TRC9601

Guidelines for Selections of Pipe Culverts

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Final Report

1999

DURABILITY STUDY OF VARIOUS CULVERT MATERIALS

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ARKANSAS HIGHWAY AND TRANSPORTATION DEPARTMENT

April 1999

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/AR-98-007		

4. Title and Subtitle
GUIDELINES FOR SELECTION OF PIPE CULVERTS

5. Report Dat April 1999

6. Performing Organization Code
0402-12003-21-1054

7. Authors
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8. Performing Organization Report No.

9. Performing Organization Name and Address
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10. Work Unit No. (TRAIS)

11. Contract or Grant No.
TRC-9601

12. Sponsoring Agency Name and Address
ARKANSAS STATE HIGHWAY & TRANSPORTATION DEPARTMENT
P. O. BOX 2261
LITTLE ROCK, AR 72203

13. Type of Report and Period Covered
FINAL REPORT
1 July 1995 - 30 June 1998

14. Sponsoring Agency Code

15. Supplementary Notes
THIS STUDY WAS CONDUCTED IN COOPERATION WITH THE U. S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION

16. Abstract
The Arkansas State Highway and Transportation Department (AHTD) funded a study to determine if the durability of culvert pipes could be correlated with certain variables. Fifty-one sites in 9 of the 10 AHTD districts were investigated. Culvert materials included galvanized corrugated metal pipe (CMP), 19 sites; bituminous-coated CMP, 13 sites; concrete, 6 sites; aluminum CMP, 4 sites; aluminized CMP, 2 sites; and plastic, 3 sites. The measured variables (culvert material type, water pH, soil resistivity, soil potential, and culvert age) were selected to describe the both soil-side and the aqueous corrosion that can affect the culvert. Atmospheric corrosion was assumed to be negligible. In no cases were unusually aggressive pH values found in the waters flowing through these culverts. A statistical analysis showed a weak correlation involving the culvert age and the water pH for the bituminous-coated CMP. This test was significant at the 0.05 level. Correlations were not found for galvanized CMP, and for other types of culverts no statistical analysis was possible because of the limited number of data points. Although no statistical correlations were possible, "engineering" conclusions include:
(1) concrete culvert pipes hold up well under all conditions observed,
(2) galvanized CMP seems suitable for "dry stream" application, but in a "wet stream" extensive damage may take place in fewer than 10 years,
(3) bituminous or polymeric coatings add from 5 to 20 years to the life of galvanized CMP,
(4) plastic, aluminum, and aluminized CMP stand up well in all environments observed.

17. Key Words
Pipe, Culvert, Corrosion

18. Distribution Statement
NO RESTRICTIONS. THIS DOCUMENT IS AVAILABLE FROM THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VA. 22161

19. Security Classif. (of this report)	20. Security Class. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	147	N/A

Notice

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Arkansas State Highway and Transportation Department.

Acknowledgments

This report is the product of research conducted for the Arkansas Highway and Transportation Department (AHTD) under contract TRC 9601. The research was conducted within the Departments of Chemical Engineering and Civil Engineering at the University of Arkansas.

The authors wish to acknowledge Mr. Walter Brown and Mr. Harold Watson for their contributions to this effort. Special recognition is given to James Sanders of the Research Division of the AHTD for his efforts as project coordinator.

Abstract

The Arkansas State Highway and Transportation Department (AHTD) funded a culvert pipe research project to determine if a correlation could be found among the variables water pH, soil resistivity, soil potential, culvert age, and culvert corrosion. This paper shows the results of that study.

Fifty-one sites were investigated throughout the state of Arkansas, with 9 of 10 AHTD districts represented, District 8 was the exception. Uncoated corrugated metal pipe (CMP), or galvanized CMP, was the most represented with 19 out of the 51 sites. Bituminous-coated CMP provided 13 sites. These two types of culverts provided enough data for a limited statistical analysis. The other types of culverts inspected, with the quantity in parentheses, included: concrete (6), aluminum (4), aluminized CMP (2), poly-coated CMP (4), and plastic (3).

The measured variables were chosen to describe the two types of corrosion that can affect the culvert. These two types are soil-side and aqueous corrosion. Atmospheric corrosion was assumed to be negligible. Water pH measurements were taken to quantify the affect of the acidity or basicity of the water that was flowing through the invert section of the culvert. In no cases were unusually aggressive pH values found. Soil resistivity and potential were measured to show the effects of soil-side corrosion. Culvert age was also a variable that was included in the study because of its obvious effect on corrosion.

Statistical analysis on uncoated and bituminous-coated culverts showed a weak correlation involving the variables of culvert age (years) and water pH for the bituminous-coated CMP. This test was significant at the 0.05 level.

Although no statistical correlation was possible, "engineering" conclusions include: (1) concrete culvert pipe holds up well under all conditions observed, (2) galvanized CMP seems suitable for "dry stream" applications, but in a "wet stream" extensive damage may take place in fewer than 10 years, (3) bituminous or polymeric coatings add many years to the life of galvanized AMP, (4) plastic, aluminum, and aluminized CMP stand up well in all environments observed.

In addition to the field work, a survey of 50 state departments of transportation was conducted. Responses received from 36 states are tabulated in Appendix A.

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1.0 Problem Statement

There are many types of pipes that have been used or currently are used by the Arkansas State Highway and Transportation Department. These types include reinforced concrete, plastic, and corrugated metal pipe of aluminum or steel with various coatings such as zinc, aluminum, asphalt and polymer. It is generally recognized that the relative performance of pipe culverts changes with the variations of environmental parameters (such as pH. resistivity, flow velocity, bed load), construction quality and hydraulic conditions. In order to determine the service life and cost effectiveness of different pipe culvert types it is necessary to look at cost, application, hydraulic performance, location, corrosion and structural qualities. A detailed evaluation of pipe culverts used in Arkansas is needed in order to make an objective selection of pipe culverts.

AREA OF STUDY: The project will focus on developing data and criteria from which a practical, objective selection of pipe culvert type can be made. The primary effort will be a review of other State highway agencies' experiences to develop a framework for comparing pipe culverts. This framework will be used with data collected from a field review of existing pipe culvert installations throughout the State, to determine the service life and cost effectiveness of different types of pipe culverts used by the Department. To the extent possible, this review will include a statistically significant sample from pipe culvert types used by the Department. The objective of this review is to check pipe culvert type, age and condition and to gather data on the environmental parameters at the pipe culvert site.

METHOD OF STUDY: The initial effort would center on evaluating information available from the literature review of similar studies by other states and private concerns. Applicable data and information will be used as a starting point for the project. Based on the field review data a correlation will be developed relating culvert type and environmental parameters to culvert life. The evaluation of this data should determine relative performance criteria for objective selection of pipe culverts. The final product should be a manual or guide for use in the objective selection of pipe culvert types and equivalent alternatives.

2.0 Introduction

Culverts, which cross under roadways, are used for transporting and directing surface water from one area to another. Proper installation, corrosion, abrasion, and erosion affect the usefulness of culverts by shortening the culvert's life span or service life. The service life of a culvert can be affected by different environmental conditions. For this reason, the appropriate culvert material along with the proper coating should be used.

Culvert materials should be chosen after considering many different factors which include the durability, the aesthetic, and the economic aspects of the culvert. Durability coupled with the lowest cost, which includes purchasing, installing, and maintaining the culvert provides the best culvert. When the wrong type of culvert is installed, money is lost. Sometimes culverts are installed and do not perform up to the expected service life. Other times just the opposite happens; the culverts exceed the expected life.

Both of the above mentioned situations can result in economic loss. The former is fairly obvious. Along with the expense of reinstalling a new culvert years later, inconvenience for the traffic using the road over the culvert must be considered. If the cross drain is under a high-traffic road, then the traffic must be delayed or diverted while the reinstallation takes place.

The second case is not quite as obvious. A corrosion problem can always be somewhat solved by using a more durable and longer lasting material. But if the culvert site has a low traffic volume, then the inconvenience of rerouting traffic during a period for culvert replacement is not as great. A less expensive culvert type might give the durability needed, since the culvert can be replaced more often. If this is the case, then installing a longer lasting, more expensive culvert might be inefficient.

In this project 51 culverts, throughout the State of Arkansas were studied. The condition of the culvert was assessed and soil resistivity, water pH, and soil potential were measured. Since the culvert rating system is inherently subjective, video recordings were made to describe the corrosion. Seven different types of culvert material were investigated; galvanized steel, bituminous-coated galvanized steel, polymer-coated galvanized steel, aluminized metal, aluminum, concrete, and polyethylene. Although other materials were included in the background section, these types are the most commonly used culverts in Arkansas.

3.0 Background

Corrosion as defined by *Durability of Drainage Pipe* [1] is the "deterioration or dissolution of or destructive attack on a material by chemical or electrochemical reaction with its environment." Corrosion, however, is not the only cause of failure for culverts. In many cases, corrosion may be associated with abrasion and/or erosion to produce greater deterioration than if corrosion were the sole factor. The definition of erosion or abrasion is "the wearing or grinding away of material by water laden with sand, gravel, or stones." [1]. Erosion/abrasion of culverts can strip the protective coating away, which then leads to accelerated corrosion.

Culverts are typically exposed to corrosion in three different environments: atmospheric, soil-side, and aqueous. The different types of corrosion are shown in Figure 1. Deterioration of the portion of pipe that is exposed only to atmospheric corrosion is generally insignificant compared with that exposed to the other environments. Many studies have been done to determine the impact of the individual variables responsible for corrosion in the underground, soil-side, and aqueous environments [6].

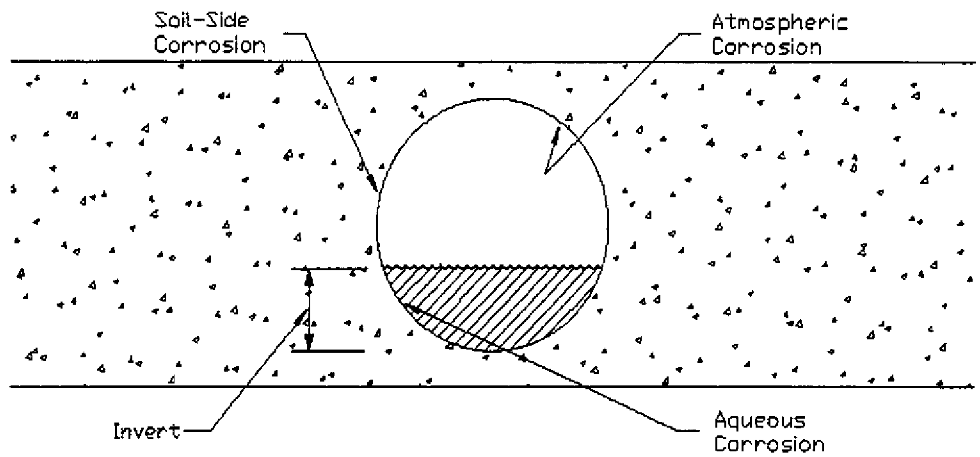


Figure 1. The different types of corrosion that can cause culvert failure

3.1 Soil-Side Corrosion

Major variables in soil properties that influence the soil-side corrosion include: texture and structure, moisture content, aeration and oxygen diffusion, and chemical make-up. The texture and structure of soil are perhaps the most important characteristics affecting soil-side corrosion because they can influence many of the other variables. For example, a dense soil, such as clay, may result in a high moisture content compared with a sandy soil that drains rapidly. Without moisture, corrosion will not occur; and as the moisture content increases, the corrosion rate should increase. Fluctuations of soil moisture often occur seasonably and thus have a far worse effect on culvert pipes than would a constant soil moisture content. This is because a protective coating can not be formed when these fluctuations occur.

Aeration influences the moisture content in the soil. The better the aeration of the soil, the less corrosive. However, as the aeration increases the oxygen content of the soil usually increases. This effect promotes corrosion. The report from the Federal Highway Administration notes "soil-side corrosion is complex but usually not significant factor in pipe life except in very arid, sandy regions where rainfall is minimal" [7].

Heavy organic soils can lead to the growth of anaerobic bacteria that can devastate both ferrous metals and concrete. A study from the State of Wisconsin have found that for culvert pipes inspected since 1972, anaerobic sulfate reducing bacteria were a contributing factor in 31% of the corrosion of galvanized steel [8]. Anaerobic corrosion usually occurs in more neutral soils (higher than pH 5.5). Acidity refers to the pH of the water; if below 6.0, the water is considered acidic. At a pH above 8.0 water is considered basic. Most soils have pH in the range of 5.0 to 8.0, but this can be changed by the leaching of naturally occurring anthropogenic acid or alkaline materials. In addition, some forms of atmospheric pollution, e.g. acid rain, can cause a higher soil acidity.

Soluble salts can be leached from the soil by heavy rainfall, but in dry environments salt concentrations may be high. Soils that are high in acidic salts (i.e., chlorides or sulfates) tend to accelerate metallic corrosion while alkaline salts can produce a protective coating on the metal surface. Soil resistivity can also effect corrosion rates. Resistivity increases as the soil deepens [1]. Higher resistivity tends to result in lower corrosion rates and thus greater durability. Soil types and how they relate to corrosiveness in various culvert types are given in Table 1. Resistivity values for the primary types of soil are contained in Table 2.

Table 1. Soil properties as they relate to corrosion [9].

Soil Type	Description of Soil	Aeration	Drainage	Color	Water Table
I Lightly Corrosive	1. Sands or sandy loams 2. Light textured silt loams 3. Porous loams or clay loams throughly oxidized to great depths	Good	Good	Uniform color	Very low
II Moderately Corrosive	1. Sandy loams 2. Silt loams 3. Clay loams	Fair	Fair	Slight mottling	Low
III Very Corrosive	1. Clay loams 2. Clays	Poor	Poor	Heavy texture, moderate mottling	2 - 3 feet below surface
IV Unusually Corrosive	1. Muck 2. Peat 3. Tidal marsh 4. Clays and organic soils	Very Poor	Very Poor	Bluish-gray mottling	At the surface

Table 2. Resistivity of common soils [9].

Classification	Resistivity (ohm-cm)
Clay	750 - 2000
Loam	2000 - 10000
Gravel	10000 - 30000
Sand	30000 - 50000
Rock	50000 - Infinity*

*-Theoretical

3.2 Water-Side Corrosion

Corrosion caused by water, in the invert section of the pipe, is generally of greater concern than is soil-side corrosion [6]. The invert section is usually defined as the lower third of the culvert. Water marks are prevalent in this section. Variables which influence aqueous corrosion of the inner pipe include: dissolved gases, mineral constituents, acidity, flow rates, and temperature of the effluent flow [6].

The various dissolved gases in the effluent impact corrosion rates in different ways. Dissolved oxygen is probably the most significant in determining the rates of corrosion of ferrous alloys. At a pH range of 6 to 9, the oxygen content generally controls the corrosion rate. In acidic conditions, the corrosion of ferrous metals is rapid and independent of oxygen content. In basic conditions, aqueous corrosion will not take place whether or not oxygen is present. Carbon dioxide controls whether a calcium carbonate protective layer can be formed, but if carbon dioxide is present in large quantities, then the corrosion rate will be accelerated due to the production of carbonic acid. Hydrogen sulfide is corrosive regardless of the presence of oxygen. Sewage, runoff from high sulfur soils, or runoff from some agricultural operations such as feed lots or large scale swine production, can result in the presence of dissolved hydrogen sulfide in the water.

Some mineral ions in the water, such as chlorides, nitrates, and sulfates negate the usefulness of protective films, thereby increasing the corrosion rate. At the other extreme, calcium and bicarbonate ions tend to decrease the rate of corrosion by forming a protective layer on the inside of the pipe. Since hard waters contain calcium or magnesium ions, the corrosion rate decreases when compared to soft waters. In general, low or high pH values tend to result in higher rates of corrosion. Low pH waters will corrode: steel, galvanized steel (at a slower rate), cast iron, aluminum, copper, lead, and concrete. High pH waters corrode concrete, the zinc layer on galvanized steel, and aluminum.

Effluent flow has a three-fold effect in the deterioration of culverts. Water at high velocities tends to remove the protective coating along with providing a replenishing oxygen source, and the corrosion rate is increased by both of these effects. Also, high velocity water can cause abrasion to the inside of the culvert by carrying sand and rocks.

At higher temperatures the corrosion rate is accelerated because of the chemical reaction that occurs. An increase in temperature helps with the solubility of minerals, which helps corrosion take place. Since gases are less soluble, the temperature effects on corrosion will be reduced as dissolved oxygen becomes less available [6].

3.3 Pipe Materials

Corrosive conditions impact the durability of culvert pipes in different ways. Not only can severe corrosion destroy the pipe, but in some cases smaller amounts of corrosion damage may result in premature mechanical failure. The scope of the literature survey is to determine if correlations exist between the field conditions and the culvert service life. Corrosion not only shortens service life but increases re-design time, re-installation time, and overall cost.

Today's culvert pipes are often manufactured from one of four materials: corrugated steel, aluminum, concrete, or a synthetic polymer (typically polyethylene or polyvinyl chloride). Other culvert pipe materials that have been used in the past (and are occasionally used today) are vitrified clay, stainless steel, and cast iron [1]. This survey will deal mostly with the first four types, as those materials are the most commonly used.

3.3.1 *Corrugated Metal Pipe (Galvanized)*

Corrugated metal pipe (CMP) has been used since 1896 [9]. Although many different replacement materials have been tried, CMP has remains popular because of its strength, durability, and cost. The composition of the steels used for CMP has been slightly changed over time for workability and structural improvement, but generally this does not make a significant difference in the overall corrosion rate [1]. Usually, soil-side corrosion is not a problem with CMP, and with the correct selection of a particular coating just about any service life can be achieved [9]. In general, CMP performs well in soils with high resistivity and moderate pH values of 6 to 8. A moisture content of over 20% is corrosive, but soils that drain rapidly like grainy soils enhance durability [9]. Chlorides and sulfates can increase soil-side corrosion, while insoluble carbonates or hydroxides can form a protective coating which decreases the rate of corrosion [9].

CMP is almost exclusively used now with a galvanized (zinc) coating. In this paper, galvanized steel pipe will be referred to as CMP. More information is given in the metallic coatings section under galvanized and galvannealed.

3.3.2 *Aluminum*

Aluminum pipe has been available since 1960 [1]. Soil resistivity and pH values are important when determining the useful life of aluminum culverts. Aluminum is best suited for neutral to mildly acidic environments. In organic soils, aluminum performs better than would be expected, though. High alkaline values also increase corrosion [1]. The general consensus of the studies done for Arizona, Georgia, Montana, Washington, and Virginia is that aluminum culvert pipes are suitable for use in soils having a pH between 5 to 9 [1, 11]. In these states differences in soil resistivity so long as it remained greater than 500 ohm-cm were not significant. Studies from California and Oregon have determined that resistivities of 2000 and 1500 ohm-cm, respectively, are required if aluminum pipes are to give satisfactory service at pH values of 5 to 9[1]. Tennessee studies have determined that a pH range of 4 to 9 with a minimum resistivity of 500 ohm-cm is acceptable [14]. Even in the correct range of pH, rapid corrosion can take place if heavy metals ions (copper, iron, etc.) are present. Abrasion can have a significant effect on the performance of aluminum pipe and the proper coating should be utilized [1].

Field studies from the State of Maine, which concluded that aluminum alloy culverts had the best durability of the metal pipes, have shown no appreciable deterioration of the culverts that are 11-32 years in age [15, 13]. A report from Wisconsin shows that if based on corrosion performance alone, aluminum pipe can be used in most of Wisconsin environments [16]. A conservative estimate from the Arizona Department of Transportation says the service life of this type of culvert is 50 years. They cited that aluminum culverts have been in place for 25-28 years, and there have been few signs of corrosion [11].

3.3.3 *Reinforced Concrete*

Concrete is highly resistant to most chemicals but can deteriorate badly when in contact with an acidic environment, such as runoff from wooded swampland [13]. A pH value of below 5 allows rapid deterioration of the concrete since concrete is basic, having a pH of 13 [13, 1]. For increased protection of concrete in an acid environment, a calcareous aggregate can be supplied for backfill [1]. Reports from Maine have estimated that the service life for concrete culverts is 65-70 years if used in environments of greater than 5.3 pH [13].

Arizona studies have given a service life of 100 years to concrete culverts. They identify three potential problems that must be tested before installing concrete culverts: (1) the soil pH is less than 5, (2) there is a high sulfate level in the soil, (3) the flow velocity of the effluent is over 40 ft/sec. In most cases if these conditions exist, a protective coating should be applied. In high velocity flows, a protective coating should be applied or the design engineer should evaluate the use of high density polyethylene [11].

Missouri has stopped using galvanized steel pipe in favor of reinforced concrete. After looking at replacement costs, installation costs, ease of maintenance, etc., they have decided that concrete performs better in their environment, although not much detail is given of their environment, than galvanized steel [10].

3.3.4 *Plastic*

Although different metals respond differently to corrosive conditions, all metal alloys used in culvert pipes are affected by corrosion [1]. Because of this, plastics have developed into a viable alternative in culvert selection. Plastics are being used more because of their high tolerance to severe environments. They are very resistant to corrosion in pH ranges of 1.25 to 14. Low resistivity values also do not harm their performance [11].

Some studies have concluded that concentrated bases and acids can soften or stress-crack plastic culverts. It should be noted, however, that most often these concentrations are the result of chemical spills rather than natural runoff [1].

Potential problems that might develop with plastic pipes include: abrasion causing degradation, ultraviolet exposure, fire exposure, and deflections. Plastic culverts perform well under slightly abrasive conditions, small rocks at moderate flow rates [1]. When the pipe is under severe abrasive conditions, the plastic pipe can possibly fail. Ultraviolet degradation becomes a problem when plastic pipe is exposed to sunlight for long periods of time. Fine carbon black fill is ordinarily combined with the plastic to offer UV resistance. Also, since usually only the ends are exposed to sunlight, head walls can be designed to provide protection. Plastics are flammable and may be vulnerable to grass fires [1]. Reports show that Maine Department of Transportation has noticed deflections and movements of some of their polyethylene pipe. This is assumed to be caused by improper backfilling procedures [15]. Since polyethylene pipe is flexible, proper backfilling is crucial to the effectiveness of the culvert.

3.3.5 *Vitrified Clay, Stainless Steel, and Cast Iron*

Clay pipe used to transport water has been found in Crete in structures estimated to be over 5000 years old [1]. Vitrified clay, made by heating and fusing together clay and shales at high temperatures, is resistant to corrosion because of its inertness. Structural strength and ease of abrasion currently limits its use.

A Pennsylvania study reports that stainless steel can be used for deep mine culverts because of its ability to withstand environments of pH ranges 2.7 to 3.8. A Colorado study has determined that certain alkaline soils rapidly corrode stainless steel, probably because of chloride salts present in the soil. Abrasion resistance of stainless steel is far superior when compared to carbon steel and galvanized steel [1].

After extensive studies by the National Bureau of Standards, they determined the maximum service life is attained when installed in an environment of pH range 4 to 8.5 and a resistivity greater than 1500 ohm-cm. Also sulfates should not be present. Mississippi has had good performance from cast iron culverts in a pH range of 5.5 to 8.5 [1].

3.4 Non-Metallic Coatings or Linings

If a specified culvert type would not be expected to provide the required service life, a protective coating or lining can be applied. Both metallic and non-metallic coatings are available. The non-metallic coatings that are available include: bituminous, bituminous paved, asbestos bonded-bituminous, polymer, epoxy, mortar, fiberglass, and clay [1]. Metallic coatings will be discussed in the next section.

3.4.1 *Bituminous Coating*

Bituminous coatings have almost become the fix-all for increasing the culvert's service life. First used by the Egyptians more than 4000 years ago, bituminous coatings can prove to be economical. How economical depends solely on each individual state [1]. Bituminous coating is most often applied to (both sides of) corrugated iron and steel, but it has also been used with aluminum, stainless steel, and concrete pipe.

Bituminous coatings provide greater protection against soil-side corrosion than to invert-corrosion [1, 7]. The AISI *Handbook of Steel Drainage and Highway Construction Products* predicts (based on California studies) that an additional 25 years of service life can be added when soil-side corrosion is the dominating factor. Arizona uses bituminous coatings on metal pipe when the soil resistivities are less than 2100 ohm-cm. Oklahoma uses bituminous coatings on metal culverts to assure a 50 year service life [17]. Another report states that New York has concluded that bituminous coatings increase the service life of galvanized steel significantly [12]. A study from Alabama concluded that bituminous-coated galvanized pipe has at least a 25 year service life in corrosive environments. A Florida report estimates that bituminous coatings increase the effective life of galvanized steel for an additional 10 years. Reports show, that for Kentucky sites with acid soils of pH 3.5, the use of bituminous-coated galvanized steel can be expected to achieve a service life addition of 3 to 6 years. Uncoated galvanized steel culverts at these very aggressive sites had previously given a service life of one month. Studies conducted in Maine show a good life span of bituminous-coated pipe in soils with resistivites more than 2400 ohm-cm [15].

Studies in Tennessee, Maryland, and Kansas reported limited increase in service life. The reasons were mainly lack of adhesion and rapid corrosion after the effects of abrasions on the bituminous coating. Kansas has discontinued bituminous coatings altogether because of their lack of adhesion to the culvert pipe. They state that the loosening of the coating could have been caused by the constant change in the moisture level of the clay soil inside the culvert [12]. Studies from Wisconsin conclude that the bituminous coating on "both galvanized steel and aluminum pipe has performed very poorly" [16]. Ohio reports bituminous coating performed adequately except for conditions of abrasion under high effluent flow capable of carrying abrasive material [17].

Since adhesion is essential to the bituminous coating process, the culvert should be carefully cleaned before the coating is applied. Field repairs, if necessary, should be made on-site to any bare metal [1].

3.4.2 *Bituminous Paved Coating*

Paving of the bituminous-coated culvert pipe adds protection for highly abrasive bedloads. First used in 1925, bituminous-paved galvanized steel pipes have an additional life of 25 to 30 years over uncoated galvanized steel [7]. A Florida report shows bituminous-paved culverts have an extended service life of 28 years [1]. A New York revision of an existing study indicates an additional 25 years onto the service life. A State of Maine report predicts a service life of 40 years for 14 gauge bituminous-paved corrugated metal pipes [13]. In an Oklahoma study, when comparing polymeric coatings with bituminous pavements, polymeric coatings did not give good service when sharp, angular rocks and high effluent velocities were present [17].

The edges of the pavement as it extends upward on the inside of the pipe are the least resistant to the corrosion-abrasion effects of the effluent. Special care should be taken to protect this area of the culvert [1]. Further problems can occur at the ends of the culvert where the pavement can develop large cracks due to sunlight and temperature extremes [1].

3.4.3 *Asbestos-impregnated Bituminous Coating*

First used in 1936, asbestos-impregnated bituminous coatings have been useful in highly corrosive-abrasive environments. Asbestos fibers help tighten the adhesion of bituminous coatings but will not be abrasion resistant themselves; however, the usual abrasion rate is decreased because of the extra adhesion [1]. Studies in Louisiana, Ohio, Utah, and Washington have reported success with asbestos-impregnated bituminous coatings in reducing the abrasion effect when compared to plain bituminous coated metal pipe. The reason given is the good adhesion of the asbestos-impregnated bituminous coating [1]. In acid, alkaline, or brackish water environments, asbestos-impregnated bituminous coated metal pipe provides a longer service life than the unpaved bituminous coated metal pipe [1]. Health concerns associated with asbestos fibers will probably limit the use of these coatings.

