONCENTRATIONS FOR BOTTOM SOIL QUALITY VARIABLES IN SAMPLES FROM 58 CATFISH PONDS IN WEST-CENTRAL ALABAMA

Variable	Average ± SD	Minimum	Maximum
Bulk density (g/cm^3)	0.92 ± 0.38	0.17	1.55
pH	7.15 ± 0.71	5.05	8.1
CaCO$_3$(%)	7.18 ± 11.18	0.0	42.9
Organic carbon (%)	1.02 ± 0.77	0.16	4.10
Total nitrogen (%)	0.08 ± 0.09	0.01	0.50
C:N ratio	18.4 ± 13.2	5.4	75
Sulfur (%)	0.07 ± 0.23	0.0	1.74
Calcium (mg/kg)	3,563 ± 2,576	76	6,958
Magnesium (mg/kg)	113 ± 95	8.2	471
Potassium (mg/kg)	105 ± 77	8.1	382
Sodium (mg/kg)	198 ± 233	2.2	845
Iron (mg/kg)	75 ± 92	4.1	434
Manganese (mg/kg)	76 ± 91	2.7	3467
Zinc(mg/kg)	1.95 ± 2.91	0.0	13.53
Copper (mg/kg)	7.08 ± 13.17	0.0	63.34
Boron (mg/kg)	0.55 ± 0.42	0.0	2.24

Calcium carbonate

The concentration of carbonate in sediment ranged from 0 to 42.9 percent of air dry weight as equivalent calcium carbonate (Table 4). The average concentration was 7.18 percent. Twenty-seven samples did not have measurable carbonate, and only 28 samples contained over 5 percent (Figure 17). Most samples containing carbonates were from the Blackland Prairie (Figure 19).

Carbonate in sediment can dissolve to increase concentrations of total alkalinity, calcium, and magnesium in water. Many other factors influenced alkalinity, calcium, and magnesium concentrations, because they were not strongly correlated with the percentage calcium carbonate in soil. The correlation coefficients were r = 0.394, 0.248, -0.088, respectively; only the one for total alkalinity was significant at P = 0.05. Nevertheless, ponds where soils contained free carbonate had total alkalinity and hardness concentrations above 60 mg/L. The concentration for total alkalinity and total hardness in water at equilibrium with solid phase calcium carbonate and normal atmospheric carbon dioxide concentration is about 60 mg/L *(8).*

There have been no studies relating calcium carbonate concentration in sediment with fish production. However, sediment containing calcium carbonate in the present study had pH values between 6.9 and 8.1. This is considered an ideal pH range for pond bottom soils *(7).*

Organic carbon

Concentrations of organic carbon were between 0.16 and 4.10 percent and averaged 1.02 percent (Table 4). Soil organic matter is about 58 percent carbon *(27),* so the samples contained from about 0.28 percent to about 7.05 percent organic matter.

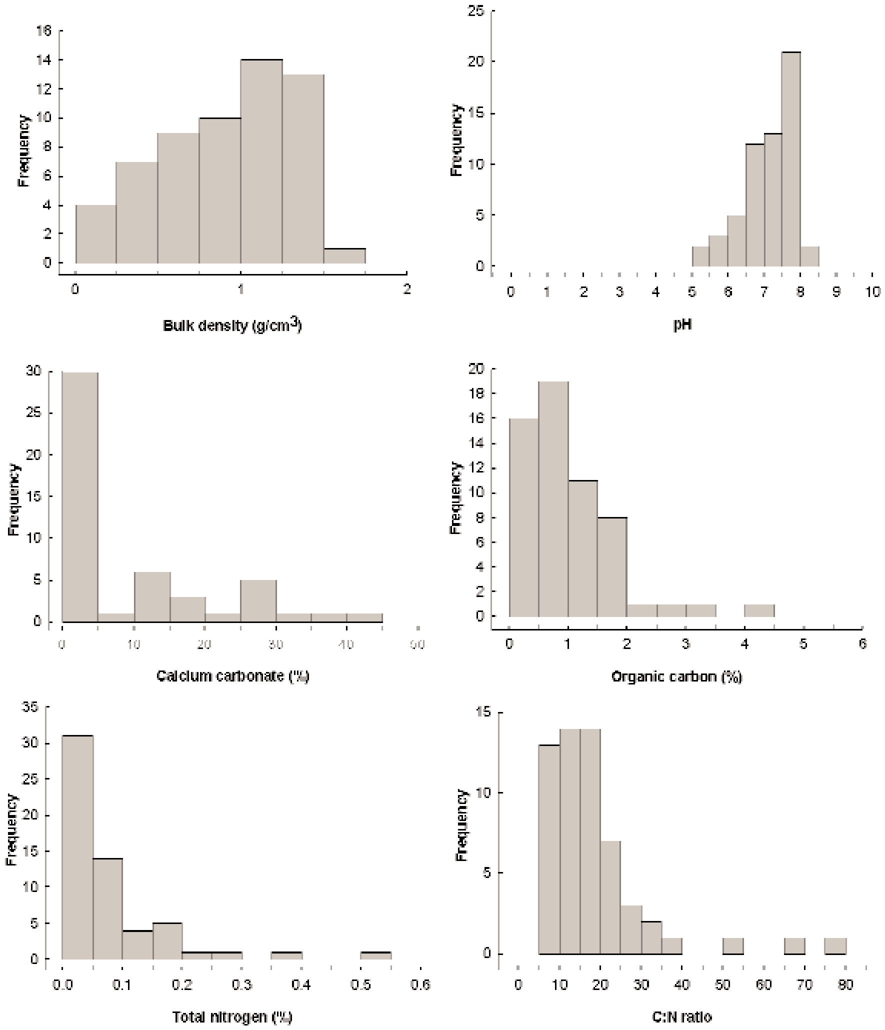


Figure 17. Frequency distribution histograms for bottom soil quality variables in 58 channel catfish ponds in west-central Alabama.

