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WATER RESOURCES DIVISION

# A PLAN FOR WATER-RESOURCES INVESTIGATIONS IN ARKANSAS WITH DEFINITION OF HYDROLOGIC UNITS

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# A PLAN FOR WATER-RESOURCES INVESTIGATIONS IN ARKANSAS WITH DEFINITION OF HYDROLOGIC UNITS

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## INTRODUCTION

Water studies by the Water Resources Division, U.S. Geological Survey, have been in progress in Arkansas since 1927. Most of the studies to date (1970) have been designed to provide answers to developmental questions such as where, how much, and what kind of water can be obtained. These studies have provided and will continue to provide excellent descriptions of Arkansas' water resources as well as much of the current-purpose data needed in the daily use of water.

Descriptive studies have been made and current-purpose data have been collected most expeditiously by studies of relatively narrow scope. In other words, if the flow of a stream was in question, only the flow at a given point was determined. If the depth to water in an aquifer was in question, only this particular parameter was determined. Water studies of this type, in varying degrees of intensity, cover the entire State. In modern hydro-modeling parlance, descriptive (qualitative) models of Arkansas' water resources have been achieved and provide most of the answers to where, how much, and what kind of water is available.

However, water development in Arkansas has advanced rapidly in the last 10 years and many of today's demands for water information are of the management type. The questions are what effect will certain developments have, what is the time frame for the effects, how can we conserve and preserve our water, what esthetics are involved, and what are the water interrelationships. These questions indicate we are entering an advanced management phase of water utilization.

The static "what, where, and what kind" models were adequate as long as the water development was small and the questions simple. When water development and use and water-quality modifications have a significant impact on the available water, the questions become complex and descriptive models become inadequate. Thus, to provide appropriate answers to these complex questions, new tools must be utilized.

Detailed and quantitative cause-effect models have been developed for the Arkansas River valley and the Sparta Sand in Arkansas for specific purposes. The use of these models has demonstrated their capability in providing answers to complex water-management type questions arising from interacting effects of water development. In these models the scope of study cannot be restricted to rivers, aquifers, springs, lakes, or reservoirs. Instead, the total water system, incorporating all the water in a given area, must be considered.

The purpose of this report is to describe an approach to water studies that will provide a statewide framework for evaluating effects of proposed water-resources development. This report includes (1) the delineation of "hydro-logical" study units or subsystem, (2) a preliminary plan for study of one subsystem (Bayou Bartholomew), and (3) a description of selected subsystems in Arkansas.

## SUBSYSTEM DELINEATION

The water resources in Arkansas comprise an immense hydrologic complex that could be studied as a single unit. However, this is not feasible because needs and priorities relative to manpower and funding do not permit a study of such scale. Consequently, a means must be devised to divide the State into smaller units. These units must be isolated as nearly as possible into independent entities with boundaries that will permit modeling. In this report these smaller units are called subsystems.

Four types of subsystems can be recognized in Arkansas. These are:

a. Alluvial aquifer-stream subsystems (fig. 2).

b. Cretaceous-Tertiary-Quaternary aquifer-stream subsystems (fig. 2).

c. Stream-aquifer subsystems (fig. 3).

d. Aquifer subsystems (figs. 4, 5, 6, and 7).

The first three types (a, b, and c) contain aquifers and streams in which the ground and surface water are interrelated. The last type (d) is primarily a deep subsurface aquifer with very limited contact with streams and tends to be isolated by confining beds above and below.

The names of these subsystems have been selected so as to identify the sources of water and its development and use by placing the principal source first with the related sources, if any, second. For example, in the Mississippi Alluvial Plain of Arkansas and in the alluvial area adjacent to the Arkansas River in the Interior Highlands, about 85 percent of the water used is obtained from alluvial aquifers. (See fig. 1.) Yet, nearly all the streams traversing these areas to some extent are in hydraulic connection with the alluvial aquifers; hence, the term alluvial aquifer-stream subsystems.

The same situation applies to subsystems in the West Gulf Coastal Plain of Arkansas, except that here multiple aquifers of Cretaceous, Tertiary, and Quaternary age are in hydraulic connection with streams; hence, the name Cretaceous-Tertiary-Quaternary aquifer-stream subsystem.

In the Interior Highlands the streams are the principal source of water but are influenced to some degree by ground water. Hence, the term stream-aquifer subsystem is used for the Interior Highlands.