As a replacement to the asbestos-impregnated bituminous coating, an armid fiber bonded coating has been suggested. Louisiana has conducted laboratory tests on both coatings bonded to galvanized steel, and the armid fiber bonded did not perform as well. In 1991, a field performance of the two was started, but the results have not yet been documented [7].

3.4.4 *Polymer Coating*

The structural strength of steel and the durability of plastics can be enjoyed by coating steel with a heavy 10 mil polymer or plastic [18]. A number of states have had favorable results from their studies. The Pennsylvania Department of Transportation conducted laboratory tests comparing asphalt, asbestos-impregnated asphalt, and polymeric coatings on corrugated steel pipe. Polymeric coating was shown to be the best coating [1]. In sandblast tests, a 12-mil-thick polymer coating equaled a 50-mil-thick asphalt coating in abrasion resistance [1]. A Wisconsin study reports that polymeric coated pipe can be used in sites that have high corrosion rates and moderate abrasion flow [16]. Tennessee DOT has authorized polymer coating to be applied if the culvert's environment falls outside of the pH and resistivity guidelines of galvanized steel and aluminum pipe [14]. A Maine study has reported that in a case in which the coating had been removed from the edges (either by construction or by cutting of the pipes), the bare metal edges do not show any signs of corrosion in the 6 year old pipe [15]. Oklahoma DOT recommends the use of polymer coated culverts in areas of moderate to severe corrosion and/or abrasion. They also note that the outside of the pipe should be polymer coated in acid soil regions to prevent soil-side corrosion [19].

Three polymer coatings have been used. The add-on service lives are approximately 7,9, and 30 years for coal tar base resin (Nexon), poly-vinyl chloride (PVC) plastisol (Beth-Cu-Loy), and ethylene acrylic acid film (DAF 625), respectively [7, 18]. It should be noted, however, that abrasion could reduce the service life. If abrasion does occur, it usually shows an effect in the first 2 years [7].

3.4.5 *Epoxy Coatings and Linings*

Since epoxy coated culverts are only steel pipe and not galvanized steel pipe, epoxy coated culverts do not have a long service life [7]. Published information estimates a service life of 5 years [7]. Wisconsin DOT only allows epoxy coated pipe as equalizers at sites that have very little current flow [16]. Sites in New York and Vermont that are under heavy bedloads have shown coating damage and rusting of the invert in a period of 5 to 8 years [7]. Documents from

Kentucky and Maine have reported some success in epoxy coated culverts. In Kentucky, a highly acidic site (pH 3.5 to 5.5) has been in service over 13 years with no traces of abrasion or corrosion. The epoxy coating at this site was at least one foot above the invert [1]. In Maine, an epoxy coated reinforced concrete pipe has performed well with no signs of deterioration in its service life of under 14 years [15].

3.4.6 *Mortar, Cement-mortar, Fiberglass, and Clay Coatings and Linings*

These coatings or linings are not used routinely in the United States. European countries such as Hungary and Poland use multi-layers of hand applied mortar as a protective coating on the inverts of concrete culverts. In the United States, labor costs make this coating uneconomical. Cement-mortar linings help protect concrete and metal pipes. This is only used as a repair method. Fiberglass coatings on concrete pipe and box culverts have been experimentally tried in Idaho with unsuccessful results. Since clay is one of the most inert materials that is readily available, clay linings are protective in acid environments, especially runoff. The procedure to make clay lined pipe has high labor costs and makes this type of culvert uneconomical [1].

3.5 Metallic Coatings

A thin layer of a metallic coating helps increase the durability of the metal culvert. Although usually highly susceptible to abrasion, the corrosion resistance is increased. Metallic coatings include: galvanized, galvannealed, aluminized, and aluminum-zinc cladding.

3.5.1 *Galvanized and Galvannealed*

The galvanizing of steel culverts was first used in 1907 to improve the corrosion resistance of corrugated steel pipe. Galvanized corrugated metal pipe has gained wide acceptance since this time [1]. Although it is widely used, this type of culvert should not be installed in highly acidic and basic environments or at intensely abrasive sites [1]. A report from Tennessee suggests that the limits should be a pH range of 6 to 10 and a minimum resistivity of 3000 ohm-cm for maximum service life [14]. Arizona and Montana transportation departments have authorized the use of galvanized steel pipe in a pH range of 6.0 to 9.0, with the Arizona DOT also requiring a minimum resistivity above 2000 ohm-cm [11, 1]. However, the report from Montana did show that the zinc coating, at one installation in a soil of pH 10, was completely corroded away; but, the resulting corrugated steel pipe was corrosion free [1]. After 8 years of service, a galvanized steel culvert that was installed in soil consisting of silts and clay in Oklahoma was in generally good condition with moderate rust and light pitting. They did note that abrasion from small gravel was a concern [20].

Missouri and Wisconsin documents show the reduced role of galvanized steel culverts in their respective states. A report from Missouri notes that reinforced concrete is far better when considering average service life in their soils [21]. A study conducted by Wisconsin shows that galvanized steel has been limited to sites that are mostly dry and known to be non-corrosive [16]. While Missouri and Wisconsin transportation departments have limited its use, South Carolina DOT has stopped using galvanized steel culverts altogether. They cite their high acidity soils, which corrode the outer wall, as the reason [22].

The *Handbook of Steel Drainage and Highway Construction Products* shows that the invert (lower inside of the pipe that is exposed to the effluent) is the part of the pipe that is most susceptible to corrosion. Invert corrosion occurs rapidly when the pH value is lower than 4.5, but a soil or water pH of 6 to 9.5 is the generally accepted range for selection of CMP [1]. The effluent affects the corrosion rate by preventing a protective layer from forming. Dissolved salts in the effluent can have a increasing or decreasing effect on the corrosion rate. Salts that ionize on the pipe decrease resistivity thereby increasing the rate of corrosion. On the other extreme, the dissolved salts can lower oxygen solubility which decreases the corrosivity of the effluent [9]. Also abrasion concerns start when the effluent velocity exceeds 7 ft/sec [11].

Specific cases in determining factors of corrosion are viewed differently in many states. Reports from Oklahoma show that in locations dominated by limestone (calcium carbonate) the corrosion process is retarded because of the protective layer that is formed, while locations dominated by salts show rapid deterioration [12]. Studies from Minnesota, Iowa, and Nebraska have determined that keeping culverts dry, especially in acid soils, equates to a long service life [12]. In Maine, the service life of CMP was determined to be 28 years. Although soil resistivity did not have much effect, water pH, age of the culvert, and effluent flow had a considerable effect on the corrosiveness of CMP [13].

Galvannealed steel has an outer surface alloy made of iron and zinc, as compared to just zinc-coated steel which is called galvanized steel. As one would expect, the corrosion resistance is approximately the same for both galvanized and galvannealed steel. Gavannealed steel, though, is not commonly used as a culvert material [1].

3.5.2 *Aluminized*

The primary coating used for aluminum coated corrugated steel is aluminized type 2 coating. Reports differ as to the life expectancy of aluminized steel as compared to galvanized steel. Recent studies state that aluminum coated type 2 steel pipe has an expected service life double that of galvanized steel when installed in pH ranges of 5 to 9 and at resistivities greater than 1500 ohm-cm [7, 11]. A study from Arizona has found acceptable results for a pH range of 7.2 and 9.0 when the resistivity is in between 1000 to 1500 ohm-cm [11]. A Wisconsin study contradicts these results. It concludes that aluminized culverts should not be used as a replacement at sites where galvanized steel has been known to fail due to corrosive conditions [16]. As of 1987, Missouri DOT was using only zinc and aluminized type 2 as a protective coating for corrugated steel pipe [1].

A Report from Maine shows that in varying conditions all pipes except one are rated in excellent condition. The exception is at an unusually abrasive site where the effluent is capable of carrying 6 to 12 inch boulders through the pipe. Abrasion has occurred with extensive loss of the coating and subsequent rusting of the invert. They have concluded that under normal conditions, aluminized type 2 coated pipe has a service life of 50 years. The expected service life should be reduced to 40 years when severely abrasive flow or extreme environmental conditions exist. All pipes examined in this study were between the ages of 10-17 years [15].

The Federal Highway Administration concludes that aluminum coated type 2 corrugated pipe should not be used under the following environments: acid mine runoff, saline water, or in effluent/soils that contain soluble heavy metals [7].

3.5.3 *Aluminum-zinc Coated and Cladding*

An aluminum-zinc protective coating helps the abrasion characteristics of aluminum while increasing corrosion resistance in galvanized pipe [1]. Although this seems like the perfect metallic coating, studies have shown that service life expectancy of aluminum-zinc coated culverts falls anywhere in the range of better than galvanized but worse than aluminized to the same as galvanized [7]. Reports from the State of Maine show that overall the service life of aluminum-zinc coated steel is longer than that of galvanized steel, although the corrosion rate of the aluminum-zinc coating could be increasing over time [13]. Field tests from sites in 9 eastern states have determined that a 0.6 oz/ft^2 aluminum-zinc coating performed as well as a 2 oz/ft^2 coating of galvanized [1].

Cladding refers to a special bonding of aluminum-magnesium-manganese alloy sandwiched in an aluminum-zinc sheet. The outside of the culvert, aluminum-zinc, is a sacrificial anode. This means, that as corrosion occurs, the aluminum-zinc sheet is sacrificed to save the inner alloy. This culvert works very well to stop corrosion but is highly sensitive to abrasion [1]. Maine has experimentally tried these culverts with good success. At the sites, the pH values were normal; and the resistivity values of the soil were greater than 10,000 ohm-cm. The corrosion rate could be accelerating with age for this culvert material [13].

3.6 Background Summary

Two summary tables have been made to tabulate the information given in the background section of this report. Since culverts can be installed in many different environments, optimum conditions in which the major culvert types should be installed are shown. The literature from some of the states had conflicting reports. Most of differing opinions have been noted after the tables. The information provided in the tables is at best an estimate of the field conditions needed for maximum service life of the culvert. Table 3 shows these conditions on the next page. Again, not all states were included in this table, only those states with information contained in the background section of the report. Table 4 shows the estimated add-on life of some non-metallic coatings. When trying to meet a specified service life, add-on coatings can play an important role. As the same as above, there are many exceptions to the rule, and the exceptions are noted at the bottom of the table. Again, not all states were included in the table.

Table 3. Field installation conditions for different culvert types.

Type of Culvert	Field Conditions
I. CMP	1. pH range: 6-8 2. Minimum Resistivity: See Below* 3. Increased corrosion: chlorides, sulfates, salts 4. Decreased corrosion: insoluble carbonates, hydroxides, limestone
II. Aluminum	1. pH range: 5-9 2. Minimum Resistivity: 500 ohm-cm** 3. Increased corrosion: heavy metal ions (copper, iron, etc.)
III. Aluminized	1. pH range: 5-9 2. Minimum Resistivity: 1500 ohm-cm***
IV. Reinforced Concrete	1. pH range: >5 2. Minimum Resistivity: none 3. Increase failure rate: high concentration of sulfates
V. Plastic	1. pH range: >1.25 2. Minimum Resistivity: none 3. Increase failure rate: concentrated acids, bases

Note: Not all states are represented in this table. This is a consensus from the background section of this report.

* - Tennessee recommends a pH range of 6-10 if the resistivity is greater than 3000 ohm-cm. Arizona recommends a pH range of 6-9 if the resistivity is greater than 2000 ohm-cm.

** - Tennessee recommends a pH range of 4-9 if resistivity is greater than 500 ohm-cm. Oregon recommends the above pH range if resistivity is greater than 1500 ohm-cm. California recommends the above pH range if resistivity is greater than 2000 ohm-cm.

*** - Arizona recommends a pH range of 7-9 if resistivity is greater than 1500 ohm-cm.

Table 4. Add-on life for various non-metallic coatings.

Type of Non-Metallic Coating	Increased Service Life Expected
I. Bituminous	25 yrs*
II. Bituminous-paved	25-30 yrs
III. Asbestos-impregnated Bituminous	see below**
IV. Polymeric	7-30 yrs

Note: Not all states are represented in this table. This is a consensus from the background section of this report.

* - for soil side corrosion. Florida reports an additional service life of 10 years for invert corrosion.

** - Louisiana, Ohio, Utah, and Washington report asbestos-impregnated performed better than ordinary bituminous.

4.0 Experimental

The objective of this project is to investigate whether a correlation can be found among the following variables: water pH, soil resistivity, soil potential and the corrosion rate of galvanized metal culverts. A correlation will be investigated for each specific variable and also for any combination of the variables together. Galvanized metal will be used as the primary researched culvert material because of the greater abundance across the state. Data will be taken for the other types, but the number of data points may not provide a significant amount of evidence to prove or disprove a correlation.

The research will be conducted for the sites provided throughout the state of Arkansas. The variables will be measured by a field pH meter, soil resistivity box, and a copper sulfate cell. Although not all states have found a meaningful relationship, some states have found a moderate to somewhat high dependence on these variables for the culvert corrosion rate.

This section of the report describes variables measured, equipment, sites, and procedure. At all sites data were recorded that describe the condition of the culvert, the environment, and the measured resistivity of the soil and pH of any water in contact with the culvert. Data sheets for each of the culverts included in this project are included in Appendix B. In addition to these observations, a video cassette record was made at most of the sites showing the condition of the culvert and the local environment. That video is included as an attachment to this report.

4.1 Variables

Many variables can affect underground corrosion. Some of these have been discussed in the literature survey; but for this project, only three are to be investigated. Water pH, soil resistivity, and soil potential have been chosen because of ease of measurement and for the information that they will give about the environment around the culvert.

Water pH should provide information on the acidity or basicity of the water that is flowing through the culvert. Water pH samples should also give information on the pH of the soil. A pH variation can be attributed to many things, including but not limited to, industrial or agricultural runoff and the specific soil type. Because of this, water pH samples will be taken instead of soil pH samples. Since there are many types of soil in the state of Arkansas, a wide variety of pH's are expected.

Soil resistivity may provide important data needed for soil-side corrosion correlations. Resistivity measures a voltage drop across a given amount of soil. In general, the higher the resistivity, the less a culvert should corrode. Since soil resistivity is a function of the soil moisture content, data will be needed to fully understand the effect that soil moisture has on the resistivity readings. One important note is that stray electrical currents can affect this reading and should be avoided. This is done by not taking the measurements directly under high-line wires, by buried underground cables, or in the vicinity of underground objects that are receiving cathodic protection.

The potential of the soil is the third variable that is to be measured. The data will quantify the amount of "driving force" there is in between the soil and the culvert for corrosion to take place. It should be noted that since potential is a measure of the ability of electric current to flow, this evaluation is only useful for metal culverts. The same caution as for the soil resistivity measurements should be stated. Stray electrical currents can affect the potential cell data.

4.2 Equipment

The field equipment used to measure the variables were: pH meter, soil resistivity box, and soil potential cell. A pH meter model number PHH-3X was bought from Omega. This pH meter has a range of 0.0 to 14.0 and an accuracy of ±0.1 pH. The meter has automatic temperature control (ATC) which accounts for a temperature difference at the site and where the meter was calibrated.

The soil resistivity box uses the Wenner Four-Electrode Method and was built in the University of Arkansas Department of Chemical Engineering Machine Shop. The Wenner Four-Electrode Method uses four pins and passes current through the outside two. The inner two pins measure the voltage drop of the current; and from Ohm's law, resistivity can be calculated. The described Wenner Method is ASTM approved with the designation: G 57 - 78 (Reapproved 1984). The advantage of this system is that the distance between pins is roughly the depth in the ground the reading is to being measured. For our equipment, a distance of 2 feet between pins will be used each time with the pins inserted 1 foot into the soil. The soil resistivity box is shown in Figure 2.

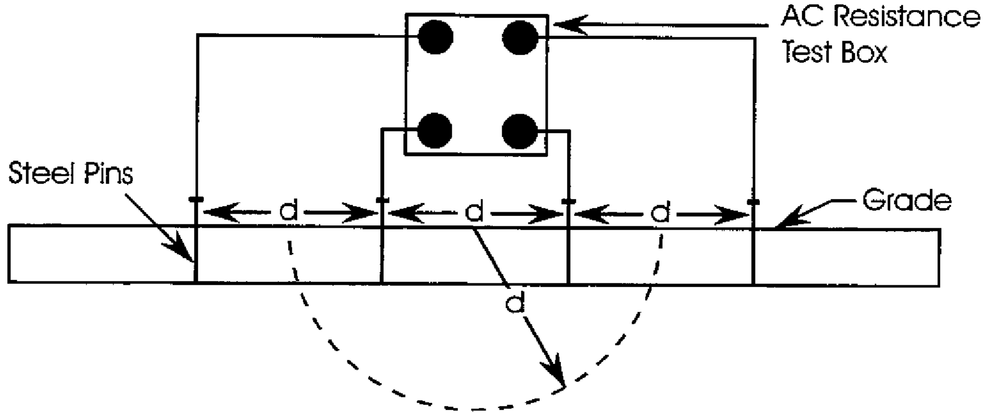


Figure 2. Diagram of the soil resistivity box used in the study.

The potential cell was also been constructed in the Machine Shop of the Chemical Engineering Department at the University of Arkansas. The cell is made up of a supersaturated copper sulfate and water solution. This liquid is in contact with a copper rod. A voltage meter is connected to the potential cell and the metal culvert. From this, a voltage difference is measured between the cell and the culvert. To insure that the copper sulfate cell is saturated, extra copper sulfate has been added to the already saturated solution. A ceramic plug is used in the bottom of the cell to provide the contact between the soil and the solution. The potential cell is shown in **4.3**

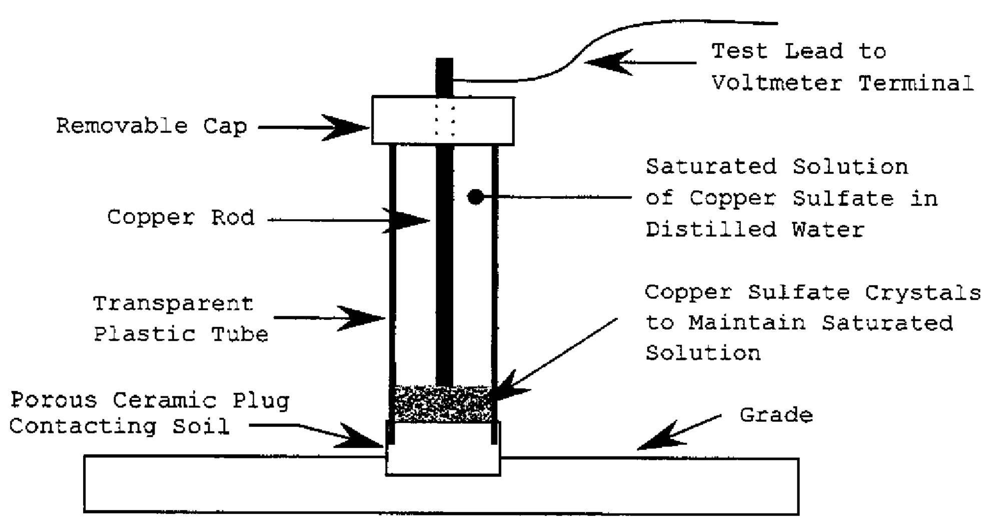


Figure 3. Diagram of the potential cell that was used in the study.

4.3 Sites

The sites for this project were chosen in conjunction with nine AHTD districts and approved by the central office. All districts, except District 8, were represented in this study. The research involved those sites suggested by the districts along with a selecte few other culverts types that were provided by others sources. This has been done to allow for other culvert materials to be included in the report.

Many different types of culverts were investigated throughout the state. Although galvanized corrugated metal pipe (CMP) was the most frequently seen culvert, seven types were represented. The different types inspected were: galvanized CMP, bituminous coated CMP, concrete, polymer coated CMP, aluminized CMP, aluminum, and plastic. Galvanized CMP was the most abundant type of culvert tested with 19 of the 51 culverts being from that class. The next highest was bituminous coated CMP with 13. The rest of the categories had 6 or fewer, with concrete having 6 test sites and aluminum and aluminized CMP having 4 and 2, respectively. Figure 4, below shows the number of sites inspected in each Arkansas county. Table 5 gives the numbers of each type of culvert studied.

Figure 4. Arkansas state map showing the number of sites by county.

Table 5. Types of culverts that were inspected in the State of Arkansas.

Culvert Type	Number of Sites	Counties Involved
CMP (galvanized)	19	1. Ashley 2. Benton 3. Chicot (2) 4. Dallas (2) 5. Garland 6. Greene (3) 7. Madison 8. Union (2) 9. Scott (5) 10. Sevier
Bituminous-coated CMP	13	1. Arkansas (3) 2. Dallas 3. Greene (4) 4. Madison (2) 5. Monroe (2) 6. White
Concrete	6	1. Carroll 2. Greene (2) 3. Monroe (2) 4. White
Aluminum	4	1. Arkansas 2. Benton 3. Sevier 4. St. Francis
Aluminized CMP	2	1. Union 2. Washington
Poly-coated CMP	4	1. Benton 2. Madison 3. Newton 4. Sevier
Plastic	3	1. Garland 2. Howard 3. Polk

Since the State of Arkansas has many different soils and environments within it's borders, a soil survey for the state was used in determining the actual soil type at each culvert location. This will help aide in characterizing the traits of the specific soil types.

Soils can be characterized using many factors including: drainage, compound content, and aeration. Appendix C contains the location of the culverts along with the soil geography maps of each county included in the survey. Polk, Scott, Sevier, and Union County soil geography maps were not available. These soil maps describe the type of soil in which the culverts were installed and what drainage has taken place. Each county map has the sites marked by site number.

4.4 Procedure

The procedure that was followed at each site included both the recording of physical data, and other observations on the data sheet, and making video of the site for future reference.

First the water pH was recorded. This was done to eliminate any error produced by the stirring of mud. Next a water sample was collected for future analysis. Soil resistivity and potential measurements were then taken. The order that these measurements were taken was irrelevant. However, where these measurements were made greatly matters.

Soil resistivity was measured close to the culvert. Since the measurement was taken at approximately two feet into the ground, the soil conditions were accurately described. The steel pins were oriented parallel to the road, perpendicular to the culvert. Care was taken to make sure that the soil that was tested was representative of the soil around the culvert, making sure that the reading does not come from the backfill soil. Two measurements were taken if a different backfill soil was used, since both types of soils were in contact with the culvert. Also, measurements were not taken directly under electric power lines because of the chance of stray current.

Potential measurements can be taken anywhere around the culvert. The ceramic plug on the bottom of the cell should be touching wet or moist soil. Some of the sites that have been tested had a stream available. If this is the case, the ceramic portion of the cell should be emerged in the water touching the stream bottom. As stated earlier, potential measurements require that a metal structure be present around the culvert. Metal culverts provide this requirement, but concrete and plastic do not. Therefore, a metal source must be found if a comparison is to be made.

After the data was recorded, the site was videotaped using commentary to describe the site. The video tried to capture the environment and also tried to represent the type of rating system used in describing the culvert. The video allowed the rating system to be understood. Also, still photographs were made from the videotape. The site number is reported along with present and past conditions. If rocks were present, then abrasion concerns were noted on the videotape. A data sheet was filled out along with the video. This data sheet described the conditions of the culvert and notes could have been made of anything odd or unusual about the culvert. Data sheets that were marked at the sites are included in Appendix B.

The rating of the culvert was decided upon and reported on the data sheet. The rating system to be used for this project was fairly subjective. Although guidelines were set, the rating was solely dependant on the inspector. The rating system assigned a number 0 to 5 for the culvert, with 0 being newly installed and 5 having the invert completely deteriorated. A rating of 1 constituted a discoloring effect, but pitting is not taking place on the culvert. The next step in the corrosion begins a pitting process. This minor pitting is associated with a rating of 2. A 3 rating showed more pitting and a slight flaking of the metal. When major holes of an inch or more in diameter develop, a 4 rating was given to the culvert. This rating constituted a failure. This was where the invert started to corrode, providing water contact with the undersoil. At this point erosion occurred and settlement usually follow.

Video was taken at the different sites, and the pictures from that video are given on the following pages. The culvert rating is shown in the caption. Only one galvanized CMP culvert received a rating of one, and video was not recorded. The rest of the galvanized culverts received ratings from 2 to 5.

5.0 Conclusions

Two different categories of conclusions can be drawn from the results of this work:

(1) observations made by the research team allowed qualitative, engineering conclusions, and

(2) statistical analyses of the observed culvert pipe conditions and the other variables produced quantitative conclusions.

Only in the cases of uncoated CMP and bituminous coated CMP were there enough data points to attempt a statistical analysis. For the uncoated CMP, no evidence of any statistical correlation was found. However, data from bituminous-coated CMP provided some evidence of a weak correlation among the variables of age, water pH, and condition. The two-variable test was significant at the 0.05 level, with both variables contributing at the 0.06 (age) and 0.07 (water pH) significance levels. The r-square value for this test was 0.574. No other variable or combination of variables met the 0.05 significance level. Details of this statistical analysis are included in Boyd's thesis [23].

5.1 Conclusions from Observations

Based on our observations of the culverts that were inspected around the state the following "engineering" conclusions can be drawn:

(1) Concrete holds up well. The oldest site studied was a 56 year old culvert in Carroll County (Site No. 39) which was rated with a Structural Condition of 1 (only discoloration). No concrete culvert received a Structural Condition rating worse than 2 (slight erosion or rusting).

(2) Galvanized CMP pipe often holds up well in a "dry stream" (i.e., one with intermittent flow), but when installed in a "wet stream" where the invert is continuously exposed to aqueous corrosion, extensive damage may take place in fewer than 10 years. Erosion, as evidenced by the presence of large rocks in the culvert, undoubtably contributes to the deterioration. But serious deterioration has been observed even in situations where the stream bed contained no rocks.

(3) The application of a bituminous (or polymeric) coating to CMP generally adds many years to the useful life to culverts. Even after the coating has disappeared many culverts appeared to be in a much better condition than would have been expected from an uncoated CMP.

(4) Although the data base is small, aluminum and aluminized CMP culverts stand up well. Aluminum culverts were often crushed at the ends, possibly from mowers impacting them, but no corrosion damage was noted. At one site (Union County site 33) the aluminized pipe was discolored while the galvanized channel showed evidence of the beginning of serious corrosion. (N.B. The practice of connecting dissimilar metals such as this is to be strongly discouraged).

(5) Four polymer coated CMP culverts were inspected. All sites were relatively new and no evidence of delamination was noted.

(6) The few plastic pipe culverts inspected were all relatively new installations (the oldest site was six years old) and all are performing well. Considerable pipe deformation was noted at one site, but its performance was unaffected.

5.2 Conclusions from Additional Analysis

Two of the chief factors affecting selection of a culvert pipe are performance and cost. The review of over 40 sites in the state gave an indication of how culvert pipe made from various materials had performed. In this study, the most-often found culvert pipe materials were galvanized CMP, bituminous-coated galvanized CMP, and Class 3 reinforced concrete; therefore, less can be deduced concerning culverts made from materials other than these.