Table 5. Averages and Ranges in Percentages of Dry Weight for Sediment Samples

Particle class	Average ± SD	Min.	Max.
Sand	50.4 ± 4.0	5.2	97.3
Silt	27.4 ± 2.5	1.4	77.8
Clay	22.2 ± 2.4	1.0	60.2

Table 6. Texture Names and Number of Ponds for each Texture

Texture name	Number of ponds
Clay	13
Clay loam	7
Silty clay	1
Silty clay loam	1
Sandy clay loam	3
Loam	2
Silt loam	6
Sandy loam	10
Loamy sand	3
Sand	10

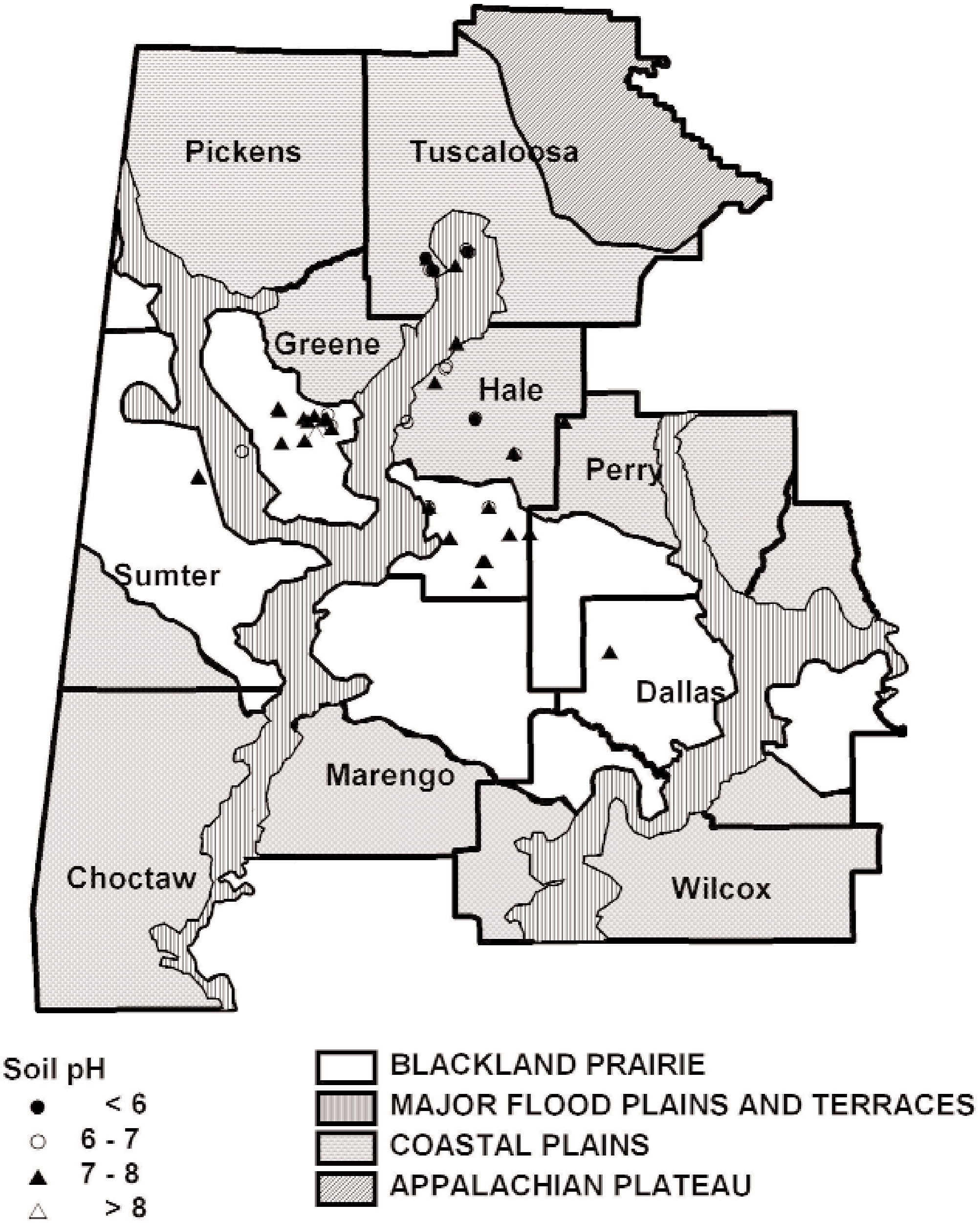


Figure 18. Distribution of pH in bottom soil of channel catfish ponds located on different soil areas in west-central Alabama.

Thirty-five samples contained less than 1 percent organic carbon and 19 samples contained 1 to 2 percent organic carbon (Figure 17).

According to Banerjea *(3),* the acceptable range of soil organic carbon for aquaculture ponds is 0.5 to 2.5 percent, and the optimum range is 1.5 to 2.5 percent. Boyd *(7)* re-evaluated organic carbon concentrations in aquaculture ponds and concluded that pond soils contain two types of organic matter. The newly deposited organic matter is highly reactive, and the old, residual organic matter decomposes very slowly. Because the methods for measuring pond soil organic matter do not distinguish between fresh, highly reactive organic matter and older, resistant organic matter, it is