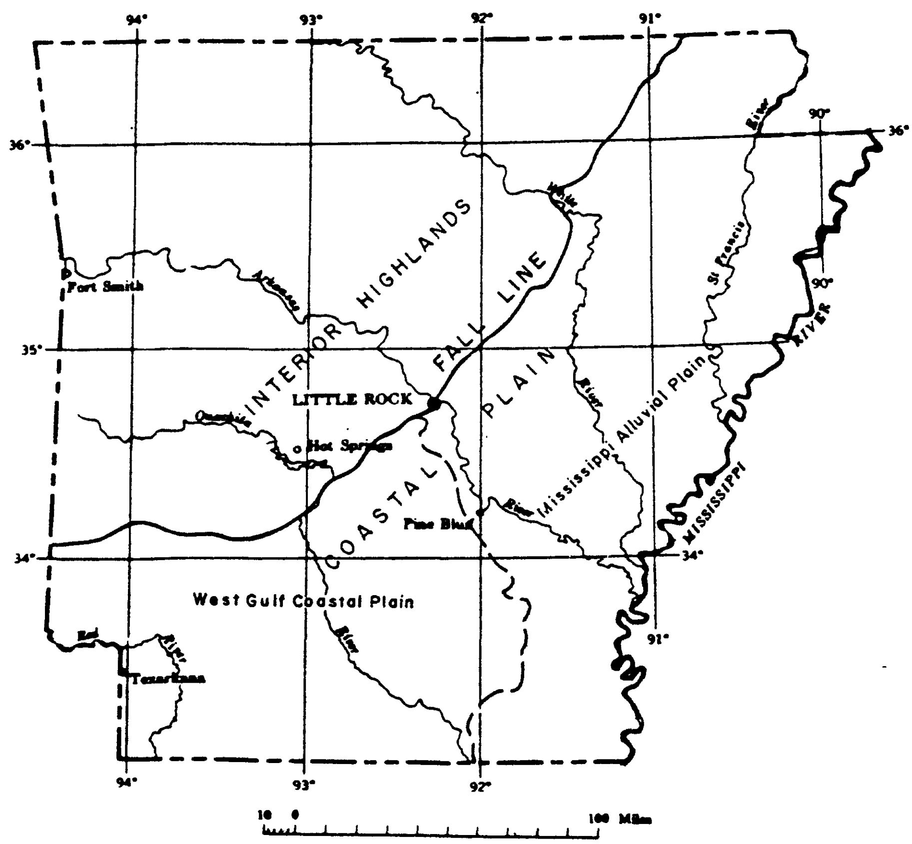


Figure 1.--Index map of Arkansas showing major physiographic divisions.

Ideal boundaries for the subsystems involving aquifers and interrelated streams (types a, b, and c) would be where the aquifer limits and topographic divides coexist. In the Coastal Plain and along the Arkansas River in the Interior Highlands, however, such a situation rarely exists. Therefore, boundaries for subsystems a and b are at the physical limits of the aquifers, thus encompassing the areas of principal interest. However, the total water resources of the subsystems--including water in streams--must be considered. Therefore, streams originating outside the limits of the aquifers but crossing the aquifers are enclosed at divides as an area of peripheral interest. The areas of principal interest (shallow aquifers) combined with the areas of peripheral interest (basins from which streamflow is brought into areas of principal interest) comprise the subsystems in the Coastal Plain and along the alluvial valley of the Arkansas River in the Interior Highlands.

In the Interior Highlands of Arkansas it is not necessary to encompass an area of peripheral interest as in the Coastal Plain. This is because, in general, the topographic divides and ground-water divides are coexistent. Thus, map boundaries for the stream-aquifer subsystems (type c) that encompass the total water resources can be placed at topographic divides.

Aquifer subsystem (type d) boundaries are placed in much the same manner as boundaries for alluvial aquifer-stream subsystems (type a). The area of principal interest is the aquifer to its physical limits. There are also areas of peripheral interest such as drainage basins of streams above their point of flow onto aquifer outcrop areas and leaky confining beds above and below the aquifer.

To confine all four types of subsystems to the District jurisdictional boundaries, that is the State, it is necessary to treat State lines as arbitrary boundaries for parts of certain subsystems. The extreme case in point is deep subsurface aquifers whose natural hydrologic boundaries may encompass several States. Although the study of an aquifer subsystem most practically could be accomplished through regional purview, State lines could be used as boundaries if head and flow conditions across the lines are known in sufficient detail.

Little has been said to this point about subsystem boundaries in the third dimension, that is at the surface and base of the subsystems. In all four types of subsystems it is obvious that precipitation, runoff, evaporation, transpiration, recharge and discharge, and interchange of water between aquifers and through confining beds must be taken into account in order to delineate boundaries in the third dimension. Generally, subsystems a, b, c, and d can be isolated at the base at natural hydrologic boundaries consisting of thick relatively impermeable clays, silts, and shales. Aquifer subsystems (type d) also can be isolated at their top by relatively thick beds of clays and shales except in outcrop areas or where overlain by alluvium.

Using the foregoing concepts it can be seen that boundaries of low permeability made up of clay, shale, and other relatively impermeable rocks; drainage divides, ground-water divides; deeply entrenched streams such as the Arkansas and Mississippi Rivers effectively penetrating shallow aquifers; and State lines can be used for subdivision of the State into hydrologic units herein called subsystems.

Subsystems are chosen as practical workable units because a team of several water-resources specialists can complete each study in 3 or more years depending upon hydrologic complexity and data-collection needs. The detailed work plan for each unit will contain provisions for breaking the study into 1- to 2-year increments. The end point for each increment will consist of a report on data analysis, conclusions reached, and application of the findings. Thus, even though a particular study, because of size or complexity, may require several years for completion, the mass of data collected will not be buried in its own profusion and the purpose for collecting the data will not be lost. Reporting on the completion of each increment will provide a decision point for any additional work needed, provide a springboard for work-plan changes and additional work-plan details needed, as well as make the results available for use much sooner than if only a single report is prepared at the conclusion of the study.

The Arkansas District is divided into subsystems as shown in the following list.