Figure 5 compares the condition rating given to culverts of these three types after observing them in the field. This figure suggests that the concrete pipe has a long service when installed in the site conditions studied, while galvanized pipe without any other coatings has a much shorter service life. Asphalt or bituminous-coated pipe also seemed to be durable, but it did not perform as well the concrete pipe.

Figure 6 presents a comparison of culvert pipe prices bid on AHTD projects in 1996 and 1997. The four types with the greater number of sizes bid were concrete, aluminized CMP, galvanized CMP, and bituminous-coated CMP. Below the 30 inch diameter range, bid prices were similar, with Class 3 reinforced concrete somewhat higher. Above the 30 inch diameter range, concrete culvert prices rose more rapidly than did prices for those of other materials.

One purpose of a study such as this is to know, in general, what to expect from a given pipe material when resources and time often limit or preclude a detailed field site investigation. From those pipe culverts studied, one could estimate the typical life of a plain galvanized CMP as 20 years, the coated pipe as 35 years, and the concrete pipe as 50 years. If the bituminous-coated and the concrete pipe studied did not deteriorate in the next one or two decades, then their average life be projections would be revised upward. Factoring both performance and cost, either the Class 3 reinforced concrete pipe or bituminous-coated culverts fared better when the diameter is less than 30 inches, while the bituminous-coated pipe culverts seemed better above 30 inches diameter.

The aluminum and aluminized CMP also performed well, and the aluminized CMP has been bid at competitive prices. While these types may be just as desirable as concrete or bituminous-coated, the smaller data base of these types limits the opinions that can be formed. More time will have to pass before a long record of use will be available for the plastic or polymer-coated CMP. While nothing to suggest problems was found with these types, AHTD should monitor the long-term effects of nicks in the polymer-coated pipes external covering.

The limited sample size and history in the state with aluminum, aluminized, plastic, and polymer-coated culvert pipe limits the observations that can be made about the advantages of using these types of pipes in culverts. Factors such as ease of maintenance, potential for pipe settling and joints openings, and ease of replacement must be considered. When estimating an expected average life across a variety of conditions, one should remember that even if the pipe material withstands the environment, crushing from earth settlement or vehicle damage can prematurely terminate a pipe's effective life, making it no better than another pipe made from the least durable material.

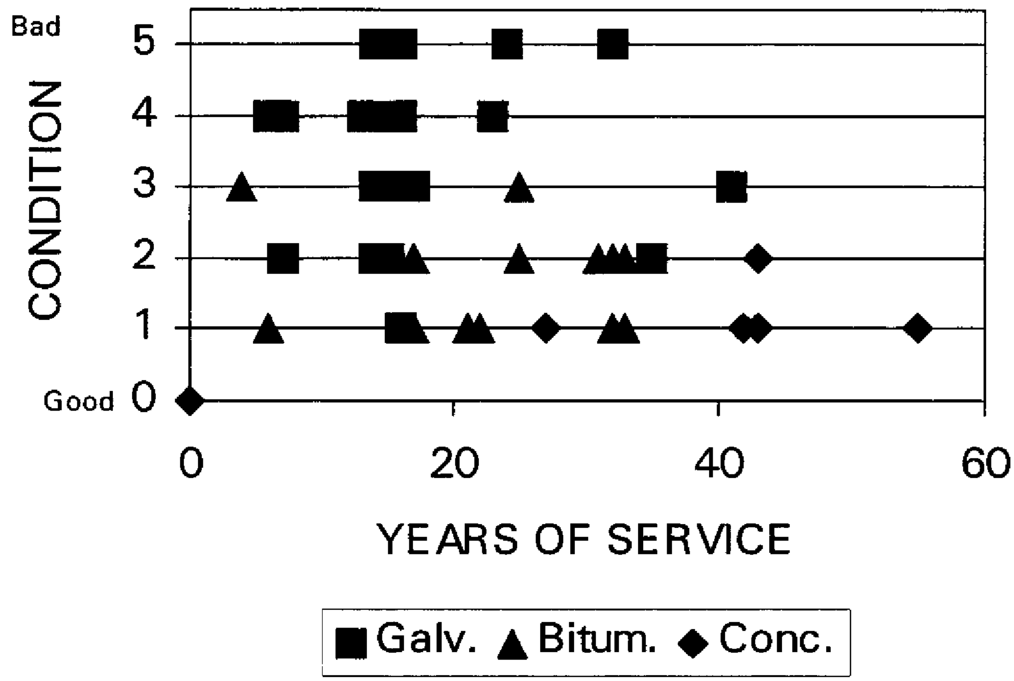


Figure 5. Comparison of Condition Ratings

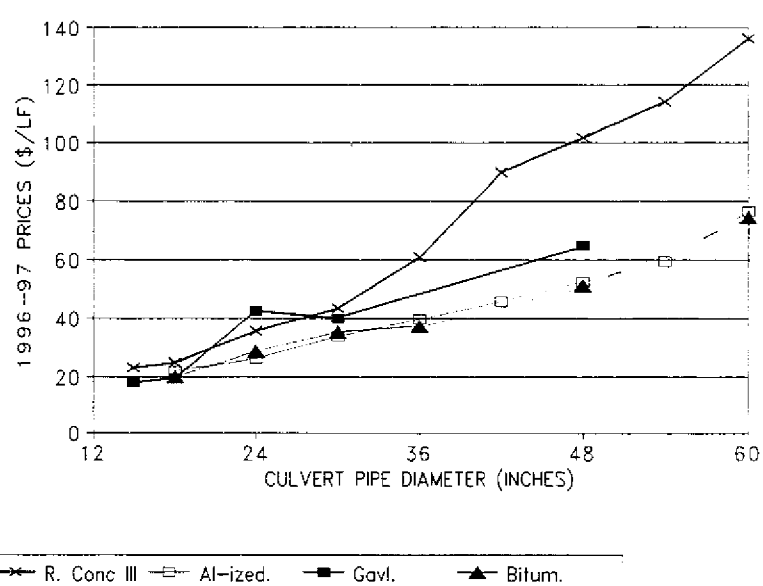


Figure 6. Culvert Bid Prices, 1996-1997

6.0 Recommendations

1. The use of uncoated, galvanized CMP should be minimized and restricted to locations in which the stream flow will be occasional to intermittent.

2. In other situations galvanized metal pipe should be coated with a polymeric or bituminous material.

3. The use of galvanized and aluminized material in the same installation should be avoided.

4. Consideration should be given to the installation of several different culvert materials in a common location for a side-by-side comparison of durability under real field conditions. By having such an experiment conducted in a roadway where several pipes are required the cost of the experiment would be greatly reduced. (Highway 248 in Scott County has a number of multiple barrel culverts that are seriously deteriorating. If they could be replaced with parallel galvanized, coated galvanized, aluminized or aluminum, and plastic pipes a real comparison could be made. Similar experiments in the eastern and southern region of the state would also be desirable.)

References

1. National Cooperative Highway Research Board, *Durability of Drainage Pipe*, Transportation Research Board, 1978.

2. CIM, 1986, Culvert Inspection Manual, Report No. FHWA-IP-86-2, Federal Highway Administration, Washington, DC.

3. Fleckenstein, L.J., and Allen, D.L., 1991, Field Performance Report on Corrugated Polyethylene Pipe, Research Report KTC-91-17, Kentucky Transportation Center, University of Kentucky, Lexington.

4. Kessler, R.J., and Powers, R.G., 1994, High Density Polylethylene Pipe Fire Risk Evaluation, Report No. 94-7A, Corrosion Research Laboratory, Florida Department of Transportation.

5. Hunt, T.R., 1991, Polyethylene Pipes for Use as Highway Culverts, Report No. CDOT-DTD-R-91-9, Colorado Department of Transportation, Denver.

6. Hyde, Luther W., et al., *Detrimental Effects of Natural Soil and Water Elements on Drainage Pipe Structures in Alabama*, Alabama Highway Research HR Report No. 40, August 1969.

7. Potter, John C., et al., *Durability of Special Coatings for Corrugated Steel Pipe*, Report No. FHWA-FLP-91-006, Federal Highway Administration, June 1991.

8. Patenaude, Robert, *Bacterial Corrosion of Steel Culvert Pipe in Wisconsin*, Transportation Research Record 1001, pp 66-69, 1984.

9. American Iron and Steel Institute, *Handbook of Steel Drainage & Highway Construction Products*, 5th ed., American Iron and Steel Institute, Washington, DC, 1994.

10. Missouri Highway and Transportation Department, *Study of Use, Durability, and Cost of Corrugated Steel Pipe on the Missouri Highway and Transportation Departments Highway System*, Missouri Highway and Transportation Department, 1987.

11. Arizona Department of Transportation, *Pipe Selection Guidelines and Procedures*, Arizona Department of Transportation, February 1996.

12. Hayes, Curtis, *Astudy of the Durability of Corrugated Steel in Oklahoma*, Oklahoma Department of Highways, 1971.

13. Jacobs, Kenneth M., *Durability of Drainage Structures*, Transportation Research Record 1001, pp 14-20, 1984.

14. Tennessee Department of Transportation, *Roadway Design Guidelines,* 1st ed. Tennessee Department of Transportation, October 1987.

15. State of Maine Department of Transportation, *Culvert Inspection Summary*, 1993-1995, State of Maine Department of Transportation, December 1995.

16. Patenaude, Robert, *Corrosion Evaluation of Experimental Metal Culvert Pipe in Wisconsin*, Wisconsin Department of Transportation, 1988.

17. Ashford, Clifton and Hayes, Curtis, *The Performance Evaluation of Coated and Paved Corrugated Steel Pipe Culverts*, Oklahoma Department of Transportation, undated.

18. Smith, L.K., Dow Chemical U.S.A. Memorandum, Dow Chemical, November 1985.

19. Koscenlny, Jennifer A., *Polymer Coated and Paved Culverts in Southeastern Oklahoma*, Oklahoma Department of Transportation, December 1992.

20. Oklahoma Department of Transportation, *Performance of Corrugated Steel Pipe Culverts Used in Low Water Stream Crossings in Eastern Oklahoma*, Oklahoma Department of Transportation, August 1991.

21. Missouri Highway and Transportation Department, *Life Expectancy Determination of Zinc-Coated Corrugated Steel and Reinforced Concrete Pipe Used in Missouri*, Missouri Highway and Transportation Department, December 1990.

22. South Carolina Department of Transportation, *Selection of Drainage Pipe for Use on South Carolina Highways*, Engineering Directive Memorandum, Numbers PC-26, C-20, M-28, January 1995.

23. Boyd, Bradley R., *Durability Study of Various Culvert Materials*, M.S.Ch.E. Thesis, University of Arkansas, Fayetteville, December 1997.

Appendix

Included in this appendix are (A) the results of a survey of the 50 state highway departments regarding culvert material selected - 36 states responded; (B) data sheets containing observations from our field study and a few on-site photographs extracted from our extensive video; Appendix (C) includes County Soil Survey Maps for the Arkansas counties involved; Appendix (D) demonstrates the mechanism of structural failure of culverts.

Appendix A

Results of State Culvert Pipe Surveys

RESULTS OF STATE CULVERT PIPE SURVEYS

In early 1996, four-page survey forms were sent to each of the 50 state departments of transportation. The following 36 states responded to the request for information.

Alaska	Missouri
Arizona	Montana
California	Nebraska
Colorado	New Hampshire
Connecticut	New Jersey
Florida	New Mexico
Georgia	New York
Hawaii	North Carolina
Idaho	North Dakota
Illinois	Ohio
Indiana	Oklahoma
Iowa	Oregon
Kansas	South Carolina
Kentucky	South Dakota
Louisiana	Texas
Mine	Utah
Maryland	Vermont
Minnesota	Wisconsin

Some states did not respond to all the questions, so question totals are sometimes less than the number of responses received. Due to differences in local terminology (e.g., referring to "corrugated metal" or "corrugated steel"), there was some difficulty in aggregating and totaling responses: some judgement was used.

1. What are the **primary standards** your agency uses when specifying materials for **culvert pipes**?

The majority of respondents used AASHTO specifications for culvert pipes. A number also use ASTM or their own state standards.

2. Are the current standards you use **adequate**?

The majority think current standards are adequate, but many also see the need for new standards in certain areas.

3. Before specifying a culvert for a particular location, does your agency normally make **site field tests**?

A sizeable minority of states routinely test sites for pH, soil conductivity or resistivity, and other factors which could damage culvert pipe. A few responded that they inspect pipe in the locale of the proposed culvert installation to identify potential problems.

4. Before specifying a culvert for a particular location, does your agency normally perform a **life-cycle cost analysis**?

The majority responded they do not normally perform a life-cycle analysis.

5. Does your agency have a **desired design life** for culverts in the following locations? (How many years should a culvert-pipe satisfactorily perform before needing replacement?)

Many of those responding listed 50 years as the desired design life for a culvert. There was a tendency to want more year's service under higher functional roadway classes (e.g., freeways) and fewer year's service under lower functional classes (e.g., collectors, locals, driveways). Figure A-10 presents survey responses.

6. In your jurisdiction, what is the status of these **culvert pipe** materials? (a list followed)

The responses showed a wide variety of pipe selection practices among the states. Among types that had been used in the past but were no longer allowed in some states were non-reinforced concrete; corrugated polyethylene (PE) pipe - M294 Type C (single wall); corrugated steel with zinc and aramid fiber (ASTM A885/M190) coating; and smooth-lined steel with aluminum and with zinc and aramid fiber (ASTM A885/M190) coatings. However, twice as many states still use non-reinforced concrete than have discontinued it.

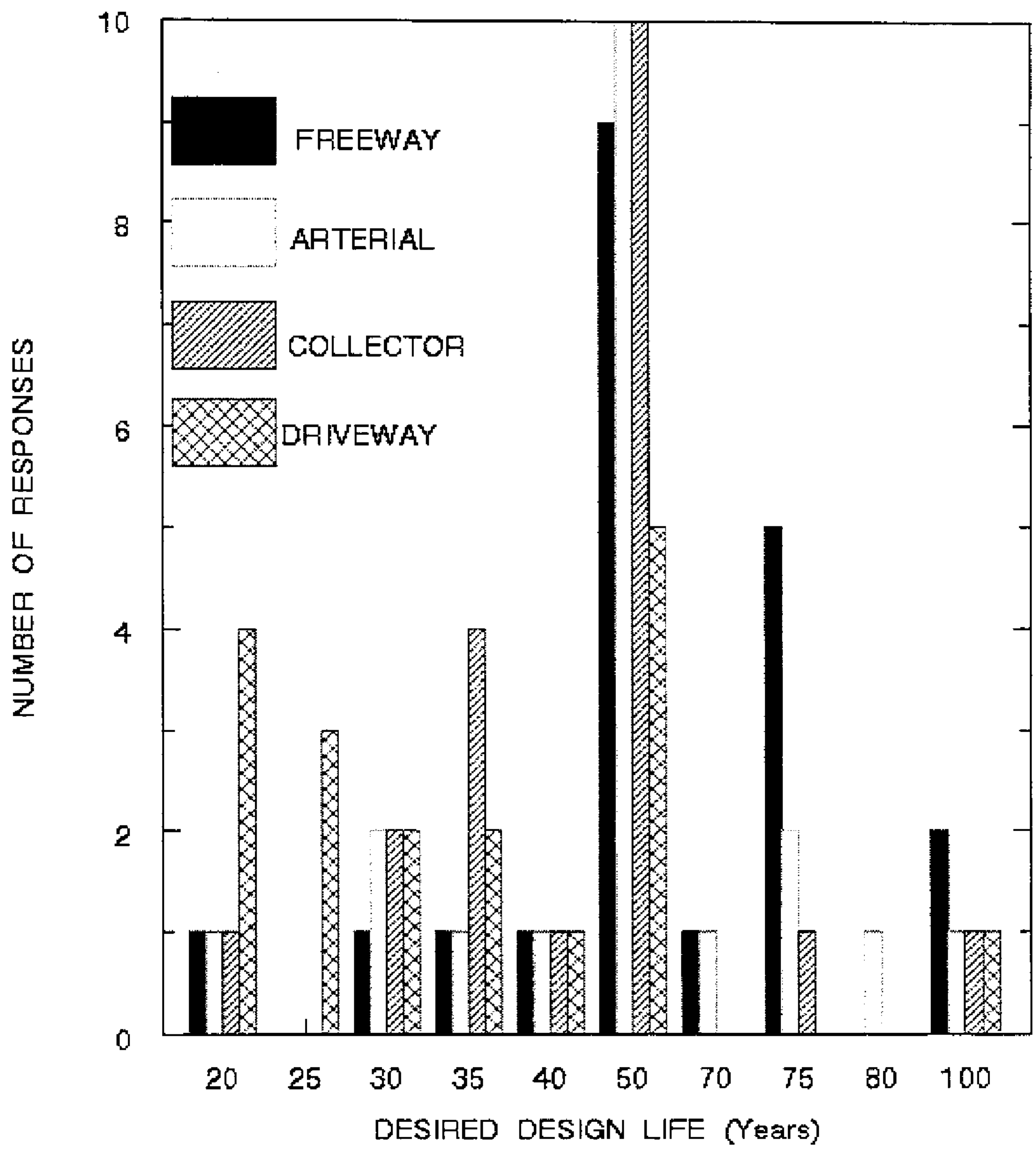


Figure 7. Design Life Responses

The 4 plastic pipes listed in the survey had the highest frequency of restricted use allowed. Concrete lined aluminum or steel also were well represented in this category.

The pipes most often allowed in most situations were corrugated aluminum, concrete, steel (M36), and corrugated steel variations. It appears that concrete is the most popular culvert pipe material.

7. In your jurisdiction, do you have **documented** experiences that any of the following have caused premature deterioration or failure of the culvert-pipes?

The most commonly reported documented problems involved metal/steel pipe carrying natural runoff; mining, mineral industry, or natural resource runoff; and agriculture/forest area runoff. It was also reported that metal/steel was damaged by debris in the flow. It should be noted that soil-side corrosion was not one of the available options to this question.

Failure experience may be somewhat a function of how frequently a culvert pipe material is used. In other words, it may not be unusual for a frequently-used pipe to have more failures, since there are more of them in use.

8. In your jurisdiction, do you strongly **encourage or require** the use of a specific culvert-pipe material for certain situations, such as depth of cover, terrain, soil or water conditions (e.g., acidic, alkaline, etc.)?

Many of the reporting state departments of transportation encourage the use of concrete pipe for the conditions specified in the survey. Metal pipe variations and plastic pipe were desired by some in acidic soil or runoff areas, as were metal pipe variations in alkaline environments. A few preferred aluminum pipe in marine (salt water) areas.

9. Do you have **documented** cases in your jurisdiction of poor connections (water/soil entering or leaving culvert at a joint) causing problems?

Pipe joint failures appear ubiquitous, as 2/3 of respondents reported having documented cases. Concrete pipe, with its shorter sections, was most often listed. Again, failure experience may be somewhat a function of how frequently a culvert pipe material is used. In other words, it may not be unusual for a frequently-used pipe to have more failures, since there are more of them out there to fail.

10. Has your agency performed or sponsored (or are you aware of any) studies regarding the selection, use, or performance of culvert-pipe materials in various types of locations?

Culvert pipe materials appear to be an ongoing object of research interest.

Summary of Responses to

SURVEY OF CULVERT-PIPE SELECTION PRACTICES

1. What are the **primary standards** your agency uses when specifying materials for **culvert pipes**?

   17 state or province transportation/highway/public works standard

   18 ASTM

   30 AASHTO

   0 NACE (Nat'l. Association of Corrosion Engr.)

   4 other

2. Are the current standards you use **adequate**? .... 27 yes 7 no

   Do **new standards** need to be developed? .... 15 yes 16 no

   IF new standards are needed, please describe "what" is needed, what needs to be addressed.

   As new products become available (3)

   Better identification of joint requirements

   Plastic products (2); PE; HDPE-large diameter

   Bedding for: plastic pipe (2); spiral-ribbed

   Need new standard CSP coatings, i.e., polymerized asphalt; Need information about metal coatings

   Need to reflect service life; Pipe longevity

   Need new selection criteria standards; Need to relate pipe material to site conditions

   Metric sizes

   ---

3. Before specifying a culvert for a particular location, does your agency normally make **site field tests** for
pH? .... 16 yes 19 no
soil conductivity of resistivity? .... 12 yes 23 no
other factors which could damage the pipe? .... 14 yes 18 no

IF you normally make other on-site tests, please describe "what" is tested.

Abrasion potential (2)
Alkalinity
Dissolved oxygen
Reduction-oxydation potential
Soil-depth of "soft" material (from a flat, coastal state)
Soil - if is collapsible
Sulfate levels and high moisture locations
Test only at "major" crossings
Performance of other pipe in the area (3)
Each project has its own geotechnical report, addressing soils, drainage, muck content, rock content, contaminated soils
Test data was collected and summarized for entire state in the past, so site-specific testing not currently done

---

4. Before specifying a culvert for a particular location, does your agency normally perform a **life-cycle cost analysis**? .... 4 yes 32 no

5. Does your agency have a **desired design life** for culverts in the following locations? (How many years should a culvert-pipe satifsactorily perform before needing replacement?)

	NO	YES; number of years
under freeway	11	21
under arterial	12	20
under collector or local	12	20
under driveway	14	18

6. In your jurisdiction, what is the status of these **culvert pipe** materials?

NOTES: if ASTM, then referenced to ASTM;
Otherwise, referenced to AASHTP Specs, 1995
*M190 is bituminous or bituminous+paved
*M245 is steel with zinc or aluminum+zinc alloy, coated with polymer

Used in the past, but no longer allow	Currently allow use only in a few circumstances	Currently allow use in most or all situations	
			ALUMINUM
1	10	21	Corrugated aluminum, M86
4	7	8	Corrugated aluminum, M196 with coatings M190 Type A, B, C, or D
1	8	6	Spiral ribbed
			CONCRETE
6	4	12	non-reinforced concrete, M86
0	0	33	Reinforced concrete, M170
2	7	13	Reinforced concrete arch, M206
1	7	17	Reinforced concrete elliptical, M207
			CONCRETE LINED, ASTM A849
2	9	5	Aluminum (Al) coated steel - type 2, M274
4	8	3	Al. Coated steel - type 2, with asphalt lining
1	9	9	Corrugated steel, M36
4	10	5	Corrugated steel, M36, with asphalt lining
			PLASTIC
6	12	5	Corrugated polyethylene (PE) pipe, M294 Type C (single wall)
0	19	10	Corrugated polyethylene (PE) pipe, M294 Type S (smooth interior, dbl.wall)
2	10	2	Polyethylene (PE) pipe, diameter > 36", similar to M294 Type S
2	10	5	Polylvinyl chloride (PVC) profile wall pipe, M304 (smooth interior,dbl.wall)
			STEEL, M36

1	8	19	Type I, circular
1	7	17	Type II, pipe-arch
			STEEL, M36 (**TYPE I** circular or **TYPE II** arch), **CORRUGATED**
1	6	16	Aluminum (Al.) Coated - type 2, M274
2	8	10	Al. Coated - type 2, M274 with coatings M245, M190 Type A, B, C, or D
2	2	10	Aluminum-zinc coated, M289
2	6	7	Al.-zinc coat, M289 with coatings M245, M190 Type A, B, C, or D
2	5	16	Zinc coated, M218
4	7	10	Zinc Coated, M218 with coatings M245, M190 Type A, B, C, or D
6	6	6	Zinc and aramid fiber, ASTM A885/M190 coating
			STEEL, M36 (**TYPE IA** or**TYPE IIA**), **INNER SMOOTH LINED**
6	2	6	Aluminum (Al.) Coated - type 2, M274
6	2	3	Al. Coated - type 2, M274 with coatings M245, M190 Type A, B, C, or D
6	1	4	Aluminum-zinc coated, M289
5	3	3	Al.-zinc coat, M289 with coatings M245, M190 Type A, B, C, or D
5	4	5	Zinc coated, M218
5	3	5	Zinc coated, M218 with coatings M245, M190 Type A, B, C, or D
6	3	2	Zinc and aramid fiber, ASTM A885/M190 coating
			STEEL, M36 (**TYPE IR** or **TYPE IIR**), **RIBBED**
3	2	10	Aluminum (A1.) Coated - type 2, M274
4	2	7	Al. Coated - type 2, M274 with coatings M245, M190 Type A, B, C, or D
4	0	6	Aluminum-zinc coated, M289
3	3	5	Al.-zinc coat, M289 with coatings M245, M190 Type A, B, C, or D
4	2	8	Zinc coated, M218
3	2	6	Zinc coated, M218 with coatings M245, M190 Type A, B, C, or D
5	1	3	Zinc and aramid fiber, ASTM A885/M190 coating
			OTHER: please describe the culvert-pipe material(s)

0	1	1	Polyvinyl chloride (PVC), M278
0	1	0	Structural plate w/spirolite plastic & conc.
0	1	0	Al. Structural plate, M219
0	1	0	Clay, M65
0	1	0	Clay, M179
0	1	0	Steel structural plate, M167, M245
0	1	0	Ductile iron, M64

7. In your jurisdiction, do you have **documented** experiences that any of the following have caused premature deterioration or failure of the culvert-pipes? **If "yes", please write the type of culvert material** to the right of the particular casual factor for deterioration/failure. If "no", then skip.

MAJOR CAUSE OF DETERIORATION/FAILURE	TYPE OF CULVERT PIPE MATERIAL
Solids abrasive, naturally occurring debris (solids such as gravel) carried by flow	Concrete, Concrete-reinforced (4) Metal (2) Metal-corrugated (7) Aluminum (2) Steel (4) Steel-corrugated (2) Steel-corrugated, galvanized (3) Steel-corrugated, aluminized Steel-structural pipe plate
abrasive, man-made debris (solids such as industrial wastes) carried by flow	Metal-corrugated (2) Aluminum Steel-structural pipe plate
Liquids natural run-off (liquids), w/o any human activity	Concrete, Concrete-reinforced (3) Metal Metal-corrugated (4) Aluminum Steel (4) Steel-corrugated (2) Steel-corrugated, galvanized (3)

run-off (liquids) from agricultural or forest areas that have been fertilized or had other additives applied

---

run-off (liquids) from streets/roads

---

run-off (liquids) from mining, mineral industry, or natural resource extraction areas (including oil fields)

---

run-off (liquids) from industrial sites

<u>Other</u>

proximity to cathodic-protection systems

other: please describe the situation

Concrete, Concrete-reinforced
Metal-corrugated (4)
Metal-corrugated, galvanized
Steel (2)
Steel-corrugated (2)
Steel-corrugated, galvanized (2)

Concrete, Concrete reinforced
Metal
Metal-corrugated (3)
Aluminum
Steel

Concrete (5)
Metal-corrugated (5)
Metal-corrugated, galvanized (3)
Metal-corrugated, aluminized
Steel
Steel-corrugated (2)
Steel-corrugated, galvanized (2)

Concrete (2)
Metal-corrugated (3)
Metal-corrugated, aluminized
Steel-corrugated, galvanized

Earth loadings . . . .
Road salt . . . .
Salt water . . . . Aluminum (2)
Acid release from Pyritic rock embankment .
Anaerobic sulfate reducing bacteria in low-
Alkalinity surface waters . . . .
Soil Sulfate content > 0.5% . . . . Concrete, Metal

Aluminum

Aluminum, Steel

Concrete (slow etching)

Steel-galvanized

Concrete (Type II cement)

8. In your jurisdiction, do you strongly **encourage or require** the use of a specific culvert-pipe material for certain situations, such as depth of cover, terrain, soil or water conditions (e.g., acidic, alkaline, etc.)?