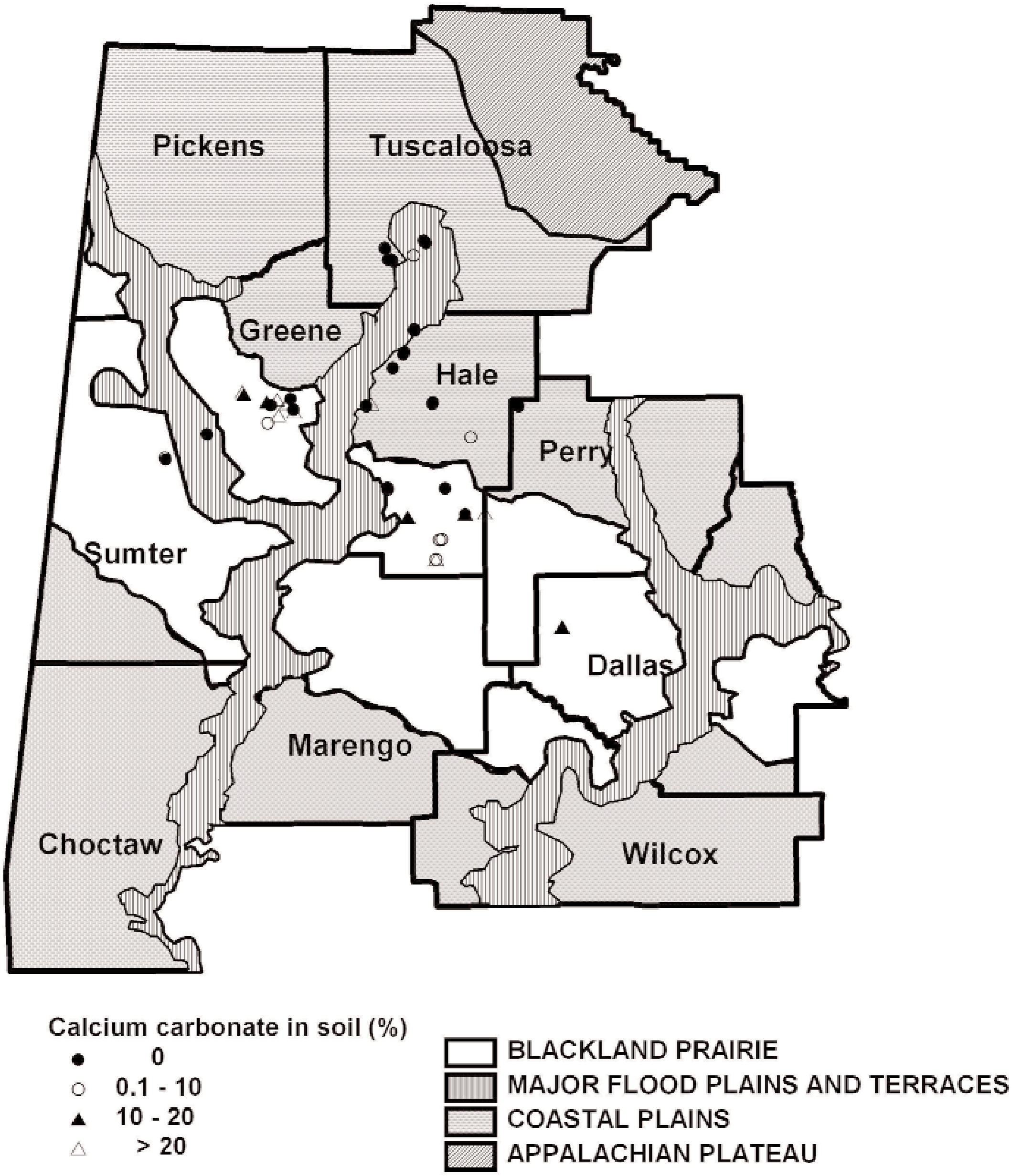


Figure 19. Distribution of concentration of free carbonate (as percentage of $CaCO_3$) in bottom soil of channel catfish ponds located on different soil areas in west-central Alabama.

difficult to recommend maximum tolerable limits for organic matter. Boyd et al. *(13)* gave a general recommendation that organic carbon concentration in pond bottom soils should be between 1 and 3 percent, but in ponds where fish are fed, organic matter concentrations below 1 percent are acceptable. When feed input is high and phytoplankton blooms are dense, enough fresh organic matter may accumulate on the pond bottom as a flocculent layer *(25)* to cause anaerobic conditions at the sediment-water interface. This scenario apparently was occurring in some of the ponds of the present study, because sediment was dark colored (anaerobic) in several ponds with soil organic carbon concentrations below 3 percent.

In spite of uncertainty about the relationship between bottom soil organic matter concentration and quality of bottom soils for fish culture, it is obvious that the ponds have not accumulated extremely high percentages of organic carbon. Some of the ponds were more than 20 years old, yet the highest organic carbon concentration observed was only 4.10 percent. Thunjai *(36)* measured sediment organic matter concentrations in 35 tilapia ponds in Thailand. These ponds were up to 39 years old, but the highest organic carbon concentration was only 3.39 percent. The average age of ponds studied by Thunjai was 15 years, and the average organic carbon concentration was 1.90 percent.

Organic carbon or organic matter concentration are likely not good indicators of bottom soil condition at a specific time. Sedimentation of fresh organic matter in uneaten feed, feces, and dead plankton onto the bottom in large amounts can temporarily spoil soil quality in ponds where the upper layer of bottom soil contains less than 1 percent organic carbon. Soil organic carbon (or organic matter) concentration is useful in determining if the sediment is becoming highly organic. Certainly, bottom soils with more than 3 or 4 percent organic carbon are likely to be highly anaerobic throughout the culture period regardless of the intensity of aquaculture in the pond *(7)*.

Native soils in west-central Alabama have low concentrations of organic carbon. When ponds are constructed in such areas, bottom soils will quickly increase in organic carbon concentration because of large inputs of organic matter from aquacultural activities and microbial degradation of organic matter because of waterlogged conditions. It was not surprising that there was no pattern with respect to soil area for pond soil organic carbon concentrations (Figure 20).

Total nitrogen

The average concentration of total nitrogen was 0.08 percent and the minimum and maximum concentrations were 0.01 and 0.50 percent, respectively (Table 4). More than half of the samples contained less than 0.05 percent total N (Figure 17). Low concentrations of nitrogen are normal in soils with low organic matter concentrations, because nitrogen is present in pond soil primarily as a component of organic matter.

Carbon:nitrogen ratios ranged from 5.4 to 75 with an average of 18.4 (Table 4). Banerjea *(3)* reported that fish production was lower in ponds with carbon:nitrogen ratios below 10 than in those with ratios above 10. Pond soils with low carbon:nitrogen ratios tend to have highly decomposable organic matter, and anaerobic conditions at the soil-water interface may be a common problem *(13)*. Samples from 13 ponds had carbon:nitrogen ratios below 10, and none of the samples were below 5 (Figure 17).

Total sulfur

Sulfur concentrations ranged from 0 to 1.74 percent, but only one sample contained more than 0.25 percent sulfur. The average concentration was only 0.07 percent (Table 4). The highest sulfur concentration sample was from a pond near Eutaw. The bottom soil in this pond obviously contained a large amount of iron sulfide, which can oxidize to sulfuric acid and create intense acidity *(16)*. Fortunately, soils