Subsystems in the Arkansas District

Alluvial aquifer-stream subsystems (fig. 2)

1. St. Francis
2. Cache
3. Bayou Meto
4. Bayou Bartholomew
5. Arkansas

Cretaceous-Tertiary-Quaternary subsystems (fig. 2)

6. Ouachita-Saline
7. Red

Stream-aquifer subsystems (fig. 3)

1. Spring-Strawberry
2. Upper White
3. Buffalo
4. Little Red
5. Illinois-Lee Creek
6. Upper Arkansas
7. Petit Jean-Fourche
8. Poteau
9. Upper Saline-Upper Ouachita
10. Rolling Fork-Cossatot-Saline-Little Missouri-Antoine, Caddo
11. Mountain Fork

Aquifer subsystem

1. Sparta-Memphis (fig. 4)
2. Wilcox (fig. 5)
3. Cockfield (fig. 6)
4. Carrizo (fig. 7)
5. Roubidoux-Gunter (fig. 7)

As examples, descriptions of one or more of the subsystems and maps showing the locations of all the subsystems are given in an appendix to this report.

## PRELIMINARY PLAN FOR STUDY OF BAYOU BARTHOLOMEW SUBSYSTEM

Surface- and ground-water resources in most of the subsystems in Arkansas are interrelated; therefore, development and management of either water regimen will affect the other. Thus, the formulation of solutions to water problems caused by development is dependent upon an understanding of the cause-effect relationships in the subsystem, upon the natural and man-induced constraints and characteristics of the subsystem, and upon accurate predictions of effects of various alternate patterns of water development and use. A model, or group of related models, has the potential of incorporating the physical characteristics and flow parameters of the subsystem and serving as a tool to predict effects of various stresses on the subsystem (fig. 8).

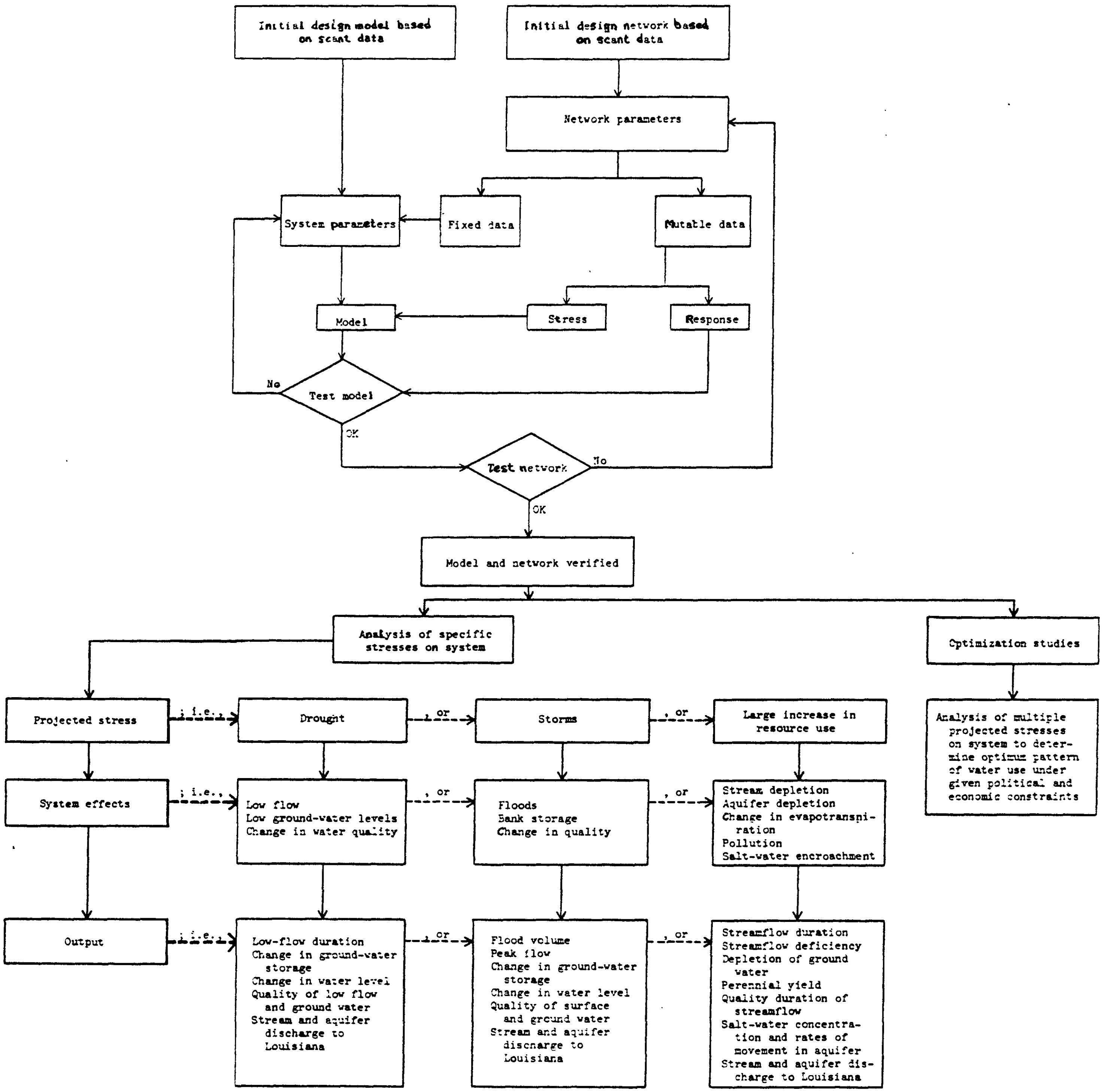


Figure 8.--Flow diagram of model and network design and analysis.