. . . . 20 yes 9 no

IF "yes", please describe the situations and the type of culvert-pipe material(s) encouraged/required with each.

SITUATION	PIPE TYPE STRONGLY ENCOURAGED/REQUIRED
High cover depth	Concrete, Concrete reinforced (14) Metal-corrugated, Metal (3) Aluminum Steel-corrugated, Steel (5) Structural pipe arch
Rock or debris in runoff	Concrete, Concrete reinforced (10) Metal Metal-corrugated w/paved invert Steel-corrugated w/paved invert (3); w/asphalt lined; polymer-paved; aluminized Steel-lined Plastic, PE

Acidic soil in runoff

Concrete, Concrete reinforced (10)
Concrete-epoxy coated
Metal
Metal-corrugated bituminous coated (2); lined
Aluminum
Steel-corrugated
Steel-corrugated w/coating (2); polymer coated
Steel-aluminized (2)
SSPPC
Plastic lined
Plastic (6), PE

Alkaline soil in runoff

Concrete, Concrete-reinforced (8)
Metal
Metal-corrugated
Aluminum
Steel-corrugated
Steel-corrugated w/coating; polymer coated
Steel-aluminized

SSPPC
Plastic (2), PE (2)

Other (please specify)

Expressway . . . . Concrete-reinforced
High-volume road . . . . Concrete
Paved road, Concrete road . . . . Concrete (3)
Marine, Tidal flow, Salt water . . . . Aluminum (4), Concrete, Polyethylene
Watertightness . . . . Concrete

---

9. Do you have **documented** cases in your jurisdiction of poor connections (water/soil entering or leaving culvert at a joint) causing problems?

. . . . 24 yes   12 no

IF "yes", please list the types of pipes with which your agency has had joint problems.

PIPE TYPE	COMMENTS
All types (3)	...unstable foundation
Concrete, Concrete-reinforced (12)	...usually due to poor installation
Metal, Metal-corrugated (7)	...in highly corrosive, in hillside embankments; ...usually due to poor installation
Steel, Steel-corrugated (3)	...with "hugger" bands; galvanized
Multiplate; Structural arch	...poor construction techniques
HDPE, PE (3)	

10. Has your agency performed or sponsored (or are you aware of any) studies regarding the selection, use, or performance of culvert-pipe materials in various types of locations?
. . . . 17 yes   17 no

thank you for your help   THE END

Appendix B

Data Sheets

These Data Sheets contain observations from our field study.
A few on-site photographs from our video cassette are included.

Site No: 1
Location: Wal-Mart Fiesta Square
County: Washington
District: 4

Date Installed: 1982
Date Inspected: Aug. 15, 1996

Inspected by: Myers, Boyd

Type of Soil:
Fill Height: N/A in

Type of Structure: CMP
Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: Full of Debris

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 40 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil N/A Ohms-cm
Potential of Soil N/A volts

Notes: Located in NE corner of Fiesta Square, behind grocery store; full of shopping carts.

Site No: 2
Location: Center Point Park, Lowell
County: Benton
District: 9

Date Installed: 1988
Date Inspected: Aug. 15, 1996

Inspected by: Myers, Boyd

Type of Structure: CMP
Type of Coating: Polymer-coated

Type of Soil:
Fill Height: 15 in.

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: Some delamination along the outside edges of the pipe.

Coating Condition:

% of Top 2/3 intact 100
% of Bottom 1/3 intact 100

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow:	[X] Intermittent	[ ] Frequent	[ ] Continuous	
Water Runoff:	[ ] Cult. Land	[ ] Pasture	[ ] Woodland	[ ] Wooded Swamp
	[ ] Swamp	[ ] Sewer	[ ] Mining Land	[X] Lawn
Stream Bed	[ ] Ledge	[ ] Gravel	[ ] Sandy	[ ] Rock Laden
	[ ] Clay	[ ] Vegetation	[ ] Silt	[X] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil 6798 Ohms-cm
Potential of Soil 0.768 volts

Notes: Delamination doesn't seem to affect the performance of the pipe

Site No: 3
Location: 1.1 miles east of 62B on SH 12 (Prairie Creek).
County: Benton
District: 9

Date Installed: 1966
Date Inspected: Aug. 15, 1996

Inspected by: Myers, Boyd

Type of Structure: Aluminum
Type of Coating: N/A

Type of Soil:
Fill Height: 15 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: Possible mower damage to edges.

Coating Condition
% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions:	[ ] Dry	[X] Running Water	[ ] Still Water	

Water Depth in Pipe 1 in
Water Velocity trickle

Stream Flow:	[ ] Intermittent	[ ] Frequent	[X] Continuous	
Water Runoff:	[ ] Cult. Land	[ ] Pasture	[X] Woodland	[ ] Wooded Swamp
	[ ] Swamp	[ ] Sewer	[ ] Mining Land	[ ] Lawn
Stream Bed	[ ] Ledge	[X] Gravel	[ ] Sandy	[ ] Rock Laden
	[X] Clay	[ ] Vegetation	[ ] Silt	[ ] None

Slope of Pipe (%) 1 estimated

pH inlet 8.04
Avg. Resistivity of Soil 7312 Ohms-cm
Potential of Soil 0.751 volts

Notes: Rocks and soil are almost halfway up inside the culvert.
Spring is the water supply.
Resistivity measurement made 4/30/97.

Site No: 4
Location: Centerton Fish Hatchery
County: Benton
District: 9

Date Installed: 1972
Date Inspected: Aug. 15, 1996

Inspected by: Myers, Boyd

Type of Structure: Galvanized CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 24 in

Structure Condition: 5

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: Deterioration below water line.

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions:	[ ] Dry	[X] Running Water	[ ] Still Water	

Water Depth in Pipe 6in
Water Velocity trickle

Stream Flow:	[ ] Intermittent	[ ] Frequent	[X] Continuous	
Water Runoff:	[ ] Cult. Land	[ ] Pasture	[ ] Woodland	[ ] Wooded Swamp
	[ ] Swamp	[ ] Sewer	[ ] Mining Land	[ ] Lawn
Stream Bed	[ ] Ledge	[ ] Gravel	[ ] Sandy	[ ] Rock Laden
	[ ] Clay	[ ] Vegetation	[X] Silt	[ ] None

Slope of Pipe (%) 0 estimated

pH inlet 7.81
Avg. Resistivity of Soil 7907 Ohms-cm
Potential of Soil 0.559 volts

Notes: Runoff is produced from a spring in the fish hachery.
Stream flow is usually high (2-3 feet).
Soil resistivity measurement made 4/30/97

Site No: 6A
Location: Hwy 276 East of Bayou Meto (first site)
County: Arkansas
District: 2

Date Installed: 1971
Date Inspected: Sept 14, 1996

Inspected by: Boyd

Type of Structure: CMO
Type of Coating: Bituminous

Type of Soil:
Fill Height: 12 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 20
% of Bottom 1/3 intact 0

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 2in
Water Velocity 0f/s

Stream Flow: [ ] Intermittent [ ] Frequent [X] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp [X] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden [ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet 8.4
Avg. Resistivity of Soil 5159 Ohms-cm
Potential of Soil N/A volts

Notes:

Site No: 6B
Location: Bayou Meto (second site)
County: Arkansas
District: 2

Date Installed: 1971
Date Inspected: Sept. 14, 1976

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 12 in

Structure Condition: 3

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 0
% of Bottom 1/3 intact 0

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[X] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 8.8
Avg. Resistivity of Soil 5389 Ohms-cm
Potential of Soil N/A volts

Notes:

Site No: 7A
Location: 130 West of Hwy. 153 (East of Stuttgart)
County: Arkansas
District: 2

Date Installed: 1963
Date Inspected: Sept. 14, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 12 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 10
% of Bottom 1/3 intact 0

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 2 in
Water Velocity trickle

Stream Flow: [ ] Intermittent [ ] Frequent [X] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet 7.5
Avg. Resistivity of Soil 5247 Ohms-cm
Potential of Soil 0.245 volts

Notes:

Site No: 7B
Location: 2.4 miles N. of Dewitt on Hwy 130
County: Arkansas
District: 2

Date Installed: N/A
Date Inspected: May 23, 1997

Inspected by: Boyd

Type of Structure: Aluminum
Type of Coating: none

Type of Soil:
Fill Height: 18 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe in
Water Velocity f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [X] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil 3403 Ohms-cm
Potential of Soil 0.833 volts

Notes:

Site No: 8A
Location: 0.25 miles N. of Clarendon on Hwy 302
County: Monroe
District: 2

Date Installed: 1974
Date Inspected: Sept. 14, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 18 in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: slight mower damage

Coating Condition:

% of Top 2/3 intact 10
% of Bottom 1/3 intact 0

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 18 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 7.4
Avg. Resistivity of Soil 1171 Ohms-cm
Potential of Soil 0.847 volts

Notes:

Site No: 8B
Location: North of Clarendon, past 302 and 241 Jct.
County: Monroe
District: 2

Date Installed: 1974
Date Inspected: Sept. 14, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 8 in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 90
% of Bottom 1/3 intact 10

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 7.8
Avg. Resistivity of Soil 6539 Ohms-cm
Potential of Soil 0.437 volts

Notes:

Site No: 9
Location: 1.6 miles S. of I-40/Hwy 75 (near Hwy 70)
County: St. Francis
District: 2

Date Installed: 1965
Date Inspected: Sept. 14, 1996

Inspected by: Boyd

Type of Structure: Aluminum
Type of Coating: N/A

~~Type of Soil:~~
Fill ~~Height:~~ 8 in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 3 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet 7.4
Avg. Resistivity of Soil 625 Ohms-cm
Potential of Soil 0.812 volts

Notes:

Site No: 10
Location: Hwy 70 (Between Brinkley and Wheatley)
County: Monroe
District: 2

Date Installed: 1953
Date Inspected: Sept. 15, 1996

Inspected by: Boyd

Type of Structure: Concrete
Type of Coating: N/A

Type of Soil:
Fill Height: N/A

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 4 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[X] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil N/A Ohms-cm
Potential of Soil N/A volts

Notes:

Site No: 11

Location: Hwy 238 (Brinkley - near county line)

County: Monroe

District: 2

Date Installed: 1969

Date Inspected: Sept. 15, 1996

Inspected by: Boyd

Type of Structure: Concrete

Type of Coating: N/A

~~Type of Soil:~~

Fill Height: 12 in.

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 2 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil N/A Ohms-cm
Potential of Soil N/A volts

Notes: Couldn't get water sample.

Site No: 12A
Location: Hwy 248 W. of Waldron towards Lake Hinkle (1st site on road)
County: Scott
District: 4

Date Installed: 1982
Date Inspected: Oct 11, 1996

Inspected by: Myers, Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 36 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 1 in
Water Velocity trickle

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 7.5
Avg. Resistivity of Soil 15,772 Ohms-cm
Potential of Soil 0.708 volts

Notes: Three barrel, 72 in. Dia.

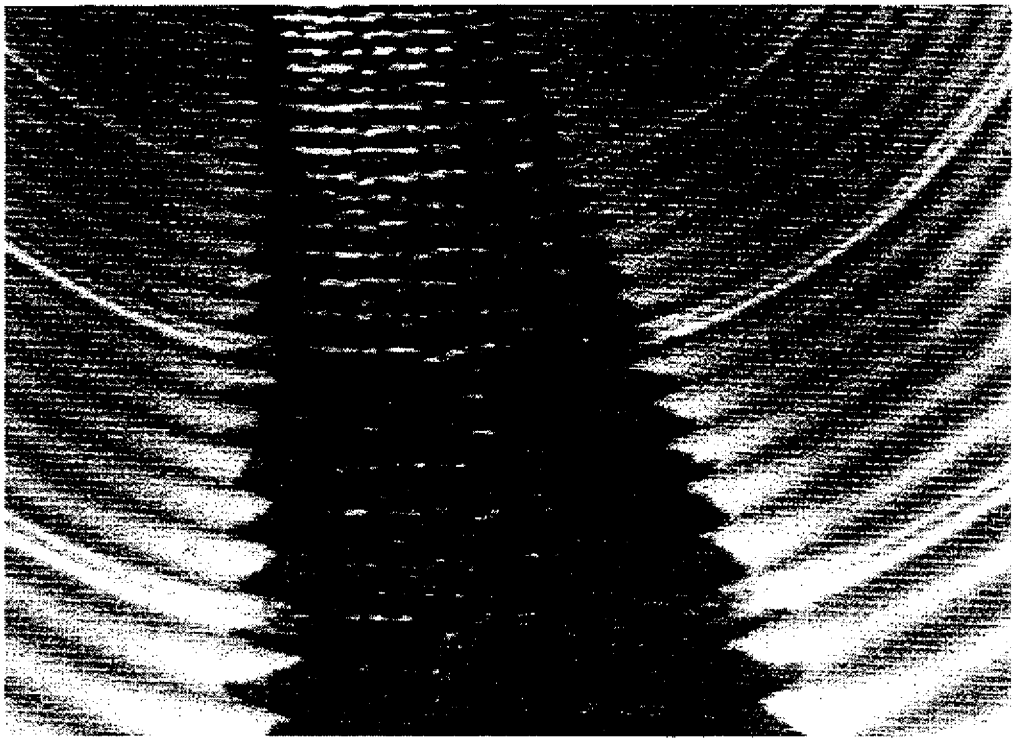


Figure 8. Inside of an uncoated CMP in Waldron, AR. This culvert had a 2 rating. The water line is consistent with corrosion.

Figure 9. Outside edge of the same uncoated CMP. Again, this culvert had a 2 rating.

Site No: 12B
Location: Hwy 248, farther West (closest to Lake Hinkle)
County: Scott
District: 4

Date Installed: 1982
Date Inspected: Oct 11, 1996

Inspected by: Myers, Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 48 in

Structure Condition: 3

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 1 in
Water Velocity 0 f/s

Stream Flow:	[ ] Intermittent	[ ] Frequent	[X] Continuous	
Water Runoff:	[ ] Cult. Land	[ ] Pasture	[ ] Woodland	[ ] Wooded Swamp
	[ ] Swamp	[ ] Sewer	[ ] Mining Land	[ ] Lawn
Stream Bed	[ ] Ledge	[ ] Gravel	[ ] Sandy	[ ] Rock Laden
	[ ] Clay	[ ] Vegetation	[ ] Silt	[X] None

Slope of Pipe (%) 0 estimated

pH inlet 7.4
Avg. Resistivity of Soil 19,263 Ohms-cm
Potential of Soil 0.778 volts

Notes: Debris dam at north end.
Stream beside the culvert gave a pH of 7.2

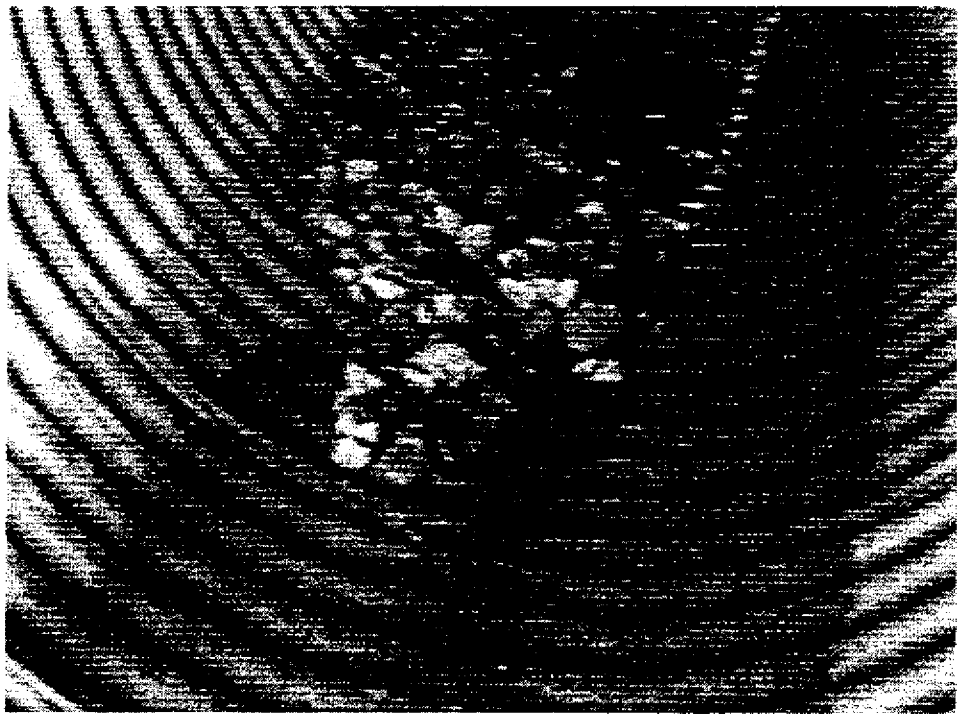


Figure 10. Inside of a CMP culvert where abrasion was a concern. This culvert received a rating of 3.

Figure 11. A close-up of the corrosion inside the same uncoated CMP. The rating was a 3.

Site No: 12C
Location: West of Site A (East of Site B)
County: Scott
District: 4

Date Installed: 1982
Date Inspected: Oct. 11, 1996

Inspected by: Myers, Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 18 in

Structure Condition: 4

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [X] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil N/A Ohms-cm
Potential of Soil 0.598 volts

Notes:

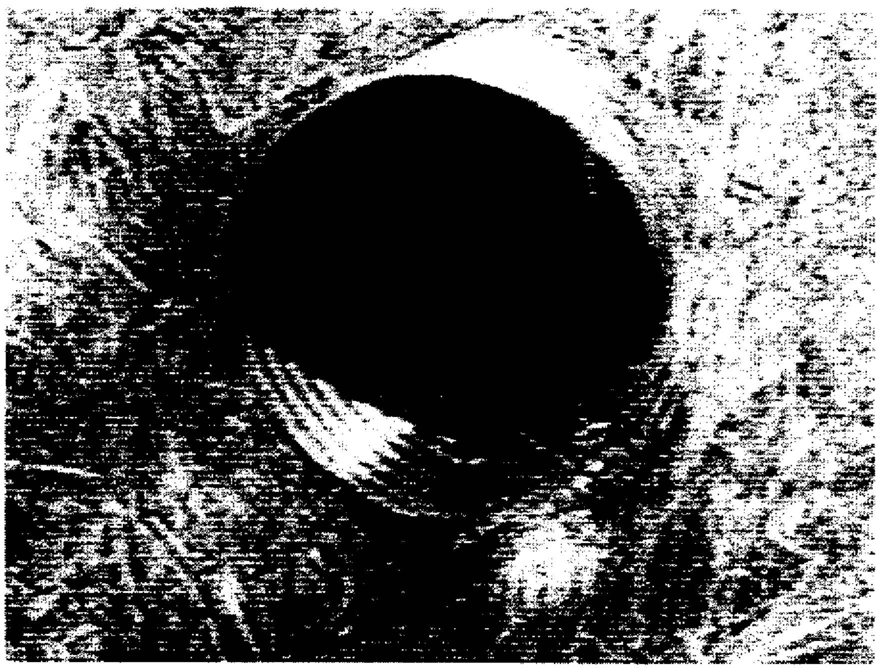


Figure 12. An uncoated CMP culvert with corrosion at the end section. This culvert was rated a 4.

Figure 13. A close-up picture of the corroded end section. This pipe was an uncoated CMP with a rating of 4.

Site No: 12D
Location: West of Site A (East of Site C)
County: Scott
District: 4

Date Installed: 1982
Date Inspected: Oct. 11, 1996

Inspected by: Myers, Gattis, Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil: ______
Fill Height: ______ in

Structure Condition: 5

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow:	[X] Intermittent	[ ] Frequent	[ ] Continuous	
Water Runoff:	[ ] Cult. Land	[ ] Pasture	[ ] Woodland	[ ] Wooded Swamp
	[ ] Swamp	[ ] Sewer	[ ] Mining Land	[ ] Lawn
Stream Bed	[ ] Ledge	[ ] Gravel	[ ] Sandy	[ ] Rock Laden
	[ ] Clay	[ ] Vegetation	[ ] Silt	[X] None

Slope of Pipe (%) 0 estimated

pH inlet 7.9
Avg. Resistivity of Soil 10,429 Ohms-cm
Potential of Soil 0.6 volts

Notes: Brush at north end.

Site No: 12F
Location: West of Site A (East of Site D)
County: Scott
District: 4

Date Installed: 1982
Date Inspected: Oct. 11, 1996

Inspected by: Myers, Gattis, Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 1.5 in

Structure Condition: 4

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 0.5 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet 8.
Avg. Resistivity of Soil 8782 Ohms-cm
Potential of Soil 0.669 volts

Notes: Extremely rocky

Site No: 15
Location: Hwy 329 (0.7 N. of Hwy 24)
County: Sevier
District: 3

Date Installed: 1995
Date Inspected: Oct. 18, 1996

Inspected by: Myers, Gattis

Type of Structure: CMP
Type of Coating: Polymer

Type of Soil: Sandy Loam
Fill Height: 12 in

Structure Condition: 0

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 100
% of Bottom 1/3 intact 100

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe in
Water Velocity f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [X] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) ________ estimated

pH inlet 10.1
Avg. Resistivity of Soil 1431 Ohms-cm
Potential of Soil N/A volts

Notes: Fertilizer runoff from adjacent pasture and hog farm.

Site No: 16

Location: Hwy 317, N. of Cowlingsville and 27 Jct.

County: Sevier

District: 3

Date Installed: 1974

Inspected by: Myers, Gattis

Date Inspected: Oct. 18, 1996

Type of Structure: CMP

Type of Soil: ~~red clay silt~~

Type of Coating: N/A

Fill Height: 36 in

Structure Condition: 4

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe N/A in
Water Velocity N/A f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp [ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden [ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet 7.5
Avg. Resistivity of Soil 16,770 Ohms-cm
Potential of Soil 0.660 volts

Notes:

Site No: 17
Location: Hwy 234, South of Paraloma
County: Sevier
District: 3

Date Installed: 1966
Date Inspected: Oct 18, 1996

Inspected by: Myers, Gattis

Type of Structure: Aluminum
Type of Coating: N/A

Type of Soil: gravel-clay
Fill Height: 12 in.

Structure Condition: 0

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe N/A in
Water Velocity N/A f/s

Stream Flow: [ ] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) N/A estimated

pH inlet N/A
Avg. Resistivity of Soil 1271 Ohms-cm
Potential of Soil 0.720 volts

Notes: Grass and dirt partially covered both ends (side drain pipe).

Site No: 18
Location: 50 ft. W. of Firetown St., Old Union
County: Union
District: 7

Date Installed: 1990
Date Inspected: Oct. 19, 1996

Inspected by: Myers, Gattis

Type of Structure: CMP
Type of Coating: N/A

Type of Soil: gravel-clay
Fill Height: 8 in

Structure Condition: 4

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe N/A in
Water Velocity N/A f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) N/A estimated

pH inlet 7.6
Avg. Resistivity of Soil 2172 Ohms-cm
Potential of Soil 0.459 volts

Notes: Upstream end of pipe covered with dirt; lower end never had water running through it (side drain pipe).

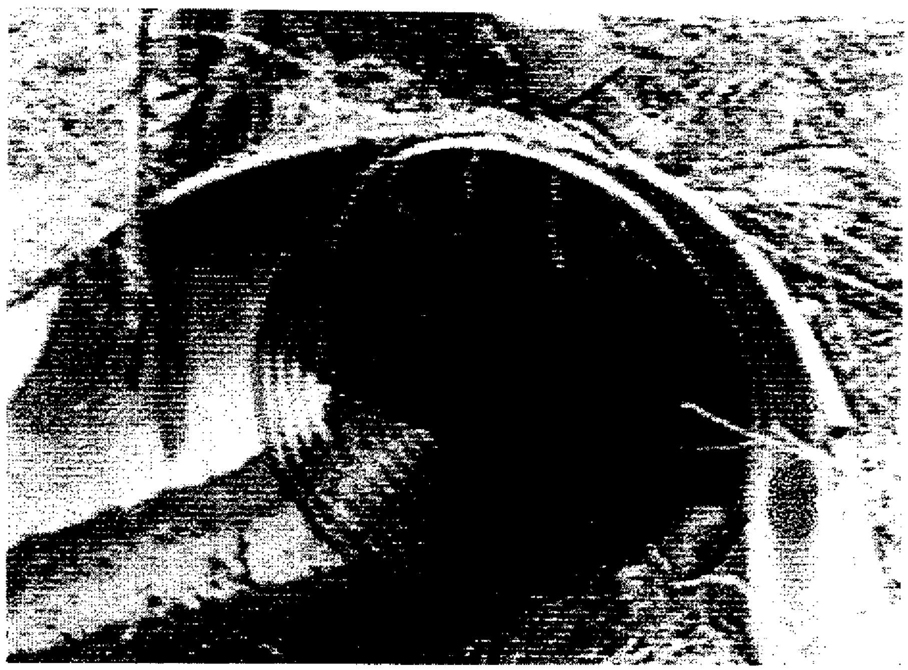


Figure 14. An uncoated CMP located in Sevier County. This culvert received a rating of 4.

Site No: 19
Location: 100 ft. West of Site 18
County: Union
District: 7

Date Installed: 1990
Date Inspected: Oct. 11, 1996

Inspected by: Myers, Gattis

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 12 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 0.5 in
Water Velocity trickle f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [X] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) N/A estimated

pH inlet N/A
Avg. Resistivity of Soil 2172 Ohms-cm
Potential of Soil 0.459 volts

Notes: Resistivity measurements were taken half way between 18 and 19 (side drain pipe).

Site No: 20A
Location: Hwy 8 East of Hwy 9
County: Dallas
District: 7

Date Installed: 1956
Date Inspected: Oct. 19, 1996

Inspected by: Myers, Gattis

Type of Structure: CMP
Type of Coating: N/A

Type of Soil: sandy loam
Fill Height: 18 in

Structure Condition: 3

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe N/A in
Water Velocity N/A f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [X] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet 7.6
Avg. Resistivity of Soil 7805 Ohms-cm
Potential of Soil 0.741 volts

Notes:

Site No: 20B
Location: Hwy 48 East of Carthage
County: Dallas
District: 7

Date Installed: 1965
Date Inspected: Oct. 19, 1996

Inspected by: Myers, Gattis

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: N/A in

Structure Condition: 5

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe N/A in
Water Velocity N/A f/s

Stream Flow: [ ] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [X] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet 7.8
Avg. Resistivity of Soil 12,495 Ohms-cm
Potential of Soil 0.630 volts

Notes: Date installed from David Archer, Ast. Maintenance Superintendent, Camden.

Figure 15. An uncoated CMP that received a rating of 5. The water marks are located almost halfway up this 60" diameter culvert. The bottom is completely deteriorated.