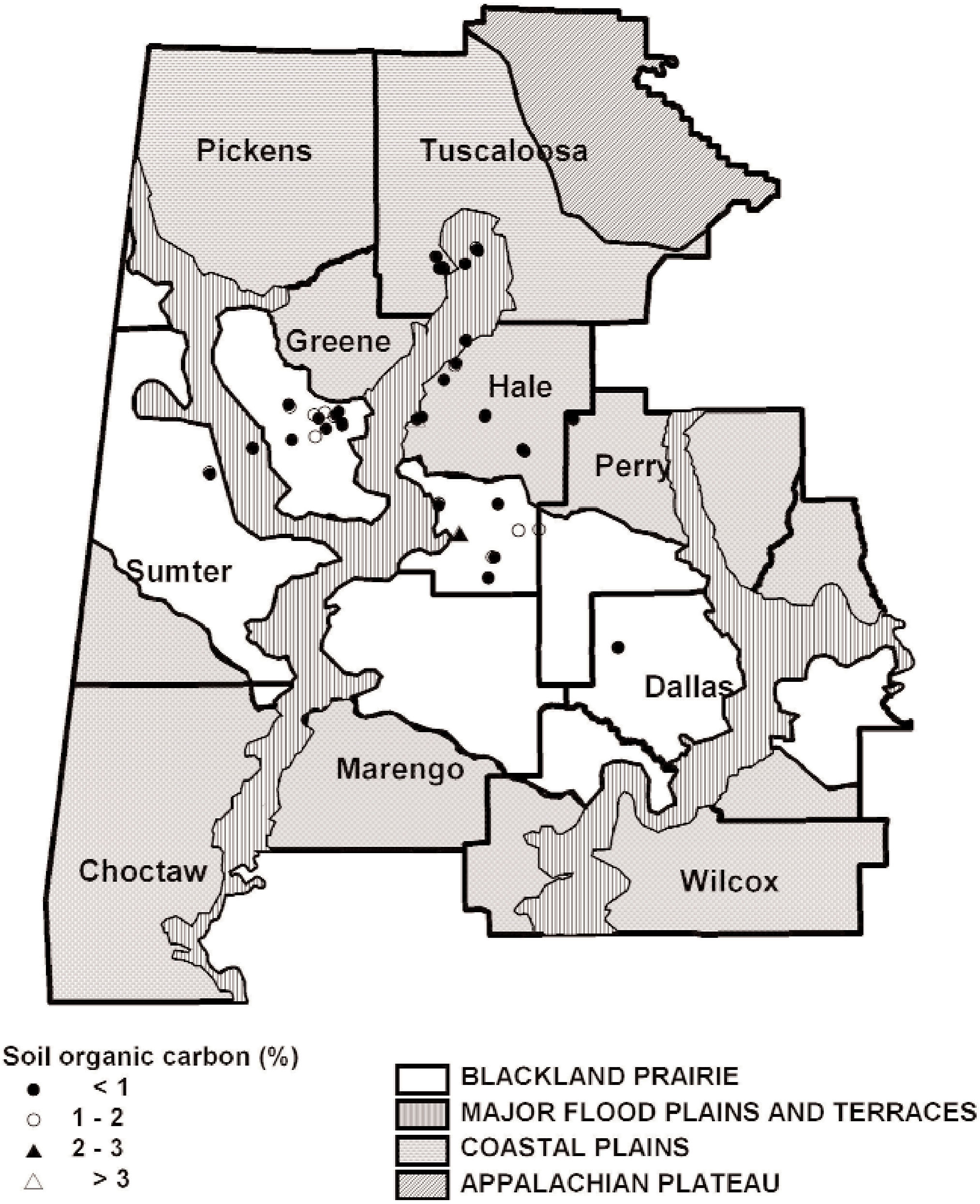


Figure 20. Distribution of organic carbon in bottom soil of channel catfish ponds located on different soil areas in west-central Alabama.

in this pond also contained carbonate that neutralized acidity, for soil and water from the pond were not acidic.

Major ions

Calcium concentrations averaged quite high (3,563 ppm) and had a very wide range (76 to 6,958 ppm) (Table 4). The distribution of calcium values was different from other variables in that there were two modes of values. One mode was skewed to the left (lower values) and the other mode was skewed to the right (higher values) (Figure 21). The calcium extracted by the acid solution included exchangeable calcium and calcium contained in carbonates. The second mode of higher values represented samples containing carbonate.

Magnesium concentrations ranged from 8.2 to 471 ppm and averaged 113 ppm (Table 4). More than half of the magnesium concentrations were less than 100 ppm (Figure 21).

Potassium concentrations were between 8.1 and 382 ppm and the average was 105 ppm (Table 4). About half of the concentrations were less than 100 ppm, and most were below 150 ppm (Figure 21).

Sodium concentrations averaged 198 ppm with a minimum value of 2.2 ppm and a maximum value of 845 ppm (Table 4). About 67 percent of the samples had sodium concentrations below 200 ppm (Figure 21).

The importance of concentrations of major cations in pond soils to pond water quality and fish production has not been elucidated. Nevertheless, it usually is assumed that high concentrations of calcium, magnesium, and potassium are beneficial. High sodium concentration is acceptable provided that there also are high concentrations of the other ions. Soils high in sodium, but low in other major cations have excessively high pH *(7)*.

No patterns in distribution of major cations related to soil areas were obvious, and maps were not included.

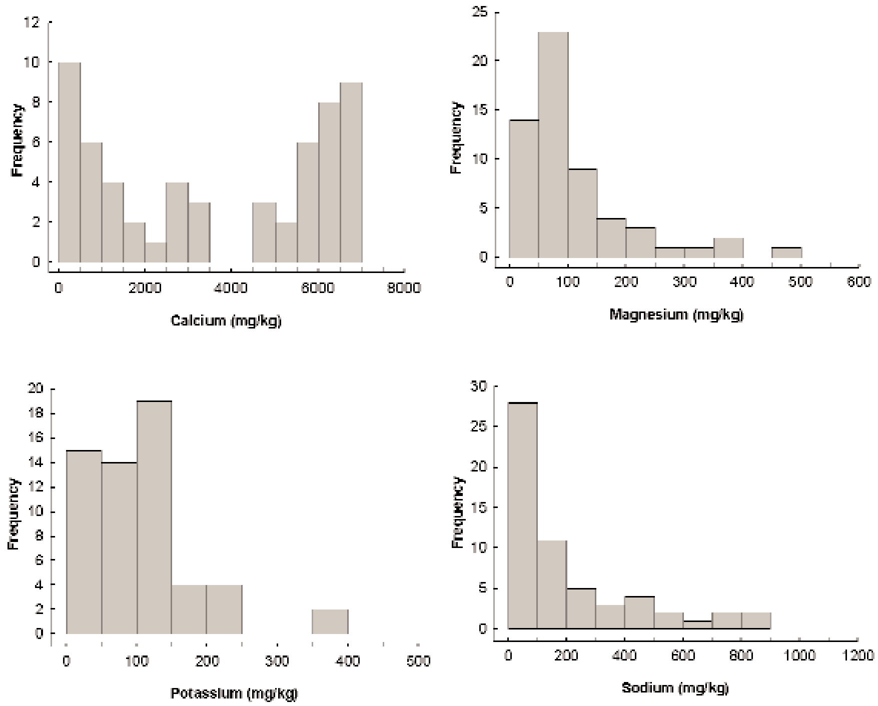


Figure 21. Distribution of major cations in bottom soil of channel catfish ponds located on different soil areas in west-central Alabama.

Major anions

Although soil solutions contain bicarbonate, sulfate, and chloride *(1),* these ions are water soluble and usually are present only in the pore water. Therefore, major anions were not measured in soil samples.

Major elements

The averages, ranges, and distribution of concentrations of iron, manganese, zinc, copper, and boron are provided in Table 4 and Figure 22. There was considerable variation in concentrations of iron, manganese, zinc, and copper, and there are no guidelines for the optimum ranges of these elements *(7)*. The concentrations of iron, manganese, and zinc probably represent natural levels, for these elements are not added intentionally in pond management. Catfish farmers frequently apply 0.5 to 2 mg/L of copper sulfate to ponds in attempts to prevent off-flavor in fish. Some ponds may be treated several times in the same year *(24)*. Copper either precipitates