A second, and very important, objective of modeling the subsystem is to evaluate the adequacy of the current data network and refine data needs for the subsystem. Data network evaluation and revision are planned to be concurrent with model testing and revision.

Development of the model and data networks is shown on the flow diagram. The initiation of the models and data networks is based on data on hand. Refinements of the models and data networks are mutually dependent and are developed by a leapfrog process. The model analysis is used to revise the data network, and the revised data network to revise the model, and so forth.

The data-network parameters are the time and space coordinates; the "when" and the "where" of the data. Subsystem parameters, the physical properties of the subsystem modeled, are derived from fixed data and mutable data. True, nothing in nature is fixed. The distinction between fixed and mutable data is made to facilitate programing and developing work plans. Some natural environmental factors are unchanged or change so slowly that only infrequent measurement is necessary; for example, drainage area, permeability, and channel slope. Parameters that change frequently are called mutable; for example, streamflow and ground-water levels. The testing of the model to obtain correspondence between the response of the model and the subsystem is a standard operation in model studies. Equal emphasis is placed here on using the model as a tool in testing the network to obtain the best data network.

A subsystem has been selected for initial study and preliminary plans for the study have been made. The subsystem selected is Bayou Bartholomew in southeast Arkansas. (See fig. 2 and page 9.)

The water supply of the Bayou Bartholomew subsystem arrives as precipitation. Underground and surface reservoirs and streams store and distribute the water, and under natural conditions the subsystem generally operates efficiently. At times the capacity of the subsystem to carry away excess water is overtaxed and some land is flooded. Locally, the ground-water reservoir is overfilled and low-lying land is waterlogged. In one locality, water of poor quality has entered the shallow underground reservoir by seeping through a break in the underground formations.

The underground reservoirs and surface streams constitute the natural means for supplying water for the needs of the people, industry, and agriculture of the area. The streams and natural oxbow lakes are a fertile habitat for fish and the swamplands provide sequestered haunts for wildlife. These features of the hydrologic environment were among the first to be exploited by man and are still valued highly. The Mississippi and Arkansas Rivers were the primary avenues of transportation for early explorers and settlers.

The underground-water reservoir is shallow and contains potable water for household use. In the early 1900's the first wells were constructed to provide irrigation water for rice. Industry and row-crop agriculture have also utilized the readily available water from the aquifer, as well as from the streams.

As long as the water needs were small, the natural water conditions accommodated the users, with perhaps only local and minor discomfiture. However, as the demand for water and development of the area increased, problems have arisen and as increasing stress is placed on the water resources more and bigger problems can be expected.

## Flow models

Flow models of the Bayou Bartholomew area will be developed in two phases. The first, a digital regression model, will combine the digital model of the aquifer and regression models for streamflow parameters. The second, a recharge-runoff model, will utilize the digital model and relations between climate and recharge for the aquifer combined with precipitation-runoff models for streamflow.

The first model for the subsystem, the digital-regression model, will be assembled in the early phases of the study. This model will provide estimates of effects of stress on long-term averages of streamflow. The second model, the recharge-runoff model, will be developed for relating flows in the subsystem to specific events of stress, for example, climatic or developmental, and will provide a tool for projecting the effects of short-term stress on the subsystem.

## Digital-regression model

Regression models for streamflow relate subsystem parameters (precipitation, drainage area, slope, cover, and mean elevation) to mean annual flow and monthly mean flows. These regression models represent about a 30-year period, from 1938 to 1968. The effect of developmental stress on the mean annual and monthly mean flows will involve a time-accounting procedure for direct withdrawal from streams, streamflow reduction by pumpage of ground water, consumptive use, and return flow to the stream.

The time accounting of streamflow reduction by either induced seepage from the streams or by reduction in base flow will be determined with the aid of the digital model of the aquifer.

The distribution of ground-water flow in the subsystem will be determined from periodic analyses of the potentiometric surface. These analyses will yield estimates of accretion distribution, base flow to streams, induced or natural recharge from streams, and effects of withdrawal from the aquifer.

The digital-regression model will serve as the initial basic-flow model of the subsystem. Initial data networks will be designed from this model. The digital-regression model, because it yields long-term means, is limited as a projection device to effects of long-term stresses. Also, the formal verification process is impractical because of the long-time period required.

To relate flows to specific events, it is desirable to supplement the digital-regression model with a recharge-runoff model.

## Recharge-runoff model

A recharge-runoff model will be developed to provide a means for evaluating the effects of short- or long-term stress on flow in the subsystem.

Factors embodied in these models will include precipitation, evapotranspiration, direct surface runoff, recharge, base flow, diversion of surface flows by withdrawal and influent seepage, pumpage from ground water, and return flow to streams.

Recharge to the aquifer will be related to climatic conditions and depth-to-water level in the aquifer.

Streamflows will be simulated by subsystem response to precipitation runoff, base flow, and withdrawal and return flow.