Site No: 21
Location: 230 ft. West of Site 20
County: Dallas
District: 7

Date Installed: 1980
Date Inspected: Oct. 19, 1996

Inspected by: Myers, Gattis

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fil Height: N/A in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe in
Water Velocity f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 7.3
Avg. Resistivity of Soil 9362 Ohms-cm
Potential of Soil 0.909 volts

Notes:

Site No: 22
Location: Stratcor Rd. at Hwy 270 adjacent to Vanadium plant
County: Garland
District: 6

Date Installed: 1981
Date Inspected: Oct. 24, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: N/A in.

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 1 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [X] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) N/A estimated

pH inlet 7.8
Avg. Resistivity of Soil 11,244 Ohms-cm
Potential of Soil 0.612 volts

Notes:

Site No: 23
Location: Hot Springs
County: Garland
District: 6

Date Installed: Aug 199 (sic)
Date Inspected: Oct. 24, 1996

Inspected by: Boyd

Type of Structure: Plastic
Type of Coating:
Structure Condition: 0

Type of Soil:
Fill Height: N/A In.

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 In
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [X] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 8.5
Avg. Resistivity of Soil 13,835 Ohms-cm
Potential of Soil 0.572 volts

Notes: side drain

Site No: 24A
Location: First Site N. on Hwy 139 toward Mounds (closest to Hwy 412)
County: Greene
District: 10

Date Installed: 1964
Date Inspected: Oct. 25, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 18 in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 30
% of Bottom 1/3 intact 10

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil 11,175 Ohms-cm
Potential of Soil 0.862 volts

Notes: Bituminous coating still noticeable

Site No: 24B
Location: Hwy 139 North of Site 24A
County: Greene
District: 10

Date Installed: 1964
Date Inspected: Oct. 25, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 18 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 60
% of Bottom 1/3 intact 10

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe N/A in
Water Velocity N/A f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp [ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden [ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) ______ estimated

pH inlet 7.6
Avg. Resistivity of Soil 1647 Ohms-cm
Potential of Soil 0.567 volts

Notes: Bituminous coating still noticeable.

Site No: 24C
Location: Hwy 139 North of Site 24B
County: Greene
District: 10

Date Installed: 1964
Date Inspected: Oct. 25, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 12 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 70
% of Bottom 1/3 intact 20

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet 7.6
Avg. Resistivity of Soil 1509 Ohms-cm
Potential of Soil 0.829 volts

Notes: Located next to cotton and milo fields.

Site No: 24D
Location: Hwy 139 North of Site 24C
County: Greene
District: 10

Date Installed: 1964
Date Inspected: Oct. 25, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: N/A In.

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 70
% of Bottom 1/3 intact 20

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil 8325 Ohms-cm
Potential of Soil 0.793 volts

Notes: Located next to cotton fields.

Site No: 25A
Location: Hwy 358 after 351 Jct; Closest to Hwy 141
County: Greene
District: 10

Date Installed: 1980
Date Inspected: Oct. 25, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 24 in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [X] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil 3793 Ohms-cm
Potential of Soil 0.692 volts

Notes:

Site No: 25B
Location: Hwy 358 East of Site 25A
County: Greene
District: 10

Date Installed: 1980
Date Inspected: Oct. 25, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 6 in

Structure Condition: 4

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 1in
Water Velocity trickle

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [X] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil 3952 Ohms-cm
Potential of Soil 0.620 volts

Notes: Sample taken after rain; possible outside-in corrosion.

Site No: 25C
Location: Hwy 358 West of 351 Jct, East of Site 25B
County: Greene
District: 10

Date Installed: 1980
Date Inspected: Oct. 25, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 36 in

Structure Condition: 3

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 1 in
Water Velocity trickle

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [X] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil 3830 Ohms-cm
Potential of Soil 0.571 volts

Notes:

Site No: 26A
Location: Hwy 135 South
County: Greene
District: 10

Date Installed: 1953
Date Inspected: Oct. 26, 1996

Inspected by: Boyd

Type of Structure: Concrete
Type of Coating: N/A

Type of Soil:
Fill Height: 12 in.

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 4 in
Water Velocity 0.5 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 7.4
Avg. Resistivity of Soil 1983 Ohms-cm
Potential of Soil 0.526 volts

Notes: Water runs through vegetation; located by fish farm.

Site No: 26B
Location: Hwy 135 South of Site 26
County: Greene
District: 10

Date Installed: 1953
Date Inspected: Oct. 26, 1996

Inspected by: Boyd

Type of Structure: Concrete
Type of Coating: N/A

Type of Soil:
Fill Height: 12 In.

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 6 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 7.5
Avg. Resistivity of Soil 1347 Ohms-cm
Potential of Soil 0.501 volts

Notes: Sample taken after rain.

Site No: 28
Location: Hwy 323 before Hwy 11 (South of I-40)
County: White
District: 5

Date Installed: 1996
Date Inspected: Dec. 28, 1996

Inspected by: Boyd

Type of Structure: Concrete
Type of Coating: N/A

Type of Soil:
Fill Height: 15 in.

Structure Condition: 0

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe N/A in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [X] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil N/A Ohms-cm
Potential of Soil N/A volts

Notes: The rock is lime; bituminous CMP had recently been replaced with concrete pipe.

Site No: 29
Location: Hwy 87 and Hwy 11 Jct
County: White
District: 5

Date Installed: 1992
Date Inspected: Dec. 28, 1996

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 12 in

Structure Condition: 3

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 90
% of Bottom 1/3 intact 20

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 12 in
Water Velocity 0 f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [X] Pasture [ ] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [X] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil N/A Ohms-cm
Potential of Soil N/A volts

Notes:

Site No: 30
Location: 1.1 miles N. of Hwy 82 on Hwy 293
County: Chicot
District: 2

Date Installed: 1990
Date Inspected: Jan. 24, 1997

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: N/A In.

Structure Condition: 4

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: ☐ Dry ☐ Running Water ☐ Still Water

Water Depth in Pipe in
Water Velocity f/s

Stream Flow: ☐ Intermittent ☐ Frequent ☐ Continuous

Water Runoff: ☐ Cult. Land ☐ Pasture ☐ Woodland ☐ Wooded Swamp
☐ Swamp ☐ Sewer ☐ Mining Land ☐ Lawn

Stream Bed ☐ Ledge ☐ Gravel ☐ Sandy ☐ Rock Laden
☐ Clay ☐ Vegetation ☐ Silt ☐ None

Slope of Pipe (%) 0 estimated

pH inlet 7.2
Avg. Resistivity of Soil 1109 Ohms-cm
Potential of Soil 0.818 volts

Notes:

Site No: 31
Location: 5.6 miles N. of Hwy 144 on Hwy 293
County: Chicot
District: 2

Date Installed: 1980
Date Inspected: Jan. 24, 1997

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: N/A in.

Structure Condition: 5

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: Culvert was replaced; structural condition is for old pipe.

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: ☐ Dry ☐ Running Water ☐ Still Water

Water Depth in Pipe N/A in
Water Velocity N/A f/s

Stream Flow: ☐ Intermittent ☐ Frequent ☐ Continuous

Water Runoff: ☐ Cult. Land ☐ Pasture ☐ Woodland ☐ Wooded Swamp
☐ Swamp ☐ Sewer ☐ Mining Land ☐ Lawn

Stream Bed ☐ Ledge ☐ Gravel ☐ Sandy ☐ Rock Laden
☐ Clay ☐ Vegetation ☐ Silt ☐ None

Slope of Pipe (%) N/A estimated

pH inlet 7.5
Avg. Resistivity of Soil 2077.8 Ohms-cm
Potential of Soil 0.630 volts

Notes:

Site No: 32
Location: Waterwell Road
County: Ashley
District: 2

Date Installed: 1980
Date Inspected: Jan. 25, 1997

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: N/A in.

Structure Condition: 3

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe N/A in
Water Velocity N/A f/s

Stream Flow: [ ] Intermittent [ ] Frequent [X] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) N/A estimated

pH inlet 6
Avg. Resistivity of Soil 13,615 Ohms-cm
Potential of Soil 0.753 volts

Notes:

Site No: 33
Location: Hwy 335 S. of Norphlet
County: Union
District: 7

Date Installed: 1988
Date Inspected: Jan. 25, 1997

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Aluminum

Type of Soil: ____
Fill Height: ____ in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 12 in
Water Velocity N/A f/s

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) N/A estimated

pH inlet 5.7
Avg. Resistivity of Soil 14,835 Ohms-cm
Potential of Soil 0.650 volts

Notes:

Site No: 34
Location: Hwy 23 near St. Paul
County: Madison
District: 9

Date Installed: 1962
Date Inspected: Apr. 26, 1997

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: N/A

Type of Soil:
Fill Height: 30 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [ ] Running Water [X] Still Water

Water Depth in Pipe 2 in
Water Velocity 0 f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[X] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet 7.5
Avg. Resistivity of Soil 12,261 Ohms-cm
Potential of Soil 0.314 volts

Notes:

Site No: 35
Location: Hwy 16 past 23 (Pettigrew)
County: Madison
District: 9

Date Installed: 1990
Date Inspected: Apr. 26, 1997

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 24 in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 90
% of Bottom 1/3 intact 10

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 1in
Water Velocity trickle

Stream Flow: [ ] Intermittent [ ] Frequent [X] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [X] Silt [ ] None

Slope of Pipe (%) N/A estimated

pH inlet 8.1
Avg. Resistivity of Soil 956 Ohms-cm
Potential of Soil 0.933 volts

Notes:

Site No: 36
Location: Hwy 103, 1 mile E. of Oark
County: Madison
District: 9

Date Installed: 1988
Date Inspected: Apr. 26, 1997

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Polymer

Type of Soil: —
Fill Height: 48 in

Structure Condition: 0

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 100
% of Bottom 1/3 intact 90

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) 0 estimated

pH inlet N/A
Avg. Resistivity of Soil 6051 Ohms-cm
Potential of Soil 0.442 volts

Notes: 37

Site No: 37
Location: 7.4 miles E. of Jasper on Hwy 74
County: Newton
District: 9

Date Installed: 1989
Date Inspected: Apr. 26, 1997

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Polymer

Type of Soil:
Fill Height: 120 in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 2in
Water Velocity trickle

Stream Flow: [ ] Intermittent [ ] Frequent [X] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 8.1
Avg. Resistivity of Soil 322 Ohms-cm
Potential of Soil 0.510 volts

Notes:

Site No: 38
Location: Hwy 74 W of Hwy 21 near Kingston
County: Madison
District: 9

Date Installed: 1979
Date Inspected: Apr. 26, 1997

Inspected by: Boyd

Type of Structure: CMP
Type of Coating: Bituminous

Type of Soil:
Fill Height: 24 in

Structure Condition: 2

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact 80
% of Bottom 1/3 intact 10

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 1in
Water Velocity trickle

Stream Flow:	[ ] Intermittent	[X] Frequent	[ ] Continuous	
Water Runoff:	[ ] Cult. Land	[ ] Pasture	[X] Woodland	[ ] Wooded Swamp
	[ ] Swamp	[ ] Sewer	[ ] Mining Land	[ ] Lawn
Stream Bed	[ ] Ledge	[ ] Gravel	[ ] Sandy	[ ] Rock Laden
	[ ] Clay	[ ] Vegetation	[X] Silt	[ ] None

Slope of Pipe (%) 0 estimated

pH inlet 7.3
Avg. Resistivity of Soil 8581 Ohms-cm
Potential of Soil 0.769 volts

Notes:

Site No: 39
Location: East of Eureka Springs on Hwy 62
County: Carroll
District: 9

Date Installed: 1941
Date Inspected: Apr. 26, 1997

Inspected by: Boyd

Type of Structure: Concrete
Type of Coating: N/A

Type of Soil:
Fill Height: 6 in

Structure Condition: 1

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [X] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [ ] None

Slope of Pipe (%) N/A estimated

pH inlet N/A
Avg. Resistivity of Soil 9137 Ohms-cm
Potential of Soil 0.490 volts

Notes:

Site No: 40
Location: CR 293 (Mena)
County: Polk
District: 3

Date Installed: 1993
Date Inspected: May 16, 1997

Inspected by: Myers, Boyd

Type of Structure: Plastic
Type of Coating: N/A

Type of Soil:
Fill Height: N/A in

Structure Condition: 0

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [ ] Dry [X] Running Water [ ] Still Water

Water Depth in Pipe 2 in
Water Velocity trickle

Stream Flow: [ ] Intermittent [X] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [X] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

Slope of Pipe (%) 0 estimated

pH inlet 8.4
Avg. Resistivity of Soil 15,392 Ohms-cm
Potential of Soil 0.602 volts

Notes: concrete headwall

Site No: 41
Location: Weyerhauser #1
County: Howard
District: 3

Date Installed: 1991
Date Inspected: May 16, 1997

Inspected by: Myers, Boyd

Type of Structure: Plastic
Type of Coating: N/A

Type of Soil:
Fill Height: 24 in

Structure Condition: 0

0 - Original Condition
1 - Only discoloration (no pitting)
2 - Slight Erosion or rusting (minor pitting)
3 - Moderate erosion or rusting (moderate pitting)
4 - Extensive erosion or rusting (major pitting)
5 - Invert completely deteriorated

Damaged by other means, explain: none

Coating Condition:

% of Top 2/3 intact N/A
% of Bottom 1/3 intact N/A

Environmental Data

Water Conditions: [X] Dry [ ] Running Water [ ] Still Water

Water Depth in Pipe 0 in
Water Velocity 0 f/s

Stream Flow: [X] Intermittent [ ] Frequent [ ] Continuous

Water Runoff: [ ] Cult. Land [ ] Pasture [X] Woodland [ ] Wooded Swamp
[ ] Swamp [ ] Sewer [ ] Mining Land [ ] Lawn

Stream Bed [ ] Ledge [ ] Gravel [ ] Sandy [ ] Rock Laden
[ ] Clay [ ] Vegetation [ ] Silt [X] None

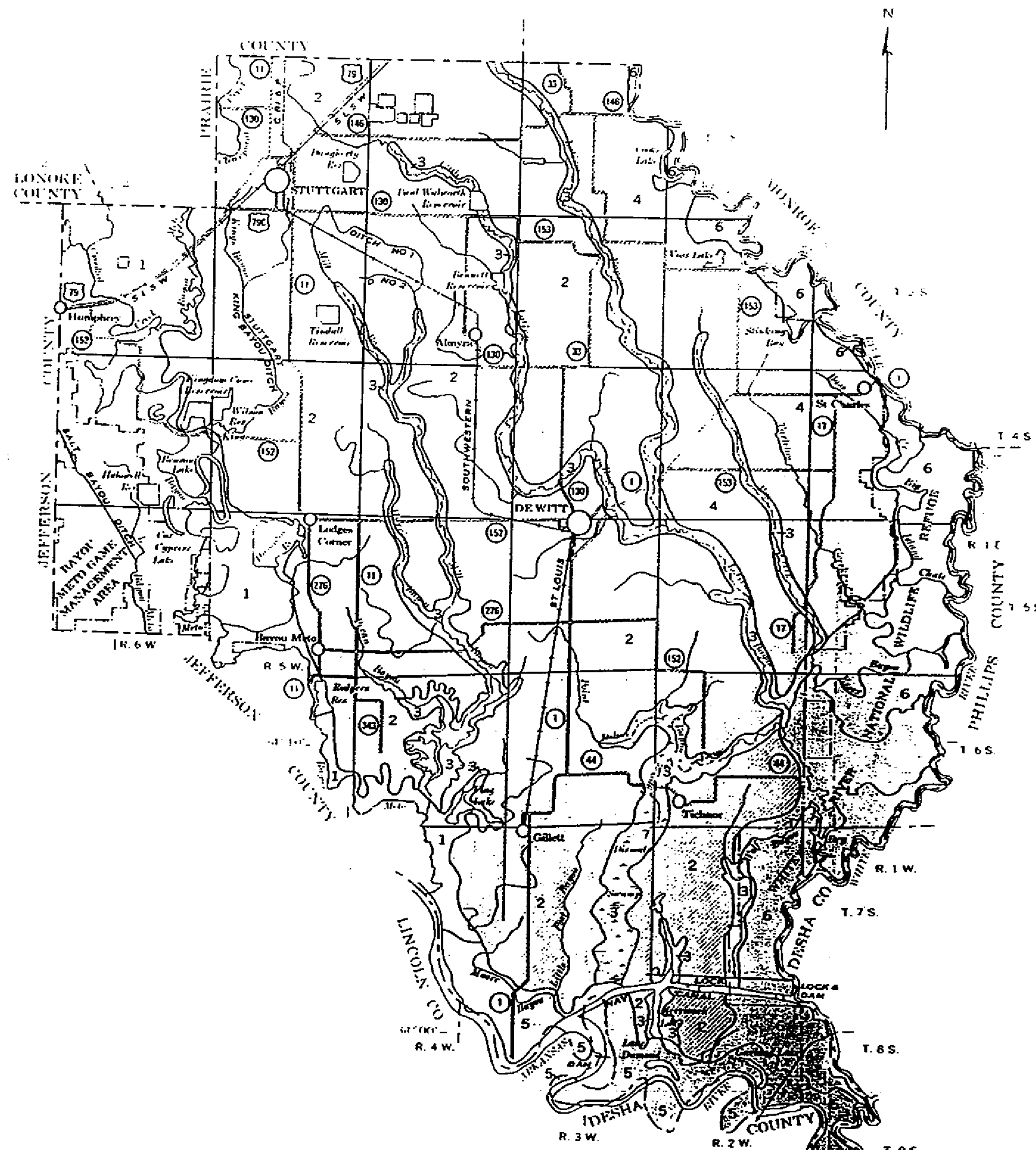
Slope of Pipe (%) 0 estimated

pH inlet 7.4
Avg. Resistivity of Soil 28,358 Ohms-cm
Potential of Soil 0.546 volts

Notes:

Appendix C

County Soil Survey Maps



This map is for general planning. It shows only the major soils and does not contain sufficient detail for operational planning.

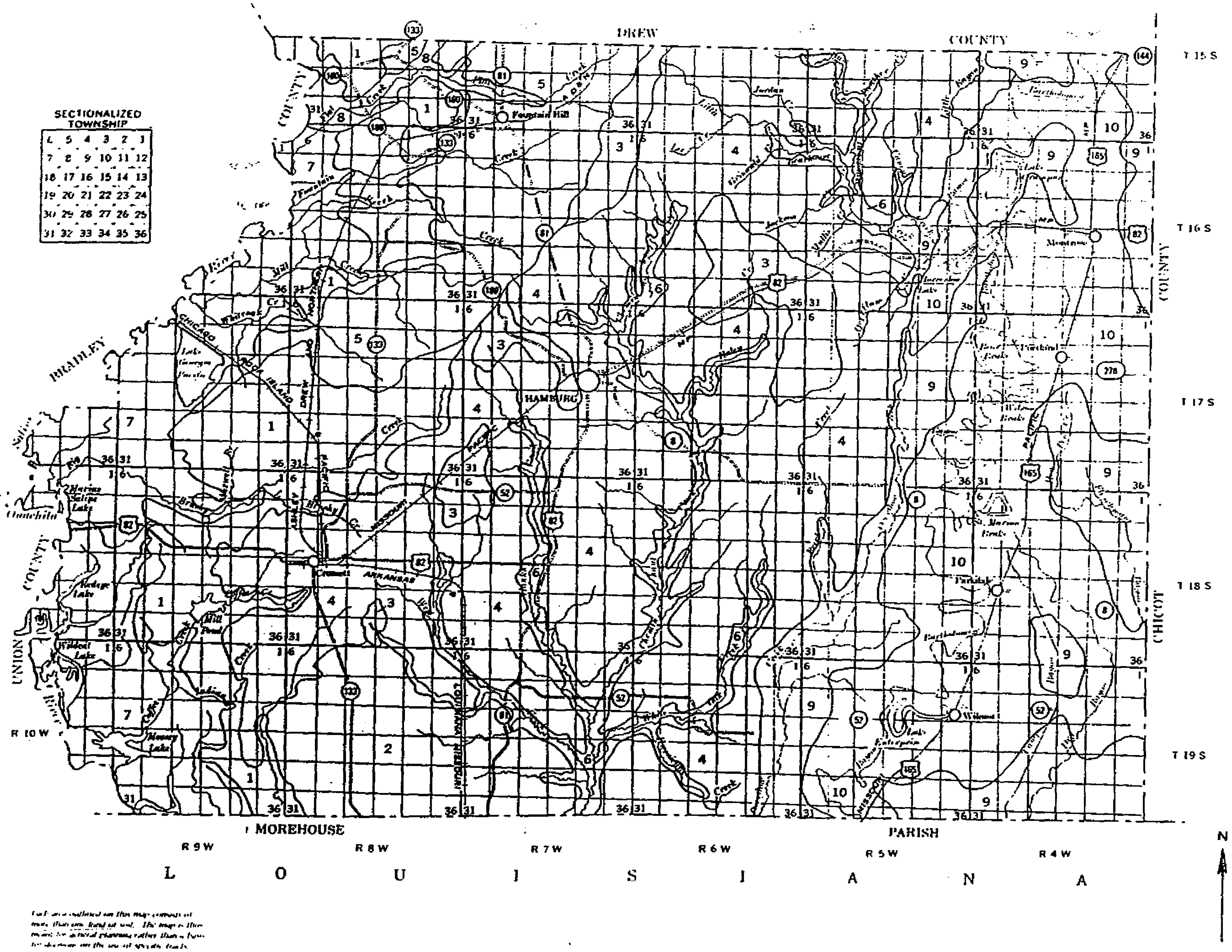
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION

GENERAL SOIL MAP
ARKANSAS COUNTY, ARKANSAS

SOIL ASSOCIATIONS*

1	Perry-Rilla-Portland association: Poorly drained to well-drained, level, clayey and loamy soils on bottom land along the Arkansas River
2	Crowley-Stuttgart-Grenada association: Poorly drained to moderately well drained, level to gently sloping, loamy soils that formed in windblown silts overlying old alluvium on upland flats and low ridges
3	Tichnor association: Poorly drained, level, loamy soils that formed in sediments from local streams
4	Grenada-Loring-Calhoun association: Moderately well drained and poorly drained, level to moderately sloping, loamy soils that formed in windblown silts on upland flats, low ridges, and escarpments
5	Norwood association: Well-drained, level and gently undulating, loamy soils on bottom land along the Arkansas River
6	Sharkey-Acadia association: Poorly drained and somewhat poorly drained, level, predominantly clayey soils in slack water areas on bottom land along the White River

* The texture given is that of the surface layer of the major soil or soils in the association.



LEGEND*

AREAS DOMINATED BY LEVEL TO MODERATELY SLOPING SOILS ON UPLANDS

1 Amy-Pheba: Poorly drained and somewhat poorly drained, level and nearly level, loamy soils; on uplands

2 Bude-Providence: Somewhat poorly drained and moderately well drained, level and nearly level, loamy soils; on uplands

3 Calhoun: Poorly drained, level, loamy soils; on uplands

4 Calloway-Grenada-Henry: Moderately well drained to poorly drained, level to moderately sloping, loamy soils; on uplands

5 Savannah-Tippah: Moderately well drained, nearly level to gently sloping, loamy soils; on uplands

AREAS DOMINATED BY LEVEL SOILS ON BOTTOM LANDS SUBJECT TO FREQUENT FLOODING

6 Arkabutla: Somewhat poorly drained, level, loamy soils; on bottom lands

7 Guyton: Poorly drained, level, loamy soils; on bottom lands and stream terraces

8 Guyton-Ouachita: Poorly drained and well drained, level, loamy soils; on bottom lands and stream terraces

AREAS DOMINATED BY LEVEL AND NEARLY LEVEL SOILS ON BOTTOM LANDS

9 Perry-Portland: Poorly drained and somewhat poorly drained, level, clayey and loamy soils; on bottom lands

10 Rilla-Hebert: Well drained and somewhat poorly drained, level to undulating, loamy soils; on bottom lands

*The texture noted in the descriptive headings applies to the surface layer of the major soils.