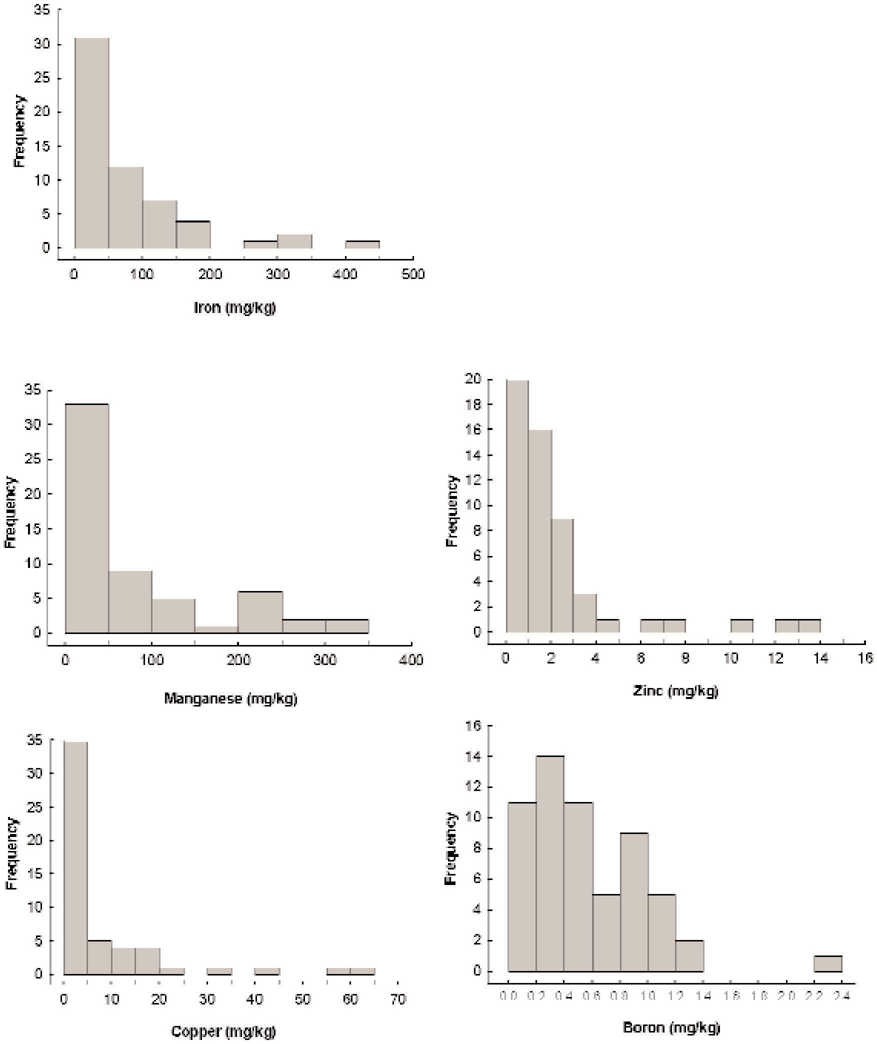


Figure 22. Distribution of minor elements in bottom soil of channel catfish ponds located on different soil areas in west-central Alabama.

from the water or is incorporated in organic copper compounds in sediment *(24)*. Thus, the copper concentrations in catfish pond soils probably are much greater than natural, background concentrations.

There are no discernable distribution patterns for minor element concentrations related to soil areas, and maps are not provided.

Relationship among soil variables

Simple linear correlation coefficients (r) were computed for regressions between selected soil quality variables (Table 7). There were many significant correlations. Soil pH was positively correlated with carbonate, calcium, sodium, and clay concentrations of soils.

The bulk density was negatively correlated with organic carbon, calcium, magnesium, potassium, sodium, and clay concentrations and positively correlated with carbon:nitrogen ratio and percentage sand. The bulk density of soil is related to texture, for the density of sand is greater than silt, and silt has a higher density than clay *(7),* and soils with a high clay content have a lower bulk density than those with a higher sand content. The major cations are attracted to and held on negatively-charged colloidal clay and organic matter in soil. Much of the organic matter in soil also is intricately associated with surfaces of clay particles. As bulk density increases, the ability of soil to hold major cations and finely divided organic matter declines. Soils with moderate amounts of clay and organic matter have a lower bulk density and greater ability to adsorb cations than silty or sandy soils. For these reasons, soils with moderate amounts of clay and organic matter are of good quality for pond aquaculture. Nevertheless, if bulk density becomes very low, the sediment becomes too soft and prone to cause various problems already mentioned.

Organic carbon concentrations were positively correlated with concentrations of major cations and clay, and negatively correlated with bulk density. The positive correlations were explained above, but the negative correlation with bulk density results because organic matter has a low density. Because of its large particle size and small surface area in comparison with smaller soil particles, sand cannot hold finely divided organic matter to surfaces as is the case for clay.

Explanations for most of the other significant correlations can be found above. In summary, the correlation matrix illustrates that for the series of samples examined in this study, those with higher pH and moderate bulk density (but still containing appreciable clay) were superior to others as bottom soil in aquaculture ponds.

Relationship between Pond Soil and Water Quality

Coefficients of determination also were obtained for regression between concentrations of selected soil variables and selected water variables (Table 8). Soil pH had a strong influence on water quality, for concentrations of water pH, TDS, specific conductance, total alkalinity, total hardness, calcium hardness, calcium, potassium, and sodium all increased with increasing soil pH.

There were no significant correlations between organic carbon and water quality variables. Nevertheless, soil organic matter must be considered an important variable, because at high concentrations of soil organic matter, microbial respiration may

TABLE 7. CORRELATIONS MATRIX FOR RELATIONSHIPS AMONG BOTTOM SOIL QUALITY VARIABLES IN SAMPLES FROM 58 CHANNEL CATFISH PONDS IN WEST-CENTRAL ALABAMA

Independent	Dependent variable										
Independent variable	pH	BD (g/cm^3)	$CaCO_3$ (%)	OC (%)	C:N	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	Na (mg/kg)	Sand (%)	Clay (%)
pH	—	0.189	0.512**	0.060	0.169	0.650**	-0.123	0.012	0.359**	-0.121	0.331*
BD (g/cm^3)	0.189	—	-0.078	-0.723**	0.409**	-0.293*	-0.314*	-0.602**	-0.343**	0.417**	-0.278*
$CaCO_3$(%)	0.512**	-0.078	—	0.169	0.020	0.681**	-0.195	0.052	0.226	-0.521*	0.503**
OC (%)	-0.060	-0.723**	0.169	—	-0.314*	0.428**	0.389**	0.702**	0.353**	-0.450**	0.314*
C:N ratio	0.169	0.409**	0.020	-0.314*	—	-0.219	-0.364**	0.373**	-0.198	0.388**	-0.244*
Ca (mg/kg)	0.649**	-0.293*	0.681**	0.428**	-0.219	—	0.094	0.401**	0.452**	-0.672**	0.687**
Mg (mg/kg)	0.123	-0.315*	-0.195	0.389**	-0.364**	0.094	—	0.632**	0.255	-0.170	0.122
K (mg/kg)	0.012	-0.602**	0.052	0.702**	-0.379**	0.401**	0.632*	—	0.509**	-0.475**	0.490**
Na (mg/kg)	0.359**	-0.343**	0.226	0.353**	-0.198	0.452**	0.255	0.510**	—	-0.301	0.352**
Sand (%)	-0.121	0.417**	-0.521**	-0.450**	0.338**	-0.672**	-0.170	-0.475**	-0.301	—	-0.779**
Clay (%)	0.331*	-0.278*	0.503**	0.314*	-0.244	0.687**	0.122	0.490**	0.352**	-0.779**	—

Definition of symbols: BD = bulk density; $CaCO_3$ = calcium carbonate; OC = organic carbon; C:N = carbon:nitrogen ratio; Ca = calcium; Mg = magnesium; K = potassium; Na = sodium.