The following equation illustrates the general form of the model which will be employed in simulating streamflow.

$$Q_O = b_O R_O + b_1 R_1 + b_2 R_2 + \ldots b_n R_n + c_O Bf_O + c_1 Bf_1 + \ldots c_n Bf_n + d_O D_O + d_1 D_1 + \ldots d_n D_n ,$$

where $Q_O$ is streamflow, R is direct surface runoff from precipitation, Bf is base flow, D is net withdrawal or return flow to the stream, and b, c, and d are distribution constants. Bf is negative for a gaining condition and positive for a losing condition. D is positive for return flow and negative for withdrawal. The subscripts 0, 1, 2, . . . n refer to the period of estimate and the 1st, 2d, 3d, . . . nth antecedent period.

APPENDIX

## Description of Selected Alluvial Aquifer-Stream Subsystems

### St. Francis subsystem

Principal area.--

1. Alluvial aquifer and streams bordered by Mississippi River on the east, Crowleys Ridge on the west, St. Francis River from northernmost point on Crowleys Ridge to the east-west extension on the Arkansas-Missouri State line (fig. 2).

2. Includes Mississippi and Crittenden Counties and parts of Clay, Greene, Craighead, Poinsett, Cross, St. Francis, Lee, and Phillips Counties.

3. Includes the following streams: Right-bank tributaries of the Mississippi River from Arkansas-Missouri State line to Helena, St. Francis River, Little River, Tyronza River, Buffalo Creek, Pemiscot Bayou, Blackfish Bayou, Fifteen Mile Bayou, and L'Anguille River below Marianna.

Peripheral area.--

1. Tributary stream drainage basins on east side of Crowleys Ridge.

2. Tertiary deposits on Crowleys Ridge and underlying the alluvium.

3. The L'Anguille River basin (on the west side of Crowleys Ridge) affects the St. Francis Alluvial Aquifer-Stream subsystem and, therefore, is a peripheral study area. For map convenience, to avoid confusion of peripheral areas in the Cache subsystem, the L'Anguille River basin has not been shown in figure 2. Point data collected on the L'Anguille River at Marianna will provide quantifiable data control.

4. In the alluvial aquifer on each side of a line between the break in Crowleys Ridge at the south end.

Nature of subsystem boundaries.--

1. Mississippi River forms an independent boundary.

2. St. Francis River forms a boundary that may be regulated by stresses on the aquifer-stream system in the principal area and in the peripheral area.

3. The Tertiary deposits underlying the alluvial aquifer and cropping out on Crowleys Ridge contain aquifers in hydraulic connection with the alluvium. Natural gradients between the alluvial and Tertiary aquifers can be altered by stress on either the alluvial or Tertiary aquifers.

4. The east-west part of the Arkansas-Missouri line is an arbitrary boundary across which streamflow and underground flow enters the principal area. Flow can be altered to some extent by regulation of water on either side of the boundary.

5. The boundary along the line between the break in Crowleys Ridge at the south end also is an arbitrary boundary across which streamflow and underground flow enters the principal area. Water in the principal area can be altered by stress on the stream or aquifer on either side of this boundary.

Description of principal area.--

1. The principal area comprises about 3,000 square miles.

2. The aquifer consists of alluvium of the Mississippi and St. Francis Rivers as much as 200 feet thick and averages about 100 feet.

3. Transmissivity is as high as 300,000 gpd (gallons per day) per foot and averages about 100,000 gpd per foot.

4. Water levels range from 1 to 30 feet below land surface.

5. Major streams in the principal area are the St. Francis and its tributaries, the Tyronza, L'Anguille, and Little Rivers.

6. The drainage area of the Tyronza River within the principal area is 561 square miles.

7. Natural recharge is by infiltration of rainfall and probably amounts to 6 inches or less per year; average annual runoff in the principal area is from 18 to 20 inches.

8. Natural aquifer discharge is principally by seepage to streams and drainage ditches.

9. The alluvial aquifer is the major source of water for irrigation of rice, row crops, and fish farming; to a lesser degree the aquifer is developed for industrial, municipal, and domestic water supplies.

10. Ground-water pumpage (1965) for irrigation was about 150 mgd; surface-water pumpage was about 16 mgd; combined total was 166 mgd.

11. Ground-water pumpage for all other uses (1965) was about 13 mgd; surface-water pumpage was about 35 mgd; combined total was 48 mgd.

12. Total ground-water use for all purposes (1965) was about 163 mgd; total surface-water use for all purposes was about 51mgd; combined total use was about 214 mgd.

13. Water in the alluvial aquifer generally is of good quality for irrigation; iron content is high, 1 to 26 mg/l (milligrams per liter); water generally is hard, 100 to 500 mg/l; and chloride content generally is less than 60 mg/l. Water from aquifers underlying the alluvial deposits generally is of very excellent quality; however, salt water is available at depth. Quality of water in aquifers is fairly well known.

14. Streamflow and stage data are avilable for the St. Francis River at St. Francis, at Lake City; at Marked Tree at Floodway near Marked Tree, at Parkin; and on St. Francis Bay at Riverfront, as well as water-quality data at each of these stations. Streamflow and quality data are available on the Tyronza River near Tyronza, and for Right Hand Chute Little River at Rivervale. No data are available for Buffalo Creek or Pemiscot Bayou. Streamflow data are available on Blackfish Bayou near Forrest City. Streamflow and water-quality data are available for Fifteen Mile Bayou near West Memphis, and for the L'Anguille River; streamflow data are available at Palestine and Wynne. Crest-stage and other miscellaneous stage and flow data are available.