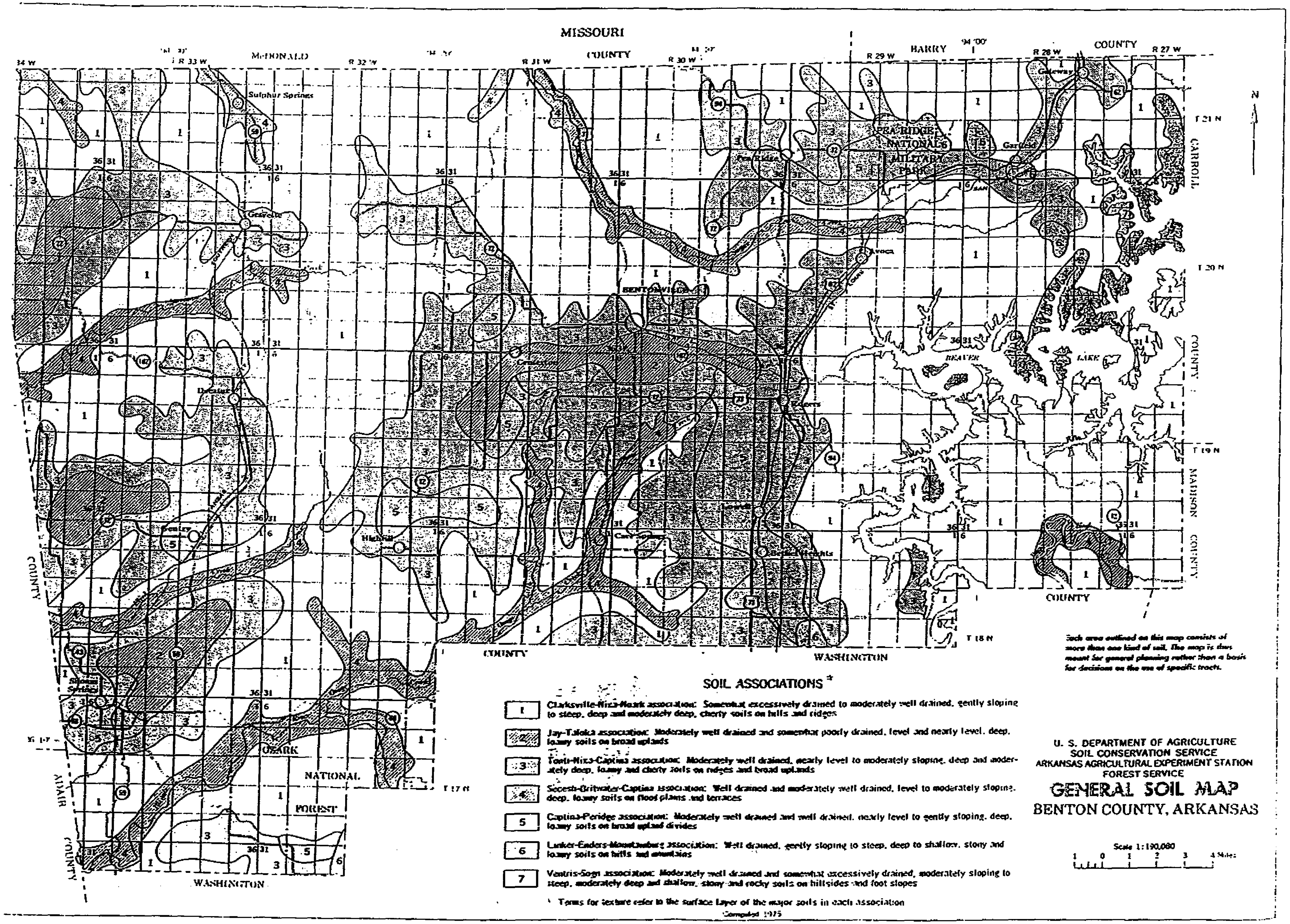
Compiled 1978

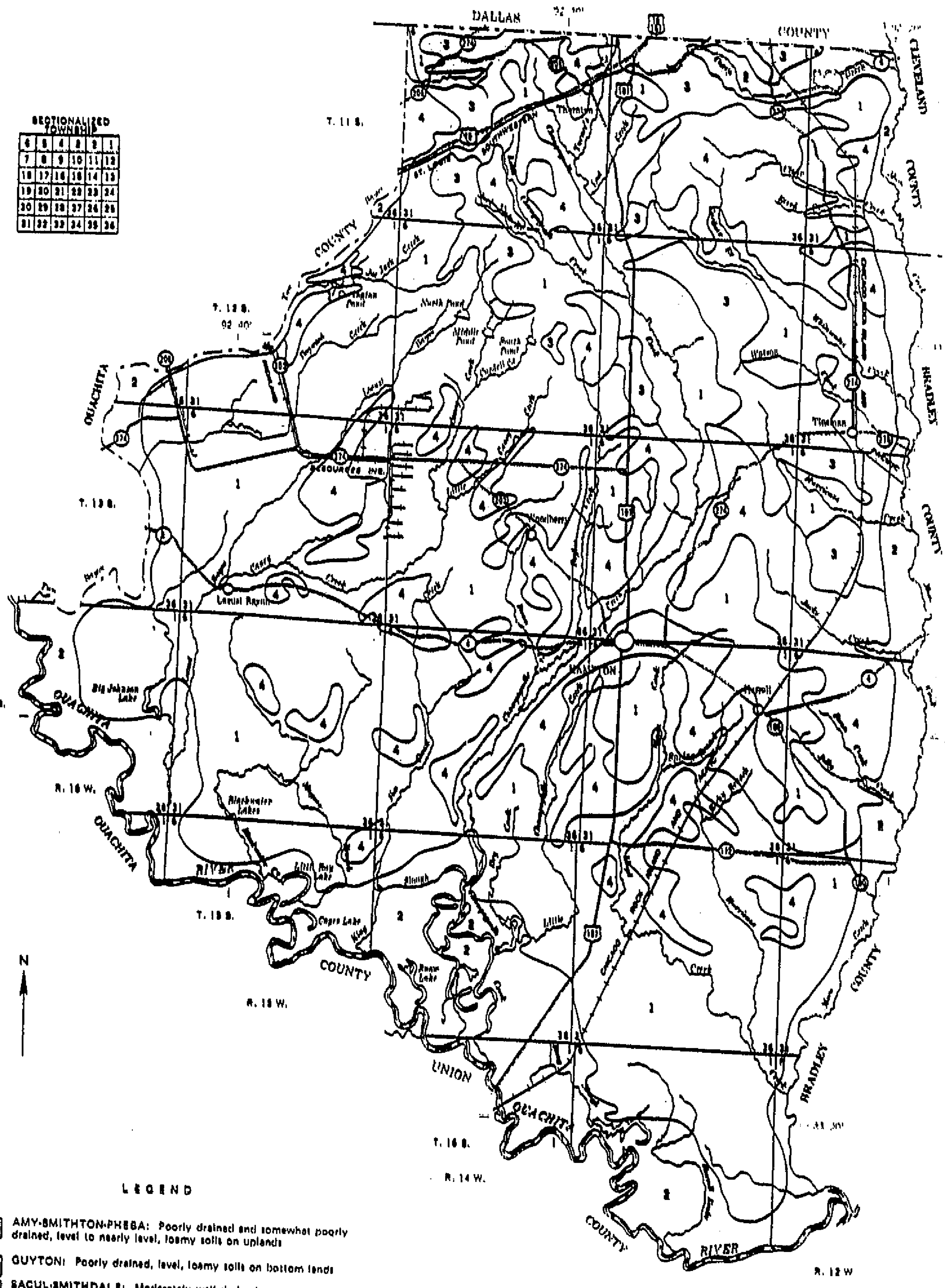
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
FOREST SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION

GENERAL SOIL MAP

ASHLEY COUNTY, ARKANSAS

Scale 1:253,440


MISSOURI
McDONALD
COUNTY
BARRY
COUNTY
CARROLL
COUNTY
MADISON
COUNTY
WASHINGTON
COUNTY
ADAIR
COUNTY
BENTONVILLE
PEA RIDGE NATIONAL MILITARY PARK
OZARK NATIONAL FOREST
BEAVER LAKE
Sulphur Springs
Gravette
Decatur
Gentry
Highfill
Siloam Springs
Cave Springs
Lowell
Avoca
Garfield
Gateway
Rogers
Bella Vista
Bethel Heights
T 21 N
T 20 N
T 19 N
T 18 N
T 17 N
R 33 W
R 32 W
R 31 W
R 30 W
R 29 W
R 28 W
R 27 W
N
Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.
SOIL ASSOCIATIONS *
1 Clarksville-Nixa-Noark association: Somewhat excessively drained to moderately well drained, gently sloping to steep, deep and moderately deep, cherty soils on hills and ridges
2 Jay-Taloka association: Moderately well drained and somewhat poorly drained, level and nearly level, deep, loamy soils on broad uplands
3 Tonti-Nixa-Captina association: Moderately well drained, nearly level to moderately sloping, deep and moderately deep, loamy and cherty soils on ridges and broad uplands
4 Secesh-Britwater-Captina association: Well drained and moderately well drained, level to moderately sloping, deep, loamy soils on flood plains and terraces
5 Captina-Peridge association: Moderately well drained and well drained, nearly level to gently sloping, deep, loamy soils on broad upland divides
6 Linker-Enders-Mountainburg association: Well drained, gently sloping to steep, deep to shallow, stony and loamy soils on hills and mountains
7 Ventris-Sogn association: Moderately well drained and somewhat excessively drained, moderately sloping to steep, moderately deep and shallow, stony and rocky soils on hillsides and foot slopes
* Terms for texture refer to the surface layer of the major soils in each association
Compiled 1975
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION
FOREST SERVICE
GENERAL SOIL MAP
BENTON COUNTY, ARKANSAS
Scale 1:190,080
1 0 1 2 3 4 Miles



LEGEND

1	AMY-SMITHTON-PHEBA: Poorly drained and somewhat poorly drained, level to nearly level, loamy soils on uplands
2	GUYTON: Poorly drained, level, loamy soils on bottom lands
3	SACUL-SMITHDALE: Moderately well drained and well drained, nearly level to moderately steep, loamy soils on uplands
4	SAVANNAH-RUSTON-SMITHDALE: Moderately well drained and well drained, nearly level to moderately sloping, loamy soils on uplands

Compiled 1978

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION

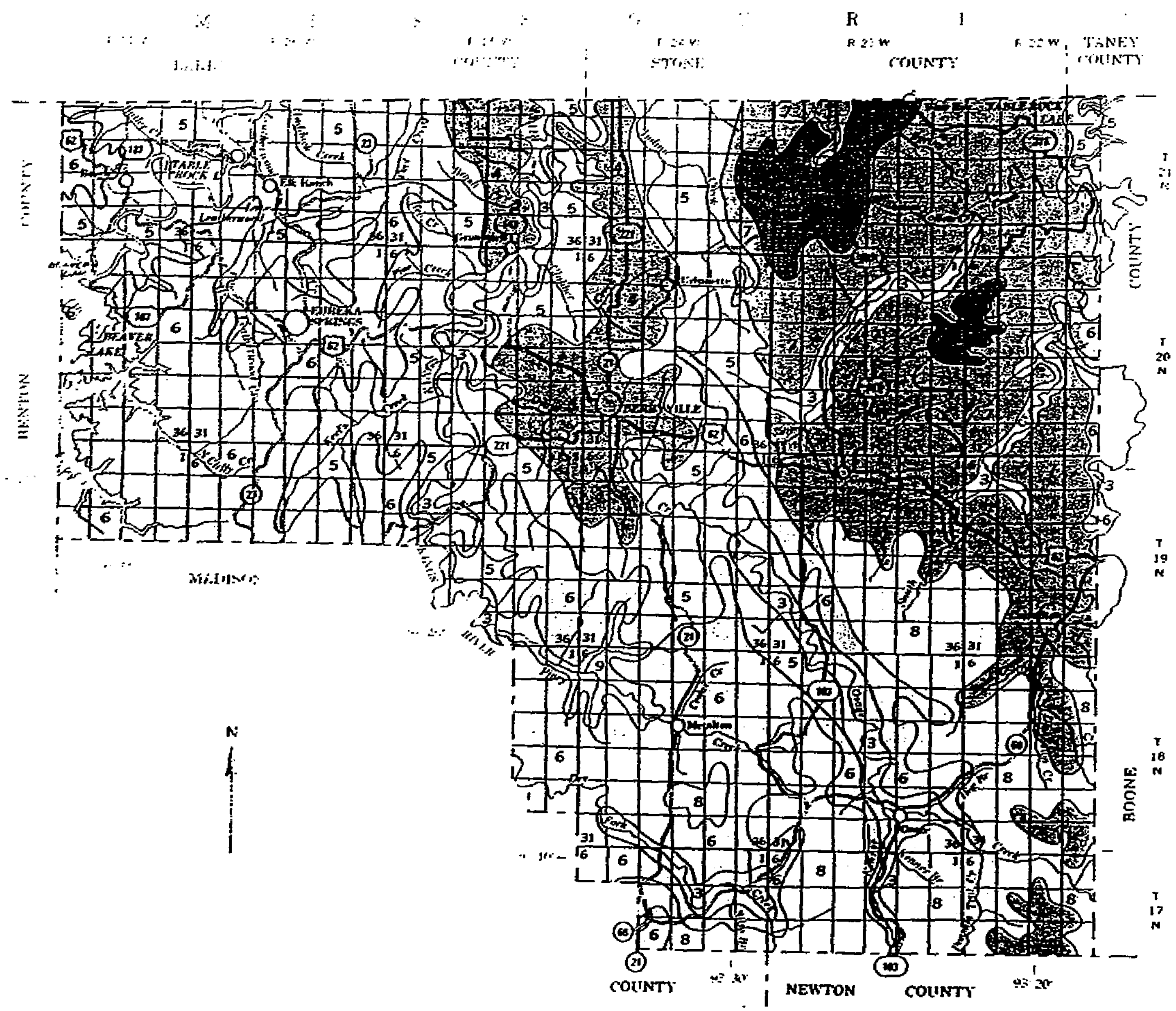
GENERAL SOIL MAP

CALHOUN COUNTY, ARKANSAS

Scale 1:253,440

0 1 2 3 4 Miles

0 4 8 Km



SECTIONALIZED TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

LEGEND

AREAS DOMINATED BY LOAMY, VERY CHERTY, STONY, AND VERY STONY SOILS: ON THE TOPS AND SIDES OF MOUNTAINS AND ON STREAM TERRACES, PLATEAUS, AND FLOOD PLAINS

Captina-Nixa: Deep, nearly level to gently sloping, moderately well drained, loamy and very cherty soils that formed in loamy and cherty material over limestone and residuum of cherty limestone

Linker-Cane-Mountainburg: Deep to shallow, gently sloping to moderately steep, well drained and moderately well drained, stony, loamy, and very stony soils that were derived from sandstone

3 — Razort-Portia-Britwater: Deep, level to moderately sloping, well drained, loamy and gravelly soils that formed in loamy alluvium, residuum of sandstone, and old alluvium from limestone

AREAS DOMINATED BY VERY CHERTY, CHERTY, AND VERY STONY SOILS: ON HILLSIDES, RIDGES, AND MOUNTAINSIDES

Arkana-Eldon: Moderately deep and deep, gently sloping and moderately sloping, well drained, very cherty and cherty soils that formed in residuum of limestone

5 — Arkana-Moko: Moderately deep and shallow, moderately sloping to very steep, well drained, very cherty and very stony soils that formed in residuum of limestone or dolomite

6 — Clarksville-Nixa: Deep, gently sloping to very steep, somewhat excessively drained and moderately well drained, very cherty soils that formed in residuum of cherty limestone

Noark: Deep, gently sloping to steep, well drained, very cherty soils that formed in residuum of cherty limestone

AREAS DOMINATED BY STONY AND VERY STONY SOILS: ON MOUNTAINS, HILLS, AND RIDGES

8 — Enders-Mountainburg-Leesburg: Deep and shallow, moderately sloping to steep, well drained, stony and very stony soils that formed in colluvium and residuum of acid shale and acid sandstone

9 — Ramsey-Lily: Shallow and moderately deep, steep, somewhat excessively drained and well drained, very stony and stony soils that formed in residuum of sandstone

*The texture given in the descriptive headings of each map unit refers to the surface layer of the major soils in the map unit.

Compiled 1982

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION

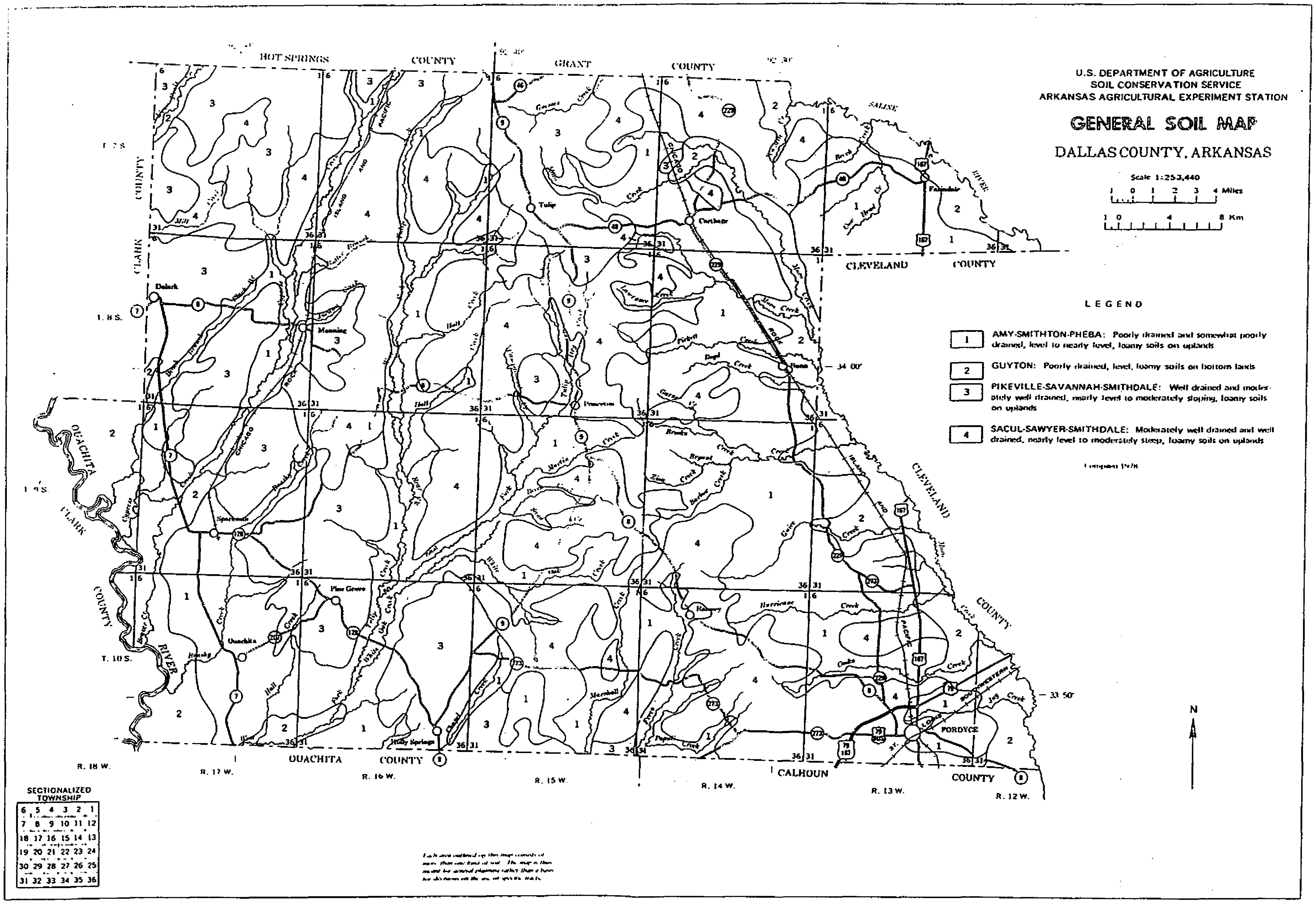
GENERAL SOIL MAP

CARROLL COUNTY, ARKANSAS

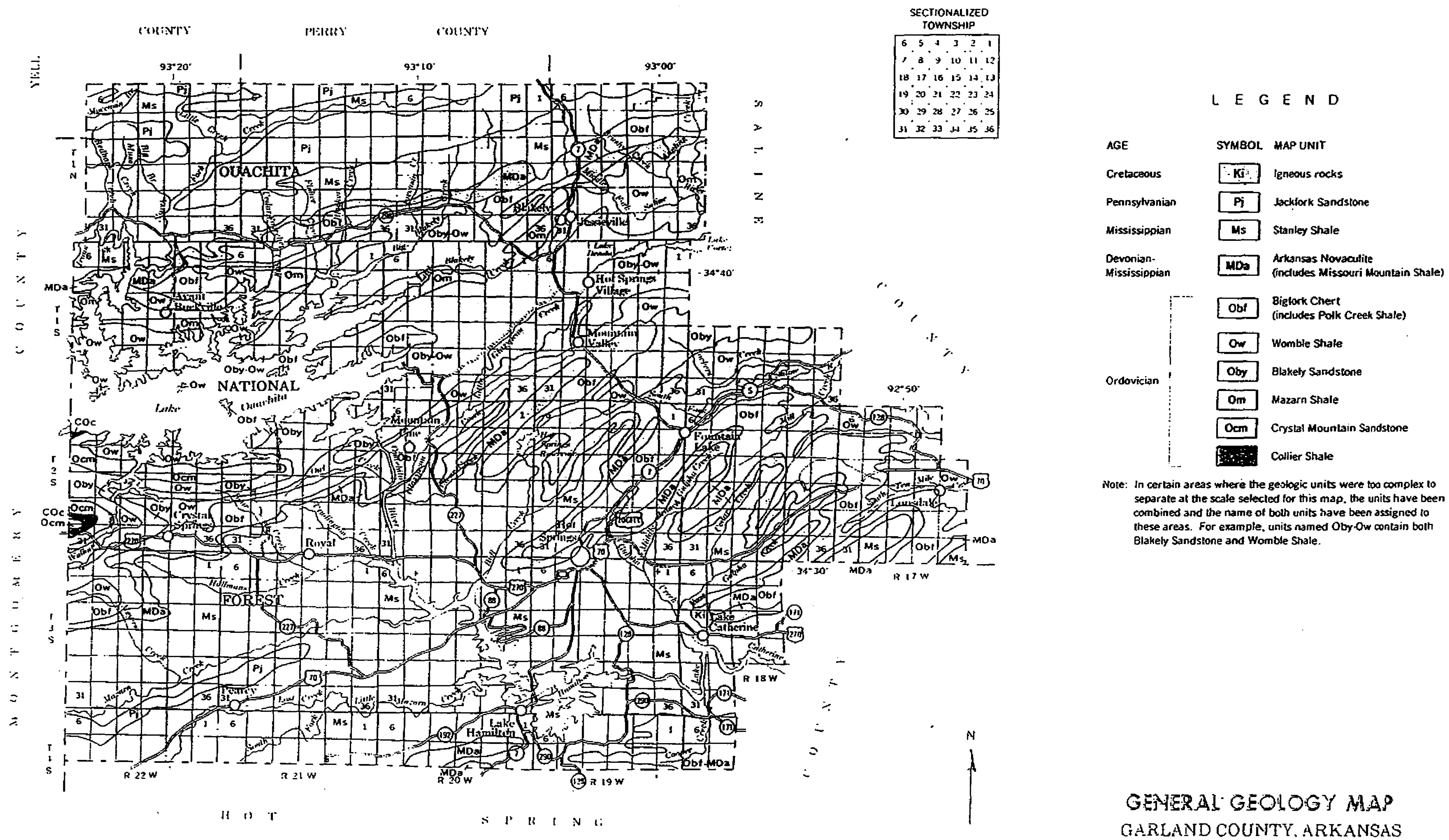
Scale 1:253,440

1 0 1 2 3 4 Miles

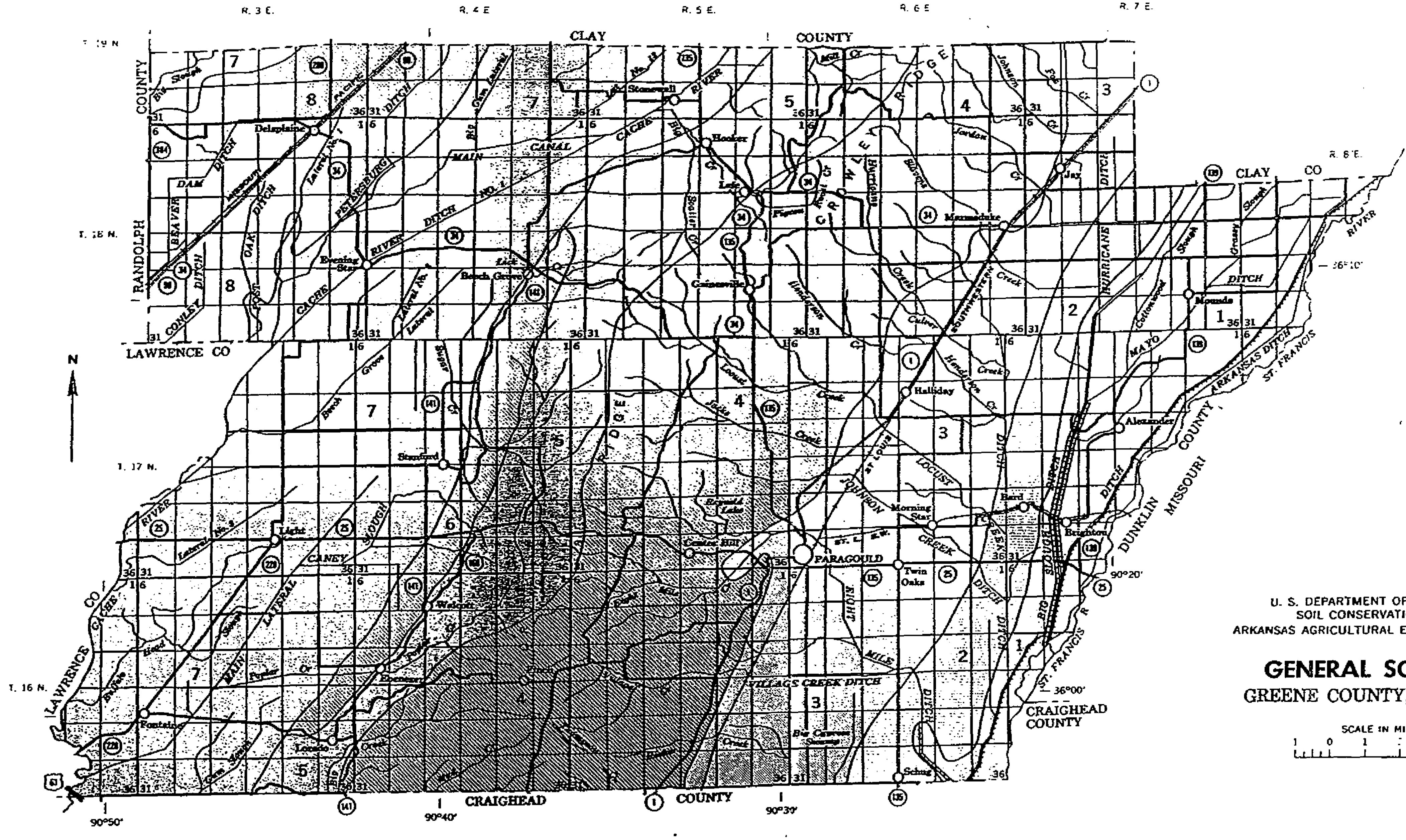
1 0 4 8 Km



U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION
GENERAL SOIL MAP
DALLAS COUNTY, ARKANSAS
Scale 1:253,440
1 0 1 2 3 4 Miles
1 0 4 8 Km
LEGEND
1 AMY-SMITHTON-PHEBA: Poorly drained and somewhat poorly drained, level to nearly level, loamy soils on uplands
2 GUYTON: Poorly drained, level, loamy soils on bottom lands
3 PIKEVILLE-SAVANNAH-SMITHDALE: Well drained and moderately well drained, nearly level to moderately sloping, loamy soils on uplands
4 SACUL-SAWYER-SMITHDALE: Moderately well drained and well drained, nearly level to moderately steep, loamy soils on uplands
HOT SPRINGS COUNTY
GRANT COUNTY
CLEVELAND COUNTY
CLARK COUNTY
OUACHITA COUNTY
CALHOUN COUNTY
OUACHITA RIVER
SALINE RIVER
Dalark
Manning
Sparkman
Pine Grove
Ouachita
Holly Springs
Tulip
Carthage
Princeton
Fordyce
Fairview
R. 18 W.
R. 17 W.
R. 16 W.
R. 15 W.
R. 14 W.
R. 13 W.
R. 12 W.
T. 8 S.
T. 10 S.
34 00'
33 50'
N
SECTIONALIZED TOWNSHIP
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36



GENERAL GEOLOGY MAP
GARLAND COUNTY, ARKANSAS



U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION

GENERAL SOIL MAP

GREENE COUNTY, ARKANSAS

SCALE IN MILES

1 0 1 2 3 4

SOIL ASSOCIATIONS

1 Sharkey association: Poorly drained, level to undulating, clayey soils in slack-water areas

2 Askew-Bosket-Bruno association: Somewhat poorly drained to excessively drained, level to undulating, loamy and sandy soils on natural levees

3 Calhoun-Calloway association: Poorly drained and somewhat poorly drained, level and nearly level soils that formed in a thick layer of silt

4 Loring-Memphis association: Moderately well drained and well drained, nearly level to steep soils that formed in a thick layer of silt