* = $P < 0.05$; ** = $P < 0.01$.

Table 8. Correlations between Bottom Soil Quality Variables and Water Quality Variables Based on Data from 58 Channel Catfish Ponds in West-Central Alabama

Soil	Water variable (Y)									
		TDS	SC	TA	TH	CaH	Ca	Mg	K	Na
variable(X)	pH	(mg/L)	(µmhos/cm)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
pH	0.307**	0.277*	0.338**	0.566**	0.389**	0.437**	0.432**	0.194	0.330*	0.306*
OC (%)	-0.045	-0.137	-0.154	-0.029	0.033	0.081	0.075	-0.107	0.203	-0.184
$CaCO_3$ (%)	-0.014	-0.035	0.016	0.394**	0.175	0.256	0.248	-0.088	-0.051	-0.015
Ca (mg/kg)	0.059	-0.018	0.013	0.521**	0.225	0.322*	0.319	-0.117	0.226	-0.034
Mg (mg/kg)	0.065	-0.106	-0.105	-0.021	-0.129	-0.156	-0.144	-0.067	0.223	-0.123
K (mg/kg)	0.035	-0.013	-0.013	0.271*	0.051	0.057	0.081	-0.064	0.442**	-0.058
Na (mg/kg)	0.239	0.287	0.358**	0.588**	0.082	0.083	0.091	0.036	0.176	0.394**

Definition of symbols: TDS = total dissolved solids; SC = specific conductance; TA = total alkalinity; TH = total hardness; CaH = calcium hardness; Ca = calcium; K = potassium; Na = sodium; OC = organic carbon; $CaCO_3$ = calcium carbonate.

* P= <0.05; ** = P<0.01.

cause anaerobic conditions in pond bottom soil with release of potentially toxic metabolites *(7)*.

There was an increase in total alkalinity in water with increasing calcium carbonate percentage in soil. Moreover, increases in the calcium concentration in soil were associated with increases in total alkalinity and calcium hardness in water. Magnesium concentrations in water were not correlated with other selected soil quality variables.

Potassium concentrations in soil were positively correlated with total alkalinity and potassium concentrations in water. Sodium concentrations in soil were positively correlated with specific conductance, total alkalinity, and sodium concentrations in water.

Relationship between Soil Areas and Water Quality

The water samples were separated into four categories: Coastal Plains, Major Flood Plains and Terraces, Blackland Prairie, and saline water (1,000 mg/L or greater TDS). Soil samples were segregated as to being from one of the four categories. Averages for individual soil or water quality variables often differed among the categories (Tables 9 and 10). For example, averages for total alkalinity and total hardness were greater in the Blackland Prairie and saline water groups than in the other two categories. Knowledge that one or more soil or water quality variables are greater on average in one or more of the categories is of little value in making predictions about the concentrations of water quality variables in an individual pond. This is because ranges of concentrations of most variables were wide and overlapped among categories.

Use of Database

The geometric coordinates of ponds were established by GPS and recorded in the database. The coordinates of a "non-database" pond could be determined by GPS and used to locate the nearest pond for which soil and water quality data were collected

TABLE 9. AVERAGES, STANDARD ERRORS, AND RANGES FOR CONCENTRATIONS OF WATER QUALITY VARIABLES IN ALABAMA CHANNEL CATFISH PONDS LOCATED ON SOILS OF THE BLACKLAND PRAIRIE, COASTAL PLAINS, AND MAJOR FLOOD PLAINS[1,2]

Category	Average ± SE	Range	Average ± SE	Range
	pH		TDS (mg/L)	
Coastal Plains	8.34±0.14 a[3]	6.7-10.4	212±18.5 a	44-395
Flood Plains and Terraces	7.71±0.23 b	5.65-10.10	310±41.5 a	77-700
Blackland Prairie	8.15±0.04 a	6.45-9.90	350±12.4 a	78-917
Saline water	7.95±0.11 b	7.25-8.65	3,246±496 b	1,086-5,778
	Specific conductance (µmhos/cm)		Total alkalinity (mg/L as $CaCO_3$)	
Coastal Plains	285±32 a	30-566	60.8±7.3 a	10-178
Flood Plains and Terraces	471±105.78 a	54-1,720	81.1±16.8 a	2-259
Blackland Prairie	500±19.07 a	52-1,504	116±3.5 b	8-257
Saline water	4,819±730.6 b	1453-9,820	128±22.4 b	32-280

continued

Table 9, continued. Averages, Standard Errors, and Ranges for Concentrations of Water Quality Variables in Alabama Channel Catfish Ponds Located on Soils of the Blackland Prairie, Coastal Plains, and Major Flood Plains [1,2]

Category	Average ± SE	Range	Average ± SE	Range
	Total hardness (mg/L as $CaCO_3$)		Calcium hardness (mg/L as $CaCO_3$)	
Coastal Plains	41.1±4.1 a	6.8-79.3	29.1±3.0 a	5.4-61
Flood Plains and Terraces	50.6±7.4 a	9.3-114	39.6±7.2 a	4.5-106
Blackland Prairie	99.0±3.3 b	11.3-235	87.2±3.1 b	9.2-228
Saline water	348±71 c	49.1-741	263±51 c	31.7-531
	Calcium (mg/L)		Magnesium (mg/L)	
Coastal Plains	11.6±1.2 a	2.1-24.4	2.9±0.2 a	0.34-6.42
Flood Plains and Terraces	15.8±2.9 a	1.8-42.4	2.6±0.2 a	1.18-4.47
Blackland Prairie	34.9±1.2 b	3.7-91.5	2.8±0.1 a	0.46-6.75
Saline water	105±20 c	12.6-212	20.6±5.0 b	2.35-51
	Potassium (mg/L)		Sodium (mg/L)	
Coastal Plains	8.6±0.9 a	1.1-20.2	36.6±5.1 a	4.9-104
Flood Plains and Terraces	13.0±1.9 ab	2.6-33.3	80.4±25.1 a	9.1-420
Blackland Prairie	13.8±0.6 b	1.2-49.8	70.0±3.8 a	6.3-290
Saline water	16.5±2.0 b	6.6-38.0	948±131 b	348-1,863
	Sulfate (mg/L)		Chloride (mg/L)	
Coastal Plains	4.5±1.4 a	0.0-45.8	54.8±8.9 a	3.2-199
Flood Plains and Terraces	11.7±3.1 a	0.0-42.3	130±35 a	4.4-503
Blackland Prairie	10.2±1.2 a	0.0-166	111±7.8 a	2.8-519
Saline water	9.5±5.8 a	0.08-83.7	1,584±233 b	439-3,087
	Iron (mg/L)		Manganese (mg/L)	
Coastal Plains	0.37±0.03 a	0.02-0.92	0.23±0.04 ab	0.01-1.13
Flood Plains and Terraces	0.86±0.17 b	0.17-3.17	0.40±0.19 ab	0.09-3.45
Blackland Prairie	0.40±0.03 a	0-3.39	0.13±0.01 a	0.02-1.42
Saline water	1.12±0.20 b	0.24-2.91	0.03±0.01 ab	0-0.12
	Zinc (mg/L)		Copper (mg/L)	
Coastal Plains	0.03±0.01 a	0-0.128	0.026±0.01 a	0.0-0.17
Flood Plains and Terraces	0.04±0.01 a	0.01-0.13	0.043±0.01 a	0.0-0.12
Blackland Prairie	0.07±0.01 a	0.01-1.47	0.04±0.01 a	0.0-0.52
Saline water	0.08±0.02 a	0.02-0.31	0.034±0.01 a	0.0-0.11
	Boron (mg/L)		TSS (mg/L)	
Coastal Plains	0.10±0.01 a	0.01-0.30	42.5±5.3 a	4.0-153
Flood Plains and Terraces	0.17±0.04 a	0.07-0.78	99.0±12.8 b	27.0-225
Blackland Prairie	0.13±0.01 a	0.05-0.55	62.0±3.7 a	6.0-917
Saline water	0.99±0.09 b	0.28-1.46	78.4±26.2 ab	15.0-340