15. The aquifer and streams generally are in hydraulic connection and stress on either can create changes in head distribution. Major regulation of water in the area is through irrigation pumpage and installation of an extensive system of drainage ditches. Flood-retention structures along the major interior streams and high stream stages probably create shallow water-level conditions in areas adjacent to the rivers for significant periods of time.

16. In a general way the hydrology of the principal area is fairly well known. With a carefully designed data-collection program, sufficient additional information can be assembled in a short time to quantify operation of the complete stream-aquifer system.

Description of peripheral area.--

1. The peripheral area comprises about 300 square miles along Crowleys Ridge and Tertiary deposits underlying the alluvial aquifer.

2. Hydrologic details in the peripheral area are not well known, particularly stream drainage from Crowleys Ridge and the nature of aquifers of Tertiary age underlying the alluvial aquifer. However, the peripheral area, with the exception of the L'Anguille River basin (938 sq mi) and Tertiary aquifers, is not large and none of the peripheral area is anticipated to have major hydrologic effects on the principal area.

3. Tertiary aquifer data must be collected on an area basis; whereas, point data, such as on the L'Anguille River at Marianna, will suffice.

Basic considerations.--

1. A problem of management of streamflow, aquifer development, flood control, and surface and subsurface drainage requiring a complete knowledge of how the subsystem operates.

2. A management tool, such as a model, that can be used to project effects of various manipulations of any part of the system.

3. Quantification of streamflow and underground flow into the principal area from the bootheel of Missouri for use in compacts and other potential litigation involving water resources crossing a State line.

4. Projections of changes in head in the aquifer and consequent effects on crops and timberland and projection of effects on water resources as a result of extensive land clearing.

5. Horseshoe Lake, Big Lake National Wildlife Refuge, Council Lake, and other lakes; their environment, nature, and future; including quality-of-water considerations.

## Cache subsystem

Principal area.--

1. Alluvial aquifer and streams bordered by the White River and the outcrop of Paleozoic, Cretaceous, and Tertiary rocks on the west, Crowleys Ridge and the Mississippi River on the east, and the Arkansas-Missouri State line on the north (fig. 2).

2. Includes parts of Desha, Phillips, Monroe, Lee, Woodruff, St. Francis, Cross, Jackson, Poinsett, Craighead, Independence, Lawrence, Greene, Clay, and Randolph Counties.

3. Includes the following streams: Left-bank tributaries of the White River below Magness and right-bank tributaries of the Mississippi River between Helena and the mouth of the White River below Henrico. Among these are the Current River, Black River, Cache River, Bayou De View, Big Creek, and Long Creek. The L'Anguille River above Marianna, a tributary to the St. Francis River, also drains the principal area.

Peripheral area.--

1. Tributary stream drainage basins in the Interior Highlands represented principally by the Spring and Strawberry Rivers and their tributaries west of the Fall Line.

2. Includes the drainage basins of Dorta and Cura Creeks west of the Fall Line.

3. Tertiary, Cretaceous, and Paleozoic rocks underlying and bordering the alluvium along the Fall Line.

4. Tertiary rocks underlying and bordering the alluvium in Crowleys Ridge.

5. Tributary stream drainage basins on the west side of Crowleys Ridge.

Nature of subsystem boundaries.--

1. The White River generally forms an independent boundary, but when under great stress probably acts as a partial boundary. Also, flow of the White River may indirectly be affected by stress on the alluvial aquifer.

2. Paleozoic rocks form a nearly impermeable boundary at the Fall Line.

3. Cretaceous rocks exposed along the Fall Line, and underlying Tertiary rocks, and the alluvium may be in hydraulic connection with the Tertiary and alluvial aquifers.

4. The Tertiary deposits underlying the alluvial aquifer and cropping out on Crowleys Ridge contain aquifers in hydraulic connection with the alluvium. Natural gradients between the alluvial and Tertiary aquifers can be altered by stress on either the Tertiary or alluvial aquifers.

5. The east-west Arkansas-Missouri State line is an arbitrary boundary across which streamflow and underground flow enters the principal area. Flow can be altered to some extent by regulation of water on either side of the line.

6. The Mississippi River forms a perfect independent boundary.

7. The boundary along the line between the break in Crowleys Ridge at the south end also is an arbitrary boundary across which streamflow and underground flow leaves the principal area. Water in the principal area can be altered by stress on the stream or aquifer on either side of this boundary.

<u>Description of principal area</u>.--

1. The principal area comprises about 5,300 square miles.

2. Aquifer is composed of alluvium of the Mississippi, White, Cache, L'Anguille, and Black Rivers as much as 175 feet thick and averages about 125 feet.

3. Transmissivity is as high as 150,000 gpd per foot and averages about 100,000 gpd per foot.

4. Water levels range from 5 to 60 feet below land surface.

5. Major streams in the principal area are the Cache, Black, Current, and L'Anguille Rivers.

6. Natural recharge is by infiltration of rainfall and probably amounts to as much as 6 inches per year; average annual runoff in the principal area is about 16 inches per year.