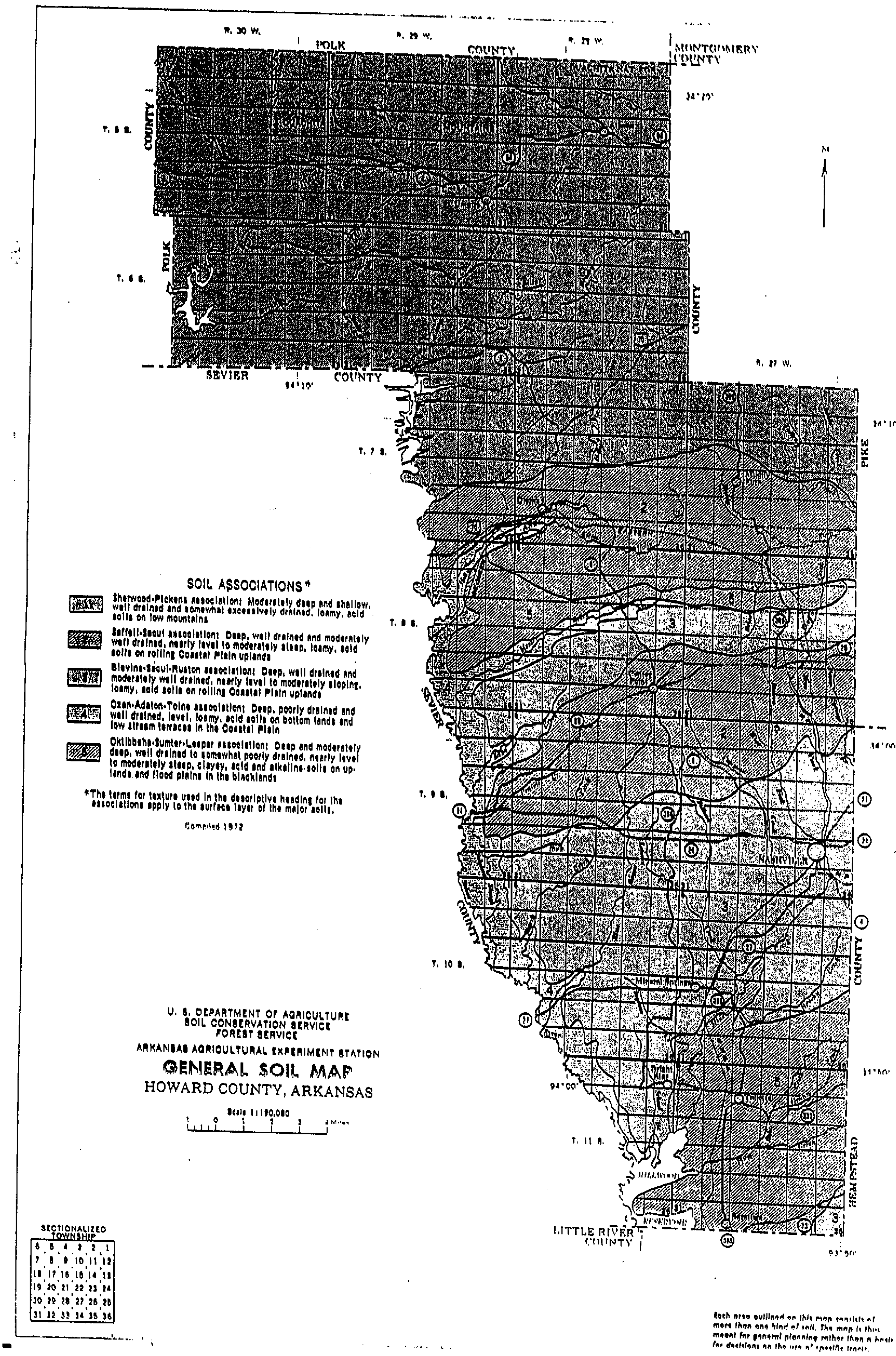
5 Brandon association: Well-drained, gently sloping to steep soils that formed in a thin layer of silt over gravelly and sandy material

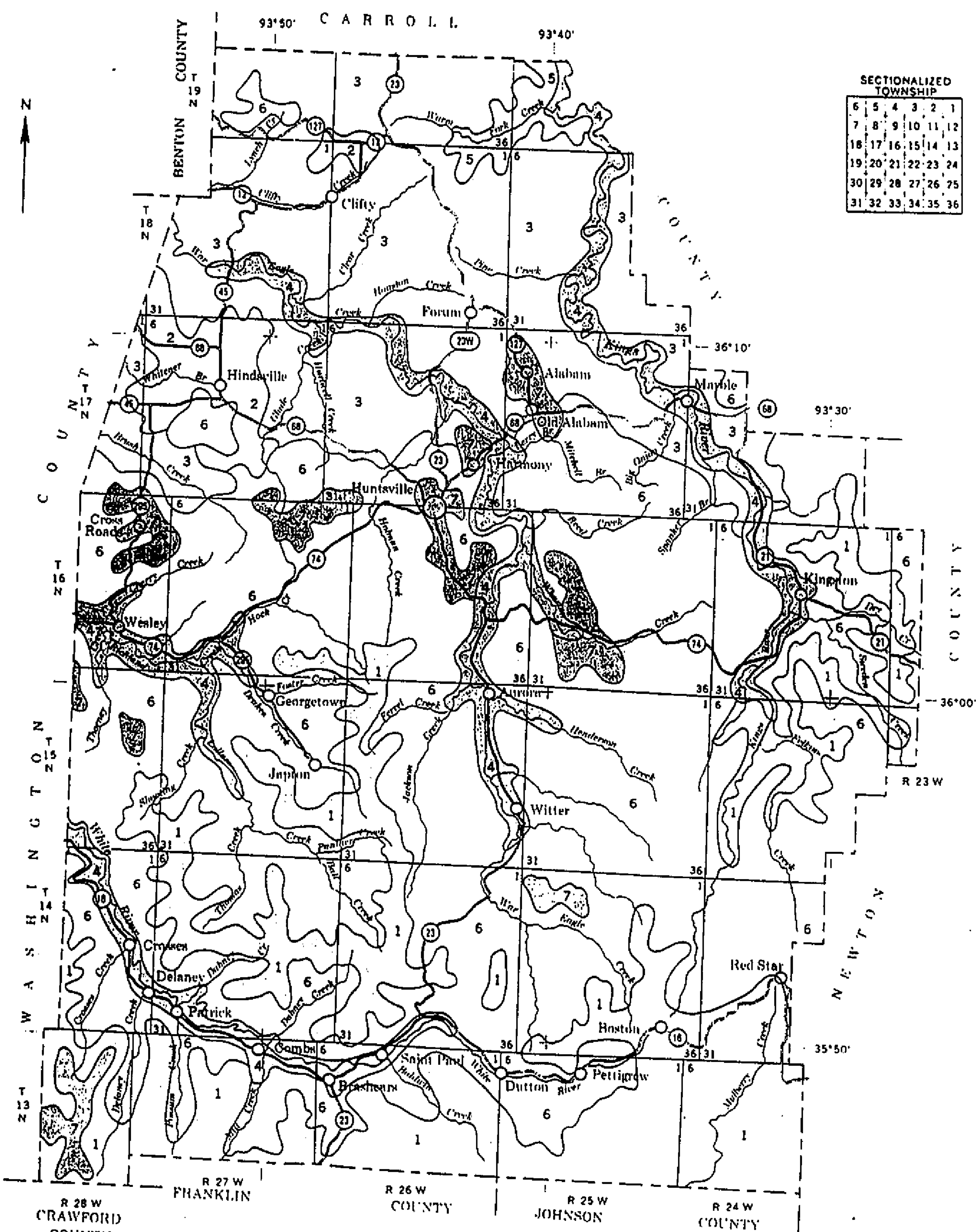
6 Falaya-Collins association: Somewhat poorly drained and moderately well drained, level soils that formed in silty alluvium

7 Foley-Alligator-Askew association: Poorly drained and somewhat poorly drained, level to undulating, loamy and clayey soils on low terraces

8 Alligator-Foley association: Poorly drained and somewhat poorly drained, level and nearly level, loamy and clayey soils on low terraces

February 1969


R. 30 W.
R. 29 W.
R. 28 W.
R. 27 W.
POLK COUNTY
MONTGOMERY COUNTY
PIKE COUNTY
HEMPSTEAD
LITTLE RIVER COUNTY
SEVIER COUNTY
SEVIER COUNTY
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
T. 9 S.
T. 10 S.
T. 11 S.
34°20'
34°10'
34°00'
33°50'
94°10'
94°00'
93°50'
NASHVILLE
Mineral Springs
N
SOIL ASSOCIATIONS*
1 Sherwood-Pickens association: Moderately deep and shallow, well drained and somewhat excessively drained, loamy, acid soils on low mountains
2 Saffell-Sacul association: Deep, well drained and moderately well drained, nearly level to moderately steep, loamy, acid soils on rolling Coastal Plain uplands
3 Blevins-Sacul-Ruston association: Deep, well drained and moderately well drained, nearly level to moderately sloping, loamy, acid soils on rolling Coastal Plain uplands
4 Ozan-Adaton-Toine association: Deep, poorly drained and well drained, level, loamy, acid soils on bottom lands and low stream terraces in the Coastal Plain
5 Oktibbeha-Sumter-Leeper association: Deep and moderately deep, well drained to somewhat poorly drained, nearly level to moderately steep, clayey, acid and alkaline soils on uplands and flood plains in the blacklands
*The terms for texture used in the descriptive heading for the associations apply to the surface layer of the major soils.
Compiled 1972
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
FOREST SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION
GENERAL SOIL MAP
HOWARD COUNTY, ARKANSAS
Scale 1:190,080
1 0 1 2 3 4 Miles
SECTIONALIZED TOWNSHIP
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36
Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.



6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

LEGEND

1 — NELLA-STEPROCK-MOUNTAINBURG: Deep, moderately deep, and shallow, gently sloping to very steep, well drained, gravelly, stony, and very stony soils that formed in colluvium and residuum of sandstone and small amounts of siltstone and shale.

2 — TONTI-PERIDGE-CAPTINA: Deep, nearly level to gently sloping, moderately well drained and well drained, loamy and cherty soils that formed in loamy and cherty material

3 — NIXA-CLARKSVILLE-NOARK: Deep, gently sloping to very steep, moderately well drained, somewhat excessively drained, and well drained, very cherty soils that formed in residuum of cherty limestone

4 — CEDA-LEADVALE-CLEORA: Deep, level to gently sloping, well drained and moderately well drained, loamy, gravelly, and cobbly soils that formed in alluvium derived mainly from sandstone, siltstone, and shale or in colluvium from sandstone and shale

5 — ARKANA-MOKO: Moderately deep and shallow, moderately sloping to steep, well drained, very cherty and very stony soils that formed in residuum of limestone or dolomitic limestone

6 — ENDERS-LEESBURG: Deep, gently sloping to steep, well drained, stony and gravelly soils that formed in residuum of acid shale and in colluvium from acid shale and sandstone

7 — STEPROCK-LINKER-MOUNTAINBURG: Moderately deep and shallow, gently sloping to moderately steep, well drained, loamy, gravelly, and stony soils that formed in residuum of acid sandstone interbedded with siltstone and shale

Compiled 1982

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
FOREST SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION

GENERAL SOIL MAP

MADISON COUNTY, ARKANSAS

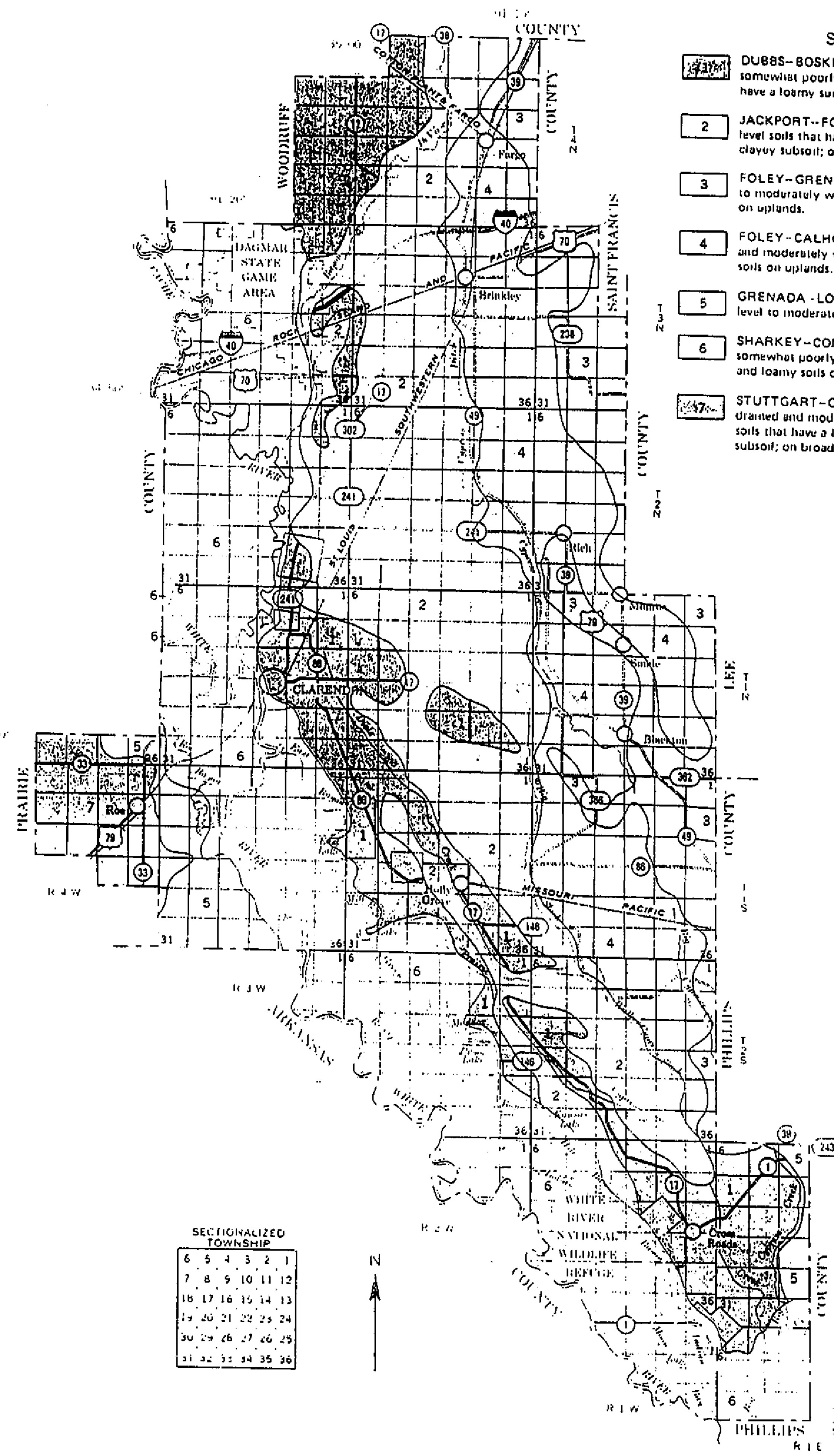
Scale 1:253,440

0 1 2 3 4 Miles

0 4 8 Km

U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE



SOIL ASSOCIATIONS

1	DUBBS-BOSKET-DUNDEE association: Well drained and somewhat poorly drained, level and gently undulating soils that have a loamy surface layer and subsoil; on bottom land.
2	JACKPORT--FOLEY-BONN association: Poorly drained, level soils that have a loamy surface layer and a loamy and clayey subsoil; on broad upland flats.
3	FOLEY-GRENADA-CALLOWAY association: Poorly drained to moderately well drained, level to gently sloping, loamy soils on uplands.
4	FOLEY-CALHOUN-GRENADA association: Poorly drained and moderately well drained, level to gently sloping, loamy soils on uplands.
5	GRENADA-LORING association: Moderately well drained, level to moderately sloping, loamy soils on uplands.
6	SHARKEY-COMMERCE association: Poorly drained and somewhat poorly drained, level and gently undulating clayey and loamy soils on flood plains.
7	STUTTGART-CROWLEY association: Somewhat poorly drained and moderately well drained, level and nearly level soils that have a loamy surface layer and a clayey and loamy subsoil; on broad upland flats.

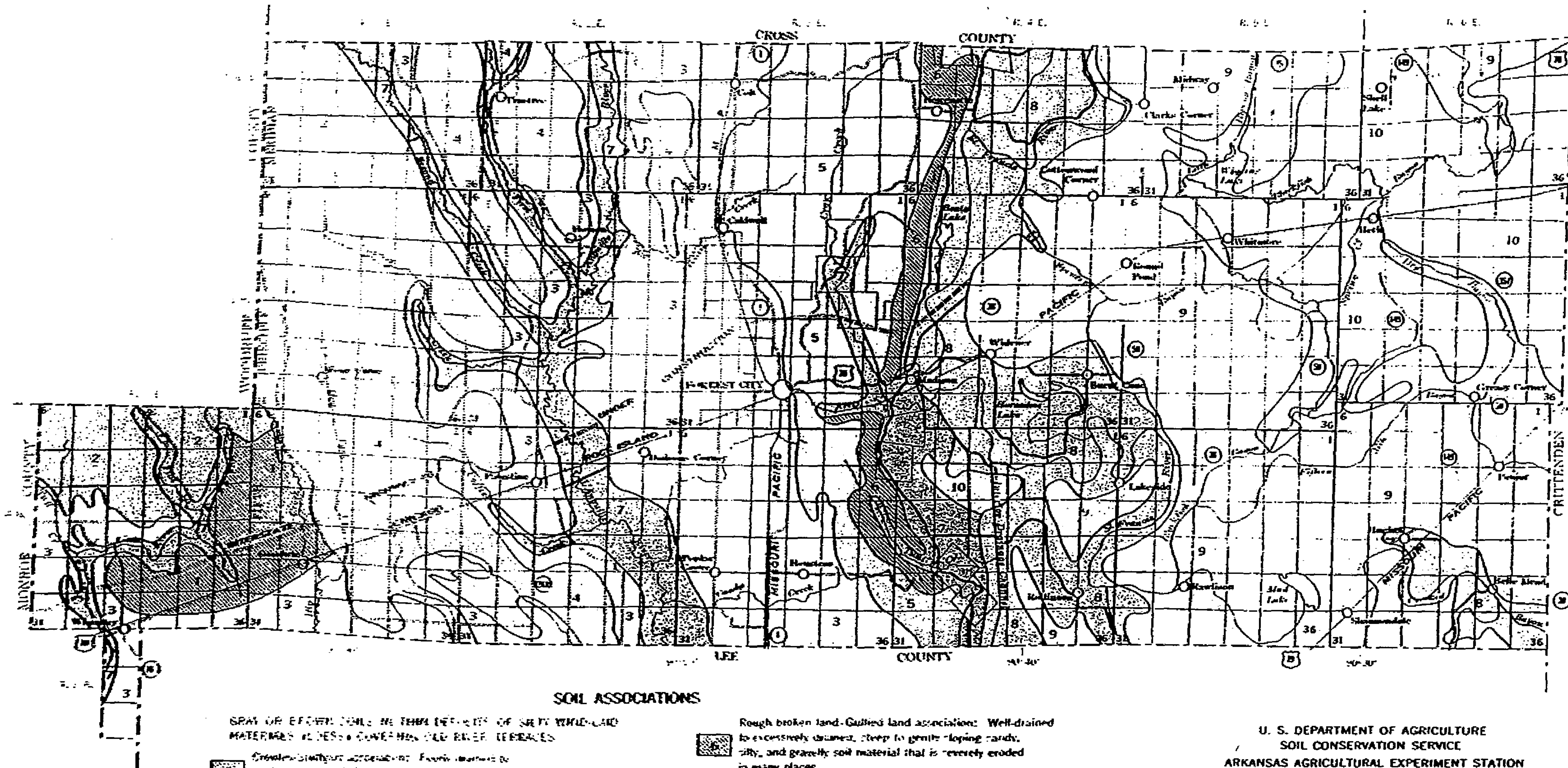
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION

GENERAL SOIL MAP

MONROE COUNTY, ARKANSAS

Scale 1:253,440

Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.



SOIL ASSOCIATIONS

GRAY OR BROWN SOILS IN THIN DEPOSITS OF SILTY WIND-LAID MATERIALS (LOESS) COVERING OLD RIVER TERRACES

1 Crowley-Stuttgart association: Poorly drained to moderately well drained, level or nearly level soils that have an acid, clayey subsoil (claypan)

GRAY OR BROWN SOILS IN THICK DEPOSITS OF SILTY WIND-LAID MATERIALS (LOESS) COVERING OLD RIVER TERRACES

2 Hillemann association: Somewhat poorly drained, level or nearly level soils that have a high content of salts (sodium and magnesium) in the lower subsoil

3 Calloway-Loring-Henry association: Moderately well drained to poorly drained, level to sloping soils that have a compact, brittle subsoil (fragipan)

4 Henry-Calhoun-Calloway association: Poorly drained or somewhat poorly drained, level or nearly level soils that have a compact, brittle subsoil (fragipan)

BROWN SOILS IN THICK DEPOSITS OF SILTY, SANDY, AND GRAVELLY MATERIALS ON HILLS AND RIDGES

5 Loring-Memphis association: Moderately well drained or well drained, nearly level to steep silty soils that have a brittle (fragipan) or firm subsoil

6 Rough broken land-Gullied land association: Well-drained to excessively drained, steep to gently sloping sandy, silty, and gravelly soil material that is severely eroded in many places

GRAY OR BROWN SOILS IN ALLUVIAL SEDIMENTS ON BOTTOM LANDS OF RIVERS

7 Zachary-Arkabutla-Collins association: Poorly drained to moderately well drained, level soils formed in thick, silty materials washed from uplands

8 Dubbs-Dundee-Beulah association: Somewhat poorly drained to somewhat excessively drained, level or undulating soils formed in sandy or silty sediments on natural levees

9 Earle-Bowdre association: Somewhat poorly drained, level or undulating soils formed in thin deposits of clayey materials over stratified sandy and clayey sediments

10 Alligator-Sharkey association: Poorly drained, level to undulating soils in thick deposits of clayey sediments

December 1965

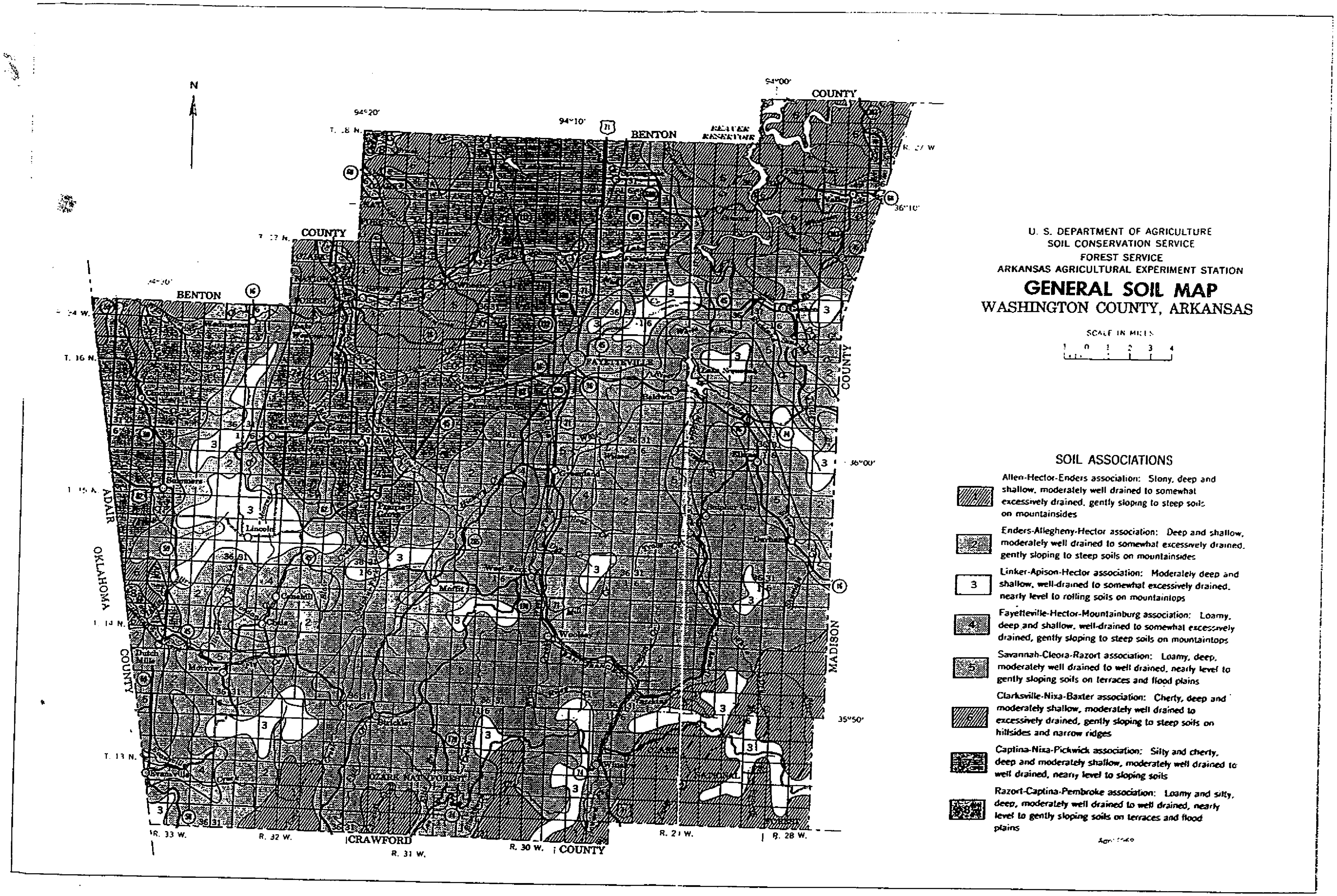
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION

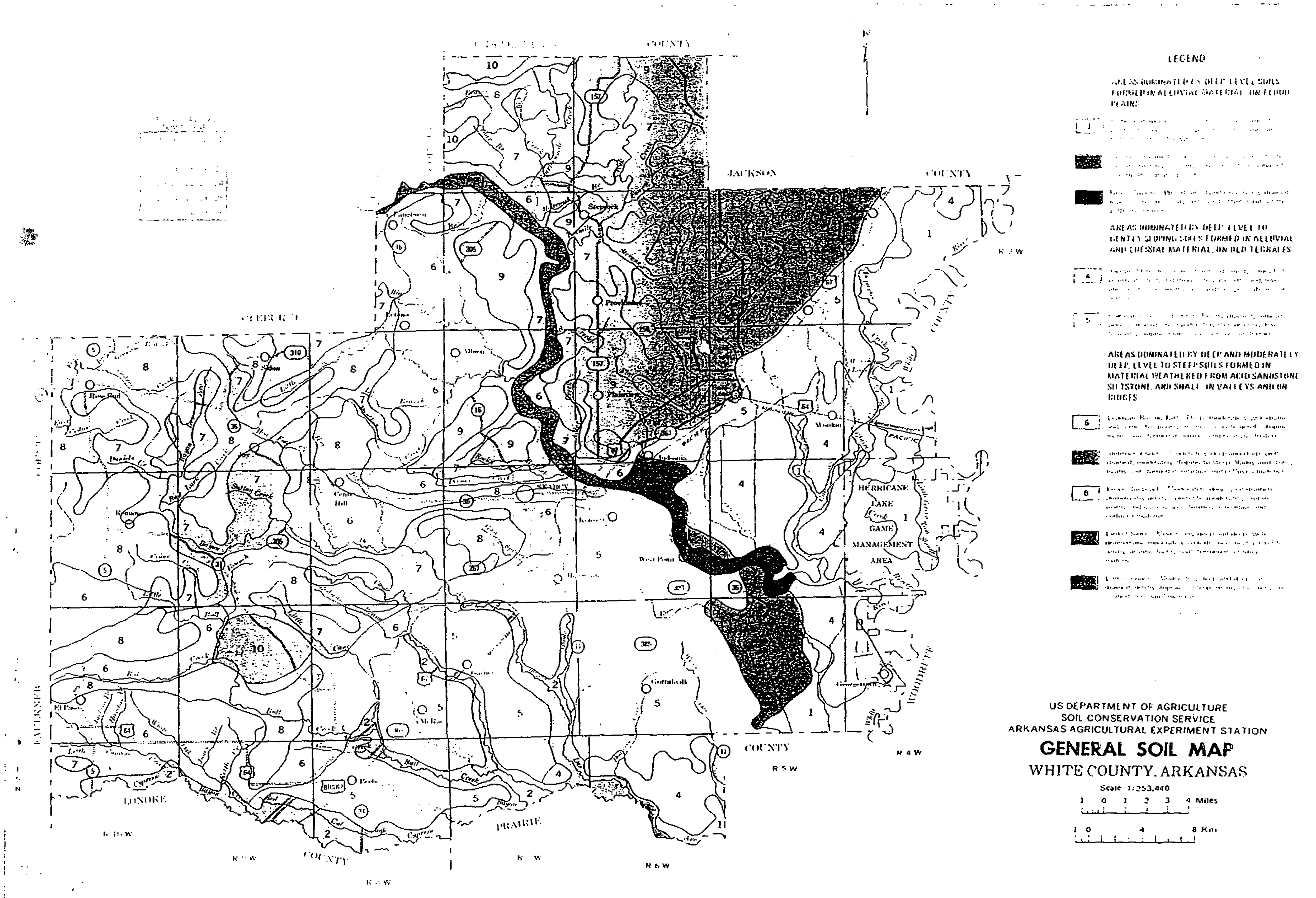
GENERAL SOIL MAP
ST FRANCIS COUNTY, ARKANSAS