[1] Numbers of ponds sampled were 159 in the Blackland Prairie, 30 in the Coastal Plains, and 14 in Major Flood Plains.

[2] In all three soil areas ponds were supplied saline water from wells and contained more than 1,000 mg/L total dissolved solids (TDS).

[3] Numbers followed by the same letter are not significantly different.

Table 10. Averages, Standard Errors, and Ranges for Concentrations of Soil Quality Variables in Alabama Channel Catfish Ponds Located on Soils of the Blackland Prairie, Coastal Plains, and Major Flood Plains[1]

Soil area	Average ± SE	Range	Average ± SE	Range
	Bulk density (g/cm^3)		pH	
Coastal Plains	1.03±0.10 a[2]	0.17-1.55	6.71±0.20 a	5.45-8.05
Flood Plains and Terraces	1.01±0.09 a	0.70-1.44	6.71±0.29 a	5.05-7.55
Blackland Prairie	0.84±0.08 a	0.27-1.34	7.49±0.07 b	6.70-8.10
	$CaCO_3$ (%)		Organic carbon (%)	
Coastal Plains	1.59±1.56 a	0.0-26.4	0.87±0.23 a	0.16-4.10
Flood Plains and Terraces	0.85±0.71 a	0.0-5.7	0.68±0.15 a	0.26-1.50
Blackland Prairie	9.06±2.70 b	0.0-35.2	1.08±0.12 a	0.31-1.92
	Total nitrogen (%)		C:N ratio	
Coastal Plains	0.07±0.03 a	0.0-0.50	23.7±5.3 a	5.4-75
Flood Plains and Terraces	003±0.01 a	0.003-0.06	19.6±3.9 a	6.7-36
Blackland Prairie	0.08±0.02 a	0.004-0.27	15.5±1.3 a	7.7-27
	Sulfur (%)		Calcium (mg/kg)	
Coastal Plains	0.03±0.01 a	0.0-0.15	1,521±444 a	76-6,663
Flood Plains and Terraces	0.02±0.01 a	0.0-0.03	1,046±383 a	214-3,275
Blackland Prairie	0.14±0.01 a	0.01-1.74	5,272±446 b	938-6,957
	Magnesium (mg/kg)		Potassium (mg/kg)	
Coastal Plains	124±32 a	8.2-470	71.3±20.8 a	8.0-364
Flood Plains and Terraces	72±14 a	21.8-123	65.4±15.2 ab	11.0-128
Blackland Prairie	107±18 a	45.4-377	119 ±12.0 b	31.0-215
	Sodium (mg/kg)		Iron (mg/kg)	
Coastal Plains	82.0±45.2 a	2.2-770	126±26 a	7-434
Flood Plains and Terraces	73.3±33.5 a	9.1-246	146±38 a	44-347
Blackland Prairie	247±52 b	29.6-768	30±10 b	4-154
	Manganese (mg/kg)		Zinc (mg/kg)	
Coastal Plains	102±21 a	3.6-301	3.18±0.79 a	0.57-13.53
Flood Plains and Terraces	123±47 a	8.0-346	1.82±0.21 a	1.03-2.74
Blackland Prairie	55.6±18.8 a	4.0-221	0.68±0.24 a	0.0-3.40
	Copper (mg/kg)		Boron (mg/kg)	
Coastal Plains	11.63±3.90 a	0.34-63.34	0.58±0.09 a	0.0-1.31
Flood Plains and Terraces	5.81±2.02 a	1.52-15.49	0.64±0.13 a	0.20-1.15
Blackland Prairie	2.09±0.96 a	0.0-15.22	0.47±0.09 a	0.0-1.34

[1] Numbers of ponds sampled were 33 in the Blackland Prairie, 17 in the Coastal Plains, and 8 in Major Flood Plains.

[2] Numbers followed by the same letter are not significantly different.

and recorded in the database. We recommend that the database provided by this study be used in this manner. Geostatistics of GIS could be applied to the data. This approach might allow more accurate predictions than could be obtained by comparing a “non-database” pond to the nearest “database” pond.

Water and soil samples were collected from 10 counties in west central Alabama. These samples provided a large amount of information because 18 variables were analyzed from each water sample and 16 variables were measured from each soil sample. The results provided a database for water quality and soil quality for catfish farms in west central Alabama. This database can be a useful tool in management of water quality and soil quality in catfish ponds in west central Alabama. In particular, fisheries extension personnel can use this database to better understand the basic water and soil quality of catfish ponds for which they must provide management information. This database can be interpolated to estimate the values for points in the area that were not actually sampled.

There are numerous interpolation techniques, but the three most common techniques are the Kriging, Spline, and Inverse Distance Weight (IDW) methods. GIS computer software like ArcView 3.2 has the interpolation capacity to estimate the unknown value from the known data points. Inverse distance weight (IDW) and the Spline method are default interpolation techniques available in ArcView 3.2. However, users need to download avenue script before they can work with the Kriging method.

The Inverse Distance Weighted (IDW) interpolator assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing cell greater than those farther away. A specified number of points, or optionally, all points within a specified radius, can be used to determine the output value for each location. The power parameter in the IDW interpolation controls the significance of the surrounding points upon the interpolated value. A higher power results in less influence from distant points. Each line in a barrier input line theme is used as a break that limits the search for input sample points. A line can represent a water or soil quality variable. A choice of no barriers will use all points specified in the number of neighbors or within the identified radius.