7. Natural discharge principally is by seepage to streams and drainage ditches.

8. The alluvial aquifer is a major source of water for irrigation of rice, row crops, and fish farming; to a lesser degree the aquifer is developed for industrial, municipal, and domestic water supplies.

9. Ground-water pumpage (1965) in the principal area for all uses was about 300 mgd.

10. Surface-water use (1965) in the principal area for all purposes was about 200 mgd.

11. More than 75 percent of the total water used in the principal area was for irrigation.

12. Water in the alluvial aquifer generally is of good quality for irrigation, iron content generally is high (0-15 or more mg/l), water generally is hard (90 to 400 mg/l), chloride content generally is less than 30 mg/l but in isolated instances may be as high as 200 mg/l. Water from aquifers underlying the alluvial deposits generally is of excellent quality; however, salt water is present at depth. Quality of water from all aquifers is fairly well known.

13. Streamflow and (or) stage data and (or) water-quality data are available for the White River at Clarendon, De Valls Bluff, Newport, and Batesville; for the Cache River at Egypt and Patterson, and near Newport and Stonewall; for the Black River at Black Rock, Jacksonport, and Pocahontas, and near Corning; for the L'Anguille River at Palestine, and near Wynne. Stage and low-flow data are also available at other points in the subsystem.

14. The White and Mississippi Rivers, boundaries of the subsystem, are in hydraulic connection with the alluvial aquifer. Other major streams in the principal area also are in hydraulic connection with the alluvial aquifer but perhaps to a lesser degree than the White and Mississippi Rivers, particularly in the upper reaches.

15. Major regulation of water in the area is through pumpage, from the alluvial aquifer, for irrigation. Also, surface water is pumped directly from streams. Most regulation of surface water in the principal area is through control of runoff by storing water relifted from drainage ditches in shallow reservoirs.

16. In a general way the hydrology of the principal area is fairly well known. Sufficient additional information can be assembled in a reasonably short time to quantify operation of the subsystem and determine the relationships among those parameters that influence the water resources.

Description of peripheral area.--

1. The peripheral area comprises about 2,300 square miles in the Interior Highlands and along Crowleys Ridge and Tertiary, Cretaceous, and Paleozoic rocks adjacent to and underlying the alluvial aquifer in the principal area.

2. Hydrologic stress on the principal area from the Interior Highlands part of the peripheral area can readily be obtained from point data collected on streams at the Fall Line. Much information is already available and can be regionalized and extrapolated to the Fall Line from point data at other locations in the part of the peripheral area.

3. The peripheral area in Crowleys Ridge is not large (less than 400 sq mi) and probably does not have major hydrologic effects. Although it cannot be ignored, extensive data collection will not be required.

4. Little is known about the hydrologic nature of the peripheral area underlying the principal area. Also, no appraisal studies have been made of the water resources of Lee, Phillips, and Monroe Counties as have been made for other counties in the Cache River subsystem. Sandy phases of Tertiary deposits are in contact with the base of the alluvium in about 1,500 square miles of the subsystem.

5. It will be necessary to collect area data throughout most of the subsurface peripheral area to determine its effect on the alluvial aquifer.

Basic considerations.--

1. A problem of management of aquifer development, streamflow, flood control, and subsurface and surface drainage requiring a complete knowledge of how the subsystem operates.

2. A management tool, such as a model that can be used to project effects of various manipulations of any part of the subsystem.

3. Quantification of total water resources available in the area for use on a maximum beneficial-use basis during a sustained period.

4. Potential overdevelopment of ground water in the alluvial aquifer, principally in western Craighead and Poinsett Counties.

5. Salt water at depth in Tertiary aquifers.

6. Quality of water; use and reuse effects and projections; significance, extent, and future with respect to pesticides, herbicides, and fertilizer applications.

7. Hydrologic effects of drainage structures and land clearing.

8. Effects of improvement and development of the water and related land resources, as proposed in the comprehensive White River Basin study report. Included are water supply, water-quality control, irrigation, navigation, levee and channel construction and improvements, hydroelectric-power development, drainage, flood control, watershed projection measures, recreation, and fish and wildlife considerations.

## Bayou Meto subsystem

Principal area.--

1. Alluvial aquifer and streams bordered by the Arkansas River on the south and west, White and Mississippi Rivers on the east, and the outcrop of Paleozoic and Tertiary rocks on the north (approximately the Fall Line) (fig. 2).

2. Includes Arkansas County and parts of Jefferson, Prairie, Desha, Pulaski, Lonoke, Monroe, White, Jackson, and Independence Counties.

3. Includes the following streams: Right-bank tributaries to the White River below Newark and left-bank tributaries to the Arkansas River below Little Rock. Among these are Lagrue Bayou, Little Lagrue Bayou, Mill Bayou, Bayou Two Prairie, Wattensaw Bayou, Bayou Des Arc, Wabbaseka Bayou, Plum Bayou, Bayou Meto, Little Bayou Meto, Salt Bayou, Departee Creek, and the Little Red River.

Peripheral area.--

1. Tributary stream drainage basins in the Interior Highlands and the Tertiary outcrop area adjacent to the Fall Line.

2. Tertiary, Cretaceous, and Paleozoic rocks underlying and bordering the alluvium along the Fall Line.

3. The peripheral area in the Interior Highlands includes the upper parts of the Little Red River, Cypress Bayou, Bayou Des Arc, Bull Creek, and Bayou Meto drainage basins.