Scale 1:190,080

0 1 2 3 4 Miles

N


U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
FOREST SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION
GENERAL SOIL MAP
WASHINGTON COUNTY, ARKANSAS
SCALE IN MILES
1 0 1 2 3 4
SOIL ASSOCIATIONS
1 Allen-Hector-Enders association: Stony, deep and shallow, moderately well drained to somewhat excessively drained, gently sloping to steep soils on mountainsides
2 Enders-Allegheny-Hector association: Deep and shallow, moderately well drained to somewhat excessively drained, gently sloping to steep soils on mountainsides
3 Linker-Apison-Hector association: Moderately deep and shallow, well-drained to somewhat excessively drained, nearly level to rolling soils on mountaintops
4 Fayetteville-Hector-Mountainburg association: Loamy, deep and shallow, well-drained to somewhat excessively drained, gently sloping to steep soils on mountaintops
5 Savannah-Cleora-Razort association: Loamy, deep, moderately well drained to well drained, nearly level to gently sloping soils on terraces and flood plains
6 Clarksville-Nixa-Baxter association: Cherty, deep and moderately shallow, moderately well drained to excessively drained, gently sloping to steep soils on hillsides and narrow ridges
7 Captina-Nixa-Pickwick association: Silty and cherty, deep and moderately shallow, moderately well drained to well drained, nearly level to sloping soils
8 Razort-Captina-Pembroke association: Loamy and silty, deep, moderately well drained to well drained, nearly level to gently sloping soils on terraces and flood plains
N
BENTON
COUNTY
FAYETTEVILLE
OKLAHOMA
ADAIR
MADISON
CRAWFORD
Lincoln
OZARK NATIONAL FOREST
R. 33 W.
R. 32 W.
R. 31 W.
R. 30 W.
R. 28 W.
T. 16 N.
T. 14 N.
T. 13 N.
94°20'
94°10'
94°00'
36°10'
36°00'
35°50'



LEGEND
AREAS DOMINATED BY DEEP LEVEL SOILS FORMED IN ALLUVIAL MATERIAL ON FLOOD PLAINS
AREAS DOMINATED BY DEEP LEVEL TO GENTLY SLOPING SOILS FORMED IN ALLUVIAL AND LOESSIAL MATERIAL, ON OLD TERRACES
AREAS DOMINATED BY DEEP AND MODERATELY DEEP, LEVEL TO STEEP SOILS FORMED IN MATERIAL WEATHERED FROM ACID SANDSTONE, SILTSTONE, AND SHALE, IN VALLEYS AND ON RIDGES
JACKSON
COUNTY
LONOKE
PRAIRIE
FAULKNER
WOODRUFF
SEARCY
HURRICANE LAKE GAME MANAGEMENT AREA
PACIFIC
R 4 W
R 5 W
R 6 W
US DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ARKANSAS AGRICULTURAL EXPERIMENT STATION
GENERAL SOIL MAP
WHITE COUNTY, ARKANSAS
Scale 1:253,440
1 0 1 2 3 4 Miles
1 0 4 8 Km

Appendix D

Causes of Structural Failure of Culverts

Causes of Structural Failure of Culverts

by

R. P. Selvan, PhD, P.E.

1. INTRODUCTION

Culverts must be designed to support the dead load of the soil over the culvert as well as live loads of traffic. Generally live loads on culverts are not as significant as the dead load unless the cover is shallow.

In most culvert designs soil surrounding the culvert plays an important structural role. The stability of the surrounding soil is important to the structural performance of most culverts.

Culverts can be classified structurally based upon material type as flexible and rigid. The steel aluminum and plastic pipe are some of the flexible culverts. They can be bent or distorted without cracking. Hence, flexible culverts depend on the backfill support to resist bending. Rigid culverts are stiff and do not deflect appreciably. Reinforced concrete provides resistance to bending on its own strength. The structural behavior of flexible and stiff culverts are well explained in the Federal Highway Administration culverts inspection manual (1).

2. PAVEMENT FAILURES DUE TO IMPROPER CONSTRUCTION

Pavement Type

Rigid pavements (concrete) bridge over minor subsurface voids while flexible pavements (asphalt) have little bridging capability. Settlement of material beneath the pavement can lead to cracking in rigid and irregular settlement in flexible pavements as explained in Fig. 1.

Structure Type

Flexible culverts will deflect if adequate lateral support is not provided by the surrounding soil. This may result in loss of support for the approach pavement and usually results in settlement over the culvert. Inadequate compaction of backfill for rigid culverts usually results in settlement beside the culvert as shown in Fig. 2.

Structure Shape

Culverts may deflect downward and displace material laterally. This may result in roadway settlement and loss of pavement support beside the culvert.

3. FLEXIBLE CULVERTS

Aluminum, steel and plastic culverts are classified as flexible structures because they respond to and depend upon the soil backrill to provide structural stability and support to the culvert. The flexible culvert resists the loading by ring compression.

The following are the possible structural failure:

1. Excessive deflection of the pipe which leads to instability of the supporting soil. For the round and vertical elongated metal pipe; if the horizontal diameter is more than 15 percent to 20 percent greater than the design diameter would indicate poor to critical condition (1).

2. Vertical and horizontal misalignment of the pipes during construction may affect structural or hydraulic performance.

3. Joint defects of the pipes may lead to backfill infiltration and water exfiltration. Excessive seepage through an open joint can cause soil infiltration or erosion of the surrounding backfill material reducing lateral support. The defects in joints can affect the surrounding as shown in Fig. 3.

4. Defects in concrete footing may lead to failure of the pipe. The possible structural defect is differential settlement as shown in Fig. 4.

5. Defects in concrete inverts may lead to erosion as shown in Fig. 5.

4. RIGID PIPE CULVERTS

Concrete culverts are classified as rigid pipe. Although the need for soil stability and side support is important for flexible pipe, it is less important with rigid pipe. However, adequate stability of the surrounding soil is necessary to prevent settlement around the culvert and to achieve load carrying capability.

Different types of failures anticipated:

1. Misalignment may indicate the presence of serious problems in the supporting soil. Alignment problems may be caused by improper installation, undermining or uneven settlement of fill. The undermining may be caused by piping, water exfiltration, or infiltration of backfill material.

2. Joint defects may lead to failure. Typical joint defects are leakage (ecfiltration and infiltration), cracks and joint separation.

Exfiltration: Exfiltration occurs when leaking joints allowing flowing through the pipe to leak into the supporting material. This can lead to piping, erosion of surrounding soil and misalignment.

Infiltration: Infiltration is the opposite of exfiltration. When the water table is higher than the culvert invert, water may seep in to the culvert between storms. This infiltration of water can cause settlement and misalignment problems if it carries fine grained soil particles from surrounding backfill.

3. Cracks: Cracks may be caused by improper handling during installation, improper gasket placement, and movement or settlement of the pipe sections. The effect of severe joint cracks are similar to separated joints.

4. Separated Joints: Joint separation causes damage similar to joint defects.

5. Longitudinal cracks: Longitudinal cracking in excess of 0.1 inch in width may indicate overloading or poor bedding. If the pipe is placed on hard material and backfill is not adequately compacted around the pipe or under the pipe, loads will be concentrated along the bottom of the pipe and may result in flexure or shear cracking as illustrated in Fig. 6.

6. Transverse Cracks: Transverse or circumferential cracks may be caused by poor bedding. Cracks can occur at the bottom of the pipe when the pipe is supported only at the ends of each section. This is generally the result of poor construction practices. Cracks may occur at the top of the pipe when settlement occurs and rocks or other areas of hard foundation material near the midpoint of a pipe section are not adequately covered with suitable bedding material. Transverse cracking is illustrated in Fig. 7.

7. Spalling: Spalling is a fracture of the concrete parallel or inclined to the surface of the concrete. In precast concrete pipe, spalls often occur along the edges of either longitudinal or transverse cracks when the cracks are due to overloading. Spalling may also be caused by corrosion. Spalling is illustrated in Fig. 8.

8. Slabbing: The term slabbing, shear slabbing or slab shear refer to a radial failure of the concrete which occurs from straightening of the reinforcement cage due to excessive deflection. It is characterized by large slabs of concrete "peeling" away from the sides of a pipe and a straightening of the reinforcement steel as shown in Fig. 9. Slabbing is a serious problem that may occur under high fills.

9. End Section Drop off: This type of failure is usually due to outlet erosion. It is caused by the erosion of the material supporting the pipe section on the outlet end of the culvert barrel.

For other type culverts such as arches and masonry; the failure mechanisms are discussed in detail in reference 1.

5. RECENT SURVEYS ON POLYETHYLENE PIPE

Fleckenstein and Allen (2) reported that polyethylene pipe appears to perform satisfactorily as cross drains, storm drains and entrance pipe when properly bedded and backfilled with high shear strength material. They found from their study after four years of installation that long-term deflections do not appear to be a problem when pipe are properly installed.

In the work of Kessler and Powers (3) on high density polyethylene pipe (HDPE) fire risk evaluation; they concluded that HDPE pipe is not at significant risk of fire when installed to present standards and exposed to fire such as that which may be encountered in roadside grass fires. Their state by state survey shows that at least forty-one states use HDPE pipe. Of the forty-one responses to the survey, only four reported fires in polyethylene pipe and were judged as minor isolated instances.

Hunt (4) from DOT Colorado reports that after three years of service the polyethylene pipes have not cracked, melted or worn and are in good overall condition. One culvert however burned from about ten feet into one end as a result of the ignition of sawdust that had collected in it from a nearby sawmill.

REFERENCES

1. CIM, 1986, Culvert Inspection Manual, Report No. FHWA-IP-86-2, Federal Highway Administration, Washington, D.C.

2. Fleckenstein, L. J., and Allen, D. L., 1991, Field Performance Report on Corrugated Polyethylene Pipe, Research Report KTC-91-17, Kentucky Transportation Center, University of Kentucky, Lexington.

3. Kessler, R. J., and Powers, R. G., 1994, High Density Polyethylene pipe Fire Risk Evaluation, Report No. 94-7A, Corrosion Research Laboratory, Florida Department of Transportation.

4. Hunt, T. R., 1991, Polyethylene Pipes for Use as Highway Culverts, Report No. CDPT-DTD-R-91-9, Colorado Department of Transportation, Denver.

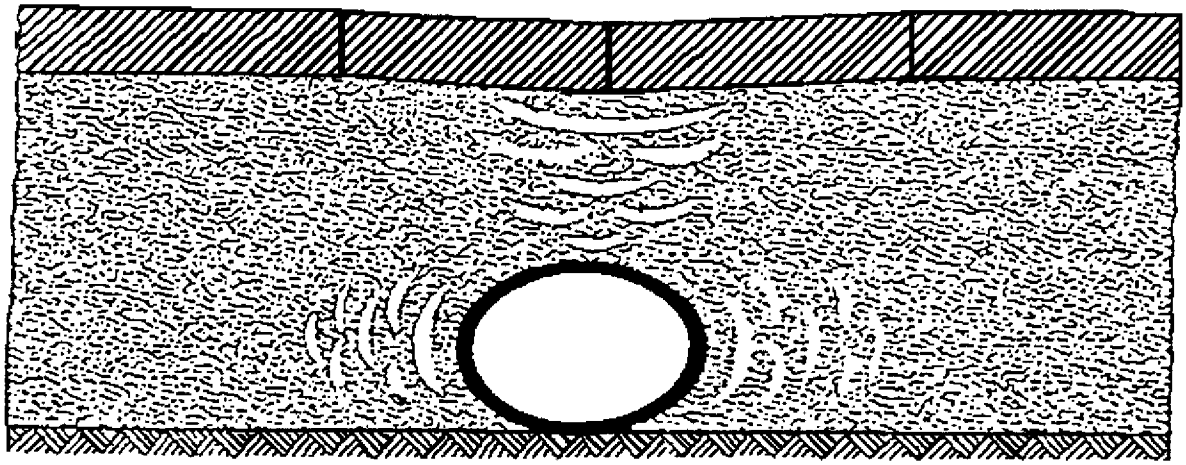


Figure 16. Pavement failure due to inadequate compaction or material quality adjacent to flexible pipe. *[Source: Effects of Loads on Storm Drains and Culverts, U.S. Army Corps of Engineers]*

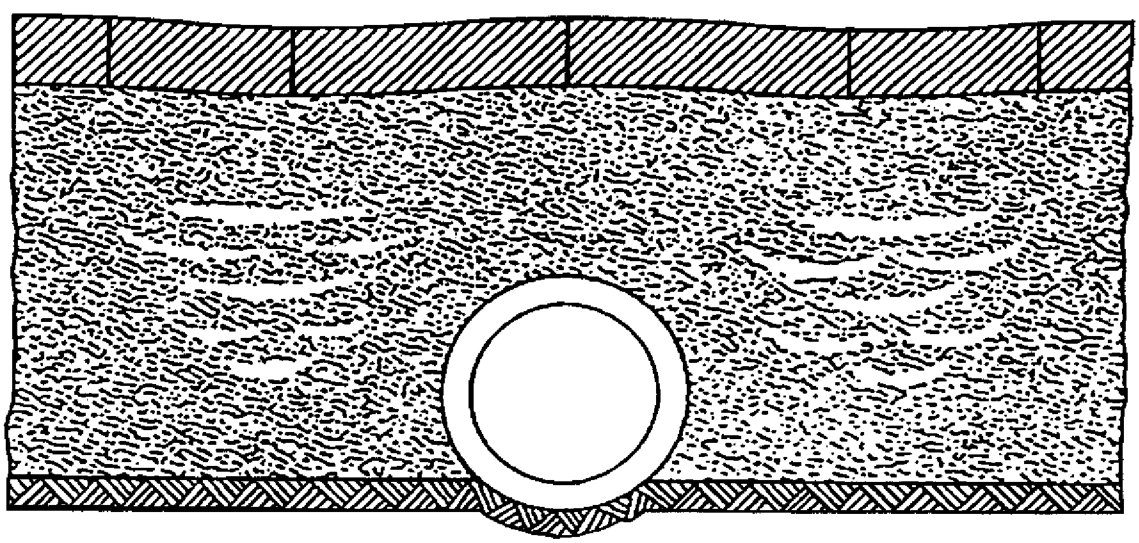


Figure 17. Pavement failure due to inadequate compaction or material quality adjacent to rigid pipe. *[Source: Effects of Loads on Storm Drains and Culverts, U.S. Army Corps of Engineers]*

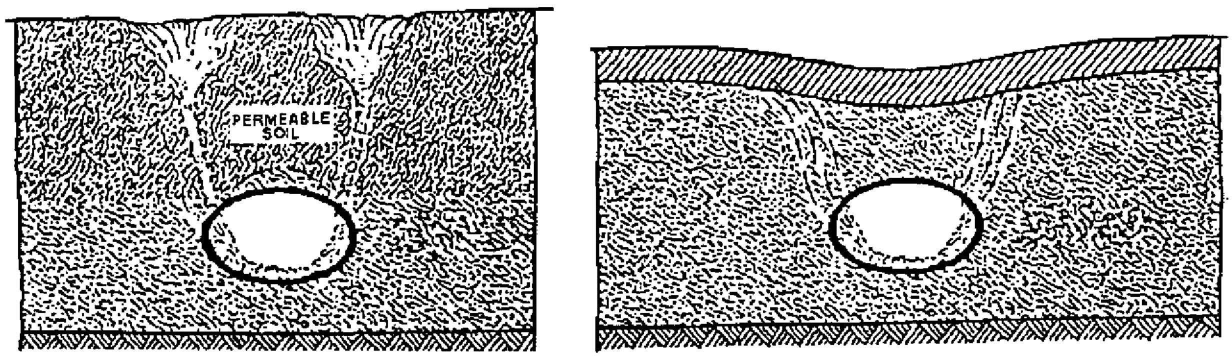


Figure 18. Surface indications of infiltration. Left: Effect on unpaved areas. Right: Effect on pavement.

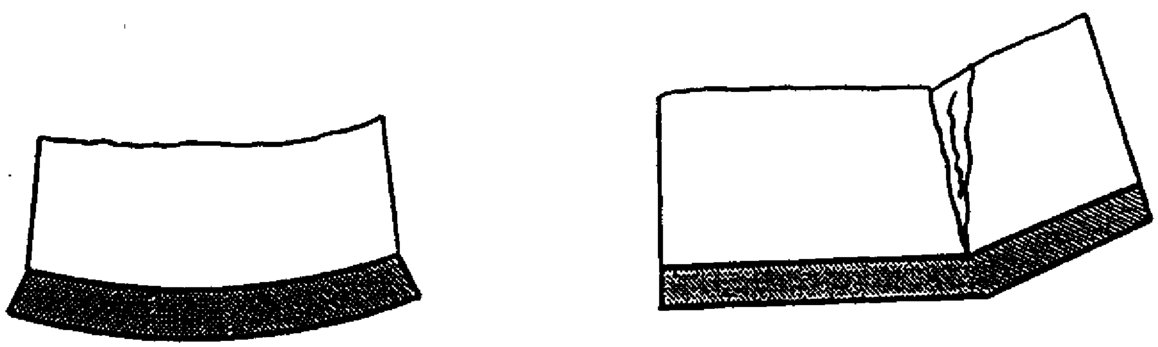


Figure 19. Differential footing settlement. Left: No distress in arch. Right: Distress in arch.

Figure 20. Erosion damage to concrete invert.

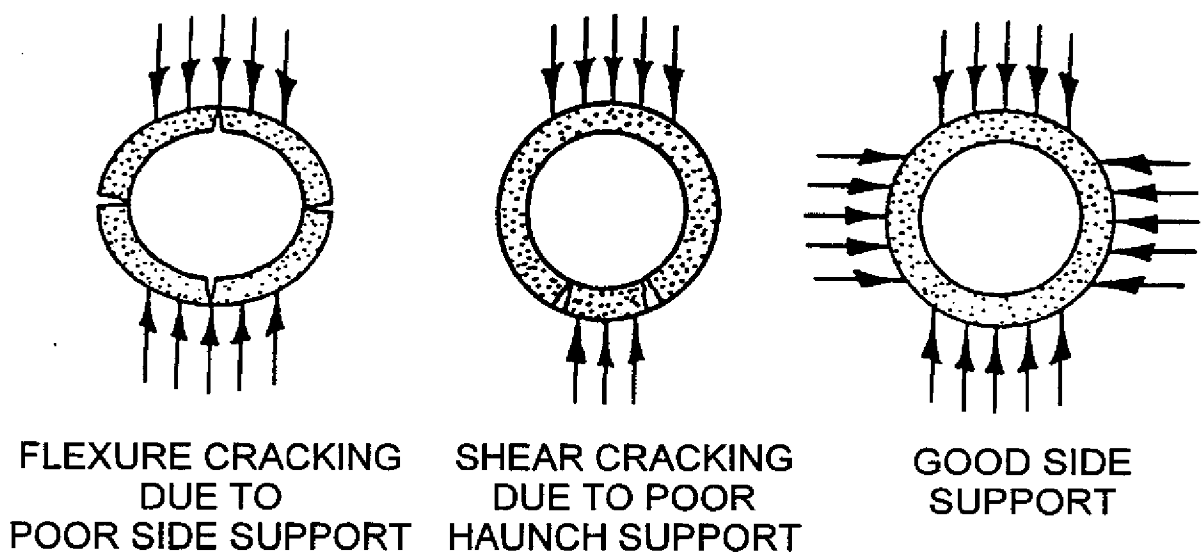


Figure 21. Results of poor and good side support, rigid pipe.

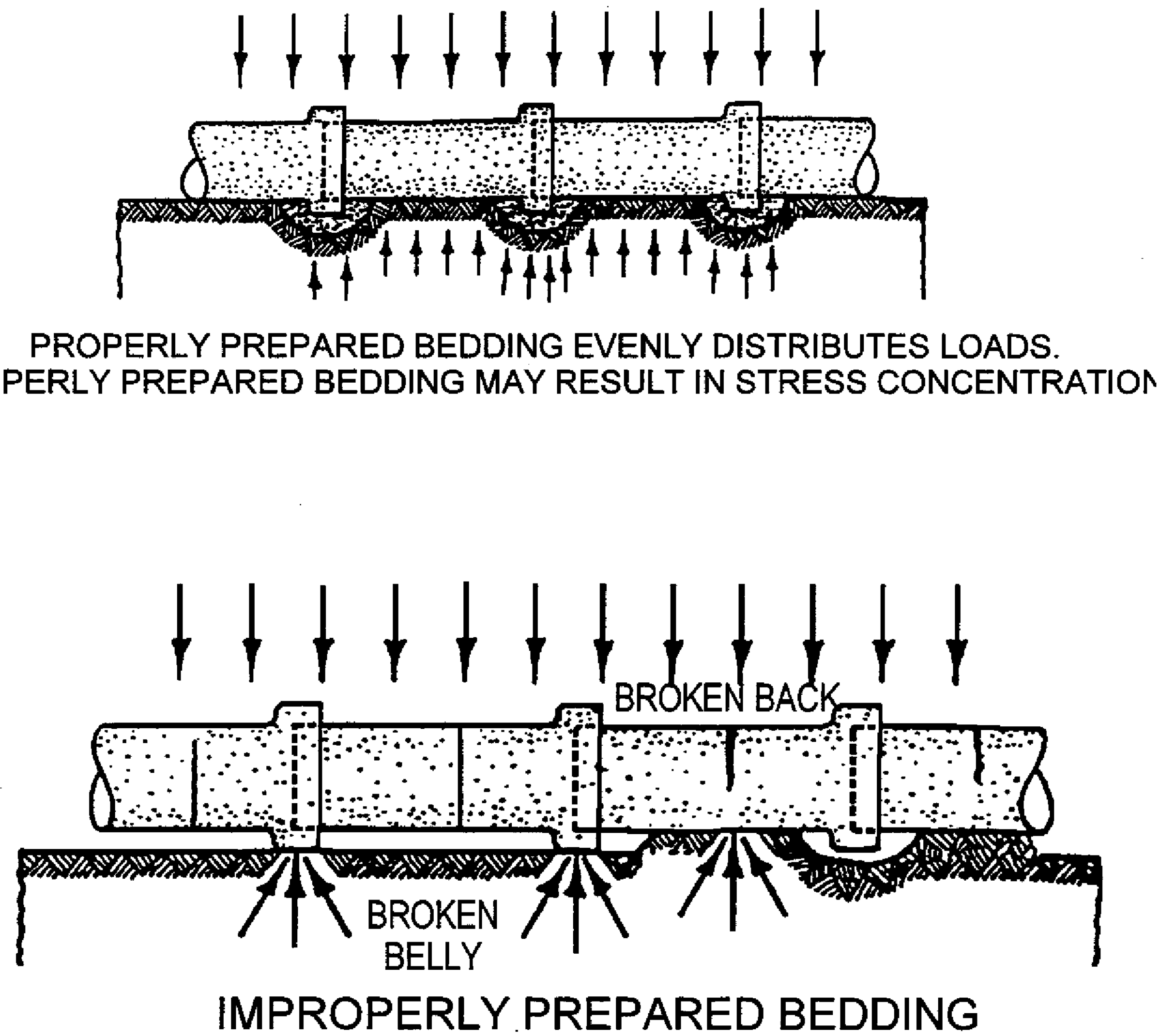


Figure 22. Transverse or circumferential cracks.

Figure 23. Spalling exposing reinforcing steel.

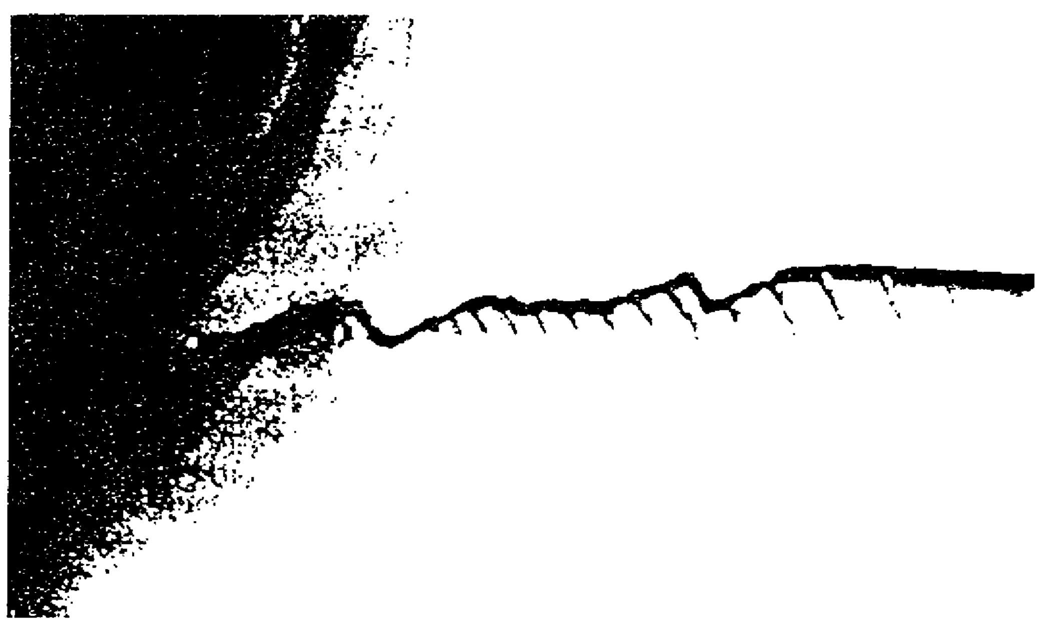


Figure 24. Shear slabbing.