The Spline interpolator is a general purpose interpolation method that fits a minimum-curvature surface through the input points. Conceptually, it is like bending a sheet of rubber to pass through the points, while minimizing the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points, while passing through the sample points. This method is best for gently varying surfaces such as elevation, water table heights, or pollution concentrations. It is not appropriate if there are large changes in the surface within a short horizontal distance, because it can overshoot estimated values. The details on interpolation in ArcView 3.2 can be achieved from the program help topics.

CONCLUSIONS

● Prediction of soil and water quality in a pond based on location in a particular soil area is subject to considerable error because soil and water quality differed greatly among ponds in the soil areas of west-central Alabama.

● Ponds in close proximity are more likely to have similar soil and water quality than ponds located farther apart. For example, two adjacent ponds usually will be more similar in soil and water quality than ponds on adjacent farms, and ponds on neighboring farms are more apt to be similar in soil and water quality than ponds in adjacent counties. The geometric coordinates of each pond in the database of this study,were determined by GPS and recorded at the time of sampling. These coordinates have been entered along with soil and water quality data for each pond on computer spreadsheets. Thus, if it is desired to refer to the database to predict soil and water quality characteristics for a pond not included in the database, the pond in the database most likely to be similar is the nearest one. The coordinates of the “non-database” pond can be determined by GPS and the soil and water quality data for the nearest “database” pond can be obtained from computer files.

● The water soil and water quality conditions identified by this study that deserve attention in pond management considerations are listed below:

–Low total alkalinity
  Indication: Total alkalinity less than 50 mg/L
  Problems: Difficulty achieving plankton blooms; unstable water quality; greater possibility for fish toxicity following copper sulfate treatment; low morning pH and high afternoon pH because of low buffering capacity

–High total alkalinity and low total hardness
  Indication: Total alkalinity concentration twice or more the concentration of total hardness
  Problems: Excessively high pH in afternoon; greater likelihood of ammonia toxicity

–Low total dissolved solids (TDS)
  Indication: TDS concentration less than 100 mg/L
  Problems: Low total alkalinity and associated problems; possible physiological imbalances in fish

–Saline water
  Indication: TDS concentration above 1,000 mg/L
  Problems: High alkalinity; high pH; greater tendency for blue green algae blooms

–Acidic bottom soils
  Indication: soil pH less than 7
  Problems: Low alkalinity water and associated problems; low benthic productivity; possible accumulation of organic matter in bottom soil

–Low clay content
 Indication: Clay content of bottom soil less than 20 percent
 Problems: Pond bottom soil deficient in nutrients; low ability to assimilate wastes
–Low bulk density
 Indication: Dry bulk density of bottom soil less than 0.5 g/cm^3
 Problems: Poor bottom soil quality; soft sediment and associated problems

● Although ponds do not have high concentrations of organic carbon, some ponds have dark colored soils and very soft sediment. Whenever ponds are drained for harvest, their bottom should be dried to promote oxidation of reduced substances and sediment accumulations should be removed.

● Although sodium chloride additions to ponds have not resulted in chloride concentrations greater than the Alabama Department of Environmental Management (ADEM) in-stream chloride standard of 230 mg/L *(34),* some ponds filled by water from saline aquifers contained more chloride than allowed by ADEM rules. These ponds could violate in-stream chloride standards when drained.

● Soil texture is extremely variable in west-central Alabama. Results of this study suggest that ponds with moderate concentrations of clay (20 to 30 percent) have superior soil and water quality. This finding should be considered when seeking sites for construction of new ponds or farms.

● The practice of seine-harvest and retaining water in ponds appears sustainable. Bottom soil organic matter concentrations are not becoming excessive, and other soil quality is generally good.

● Measurements of specific conductance with a portable conductivity meter could provide much information on general water quality characteristics, for specific conductance was strongly correlated with several other water quality variables.

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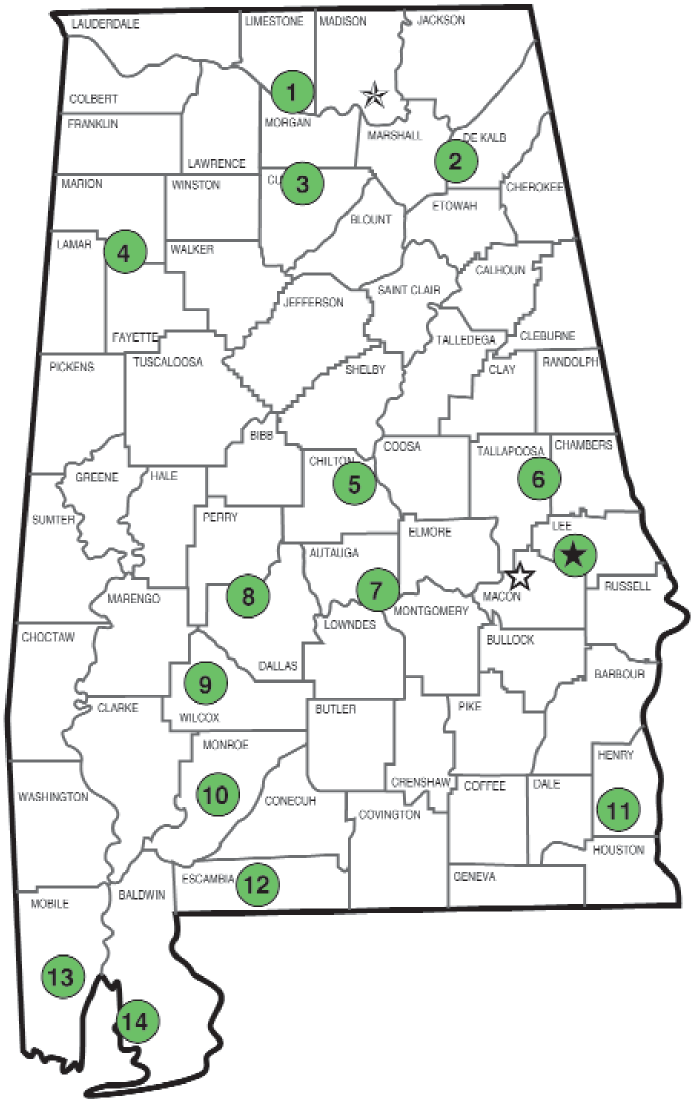

Research Unit Identification

★ Main Agricultural Experiment Station, Auburn.
✯ Alabama A&M University.
☆ E. V. Smith Research Center, Shorter.

1. Tennessee Valley Research and Extension Center, Belle Mina.
2. Sand Mountain Research and Extension Center, Crossville.
3. North Alabama Horticulture Research Center, Cullman.
4. Upper Coastal Plain Agricultural Research Center, Winfield.
5. Chilton Research and Extension Center, Clanton.
6. Piedmont Substation, Camp Hill.
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11. Wiregrass Research and Extension Center, Headland.
12. Brewton Agricultural Research Unit, Brewton.
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