Nature of subsystem boundaries.--

1. The Arkansas and Mississippi Rivers form independent boundaries.

2. The White River generally forms an independent boundary, but when under great stress probably acts as a partial boundary. Also, flow of the White River may indirectly be affected by stress on the alluvial aquifer.

3. Paleozoic rocks form a nearly impermeable boundary at the Fall Line.

4. Tertiary and Cretaceous rocks underlying the alluvium contain aquifers that are recharged by seepage from the alluvium; gradients are reversible depending upon amount and location of stress on the units.

Description of principal area.--

1. The principal area comprises about 3,400 square miles.

2. Aquifer is composed of alluvium of the White, Arkansas, and Mississippi Rivers as much as 150 feet thick and averages about 120 feet.

3. Transmissivity is as high as 250,000 gpd per foot and averages about 160,000 gpd per foot.

4. Water levels range from 4 to 85 feet below land surface.

5. Natural recharge is by infiltration of rainfall and probably amounts to less than 3 inches per year; average annual runoff in the principal area is about 18 inches per year.

5. Natural recharge is by infiltration of rainfall and probably amounts to less than 3 inches per year; average annual runoff in the principal area is about 18 inches per year.

6. Natural discharge is principally by seepage to streams.

7. The alluvial aquifer is a major source of water for irrigation of rice and row crops, and for fish farming. The aquifer also is developed to a lesser degree for irrigation for industrial, municipal, and domestic use.

8. Ground-water pumpage (1965) in the principal area for all uses was about 340 mgd.

9. Surface-water use (1965) in the principal area for all purposes was about 165 mgd.

10. About 75 percent of the total water used in the principal area in 1965 was for irrigation.

11. Water in the alluvial aquifer generally is of good quality for irrigation, iron content generally is high (0-7 mg/l), water generally is hard (50-400 mg/l), chloride content generally is less than 30 mg/l. Water from aquifers underlying the alluvial deposits generally is of excellent quality; however, salt water is present at depth. Quality of water in the alluvial aquifer is fairly well known.

12. Streamflow and (or) stage data are available for the Arkansas River at Pendleton, at Pine Bluff, near Altheimer, near Redfield, and at Little Rock; for the White River at Clarendon, De Valls Bluff, Newport, and Batesville; for the Little Red River at Heber Springs; Bayou Des Arc near Garner; Cypress Bayou near Beebe; Wattensaw Bayou near Lonoke; Lagrue Bayou near Stuttgart; Little Lagrue Bayou near De Witt; Bayou Meto near Lonoke and Stuttgart; and Crooked Creek near Humphrey. Stage and low-flow data are also available at other points in the subsystem.

13. The Arkansas, White, and Mississippi Rivers, boundaries of the subsystem, are in hydraulic connection with the aquifer. The lower part of Bayou Meto may be hydraulically connected to the aquifer as may be the lower parts of other streams such as Bayou Des Arc, the Little Red River, and Plum Bayou. In general, stream-aquifer connection in the principal area is limited, particularly in the headwaters of streams, as compared to other subsystems in the State where there is a thinner capping layer of clay over the sands and gravels of the alluvial deposits.

14. Major regulation of water in the area is through irrigation pumpage from the alluvial aquifer. Also, surface water is pumped for direct application to crops, although the more common practice is to relift surface water into shallow reservoirs for storage and irrigation of crops at a later time. Several hundred reservoirs of this type dot the countryside and have limited hydraulic connection to the aquifer.

15. In a general way, the hydrology of the principal area is fairly well known. Sufficient additional information can be assembled in a short time to quantify operation of the subsystem and determine the effects of stress on the water resources.

Description of peripheral area.--

1. The peripheral area comprises about 2,300 square miles in the Interior Highlands and Tertiary, Cretaceous, and Paleozoic rocks adjacent to and underlying the alluvial aquifer in the principal area.

2. Hydrologic stress on the principal area from the Interior Highlands part of the peripheral area can readily be obtained from point data collected on streams at the Fall Line. Much information already is available and can be regionalized and extrapolated to the Fall Line from point data at other locations in the peripheral area.

3. Little is known about the hydrologic nature of the peripheral area underlying the principal area. The effect of this part of the peripheral area on the principal area, however, probably is negligible at distances of 3 or more miles southeast of the Fall Line. Consequently, collection of areal data on the Tertiary, Cretaceous, and Paleozoic rocks underlying the alluvial aquifer can be concentrated in a relatively small band near the Fall Line. Generally, widely spaced data-collection points on the subsurface peripheral area away from the Fall Line may have to be established to confirm lack of effect on the alluvial aquifer.

Basic considerations.--

1. A problem of management of aquifer development, streamflow, flood control, and surface and subsurface drainage requiring a complete knowledge of how the subsystem operates.

2. A management tool, such as a model that can be used to project effects of various manipulations of any part of the system.

3. Quantification of total water resources available in the area for use on a maximum beneficial use basis during a sustained period.

4. Overdevelopment of ground water in the alluvial aquifer, principally in the Grand Prairie Region, Arkansas County.

5. Hydrologic effects of drainage structures and land clearing, principally in the Bayou Meto drainage basin.

6. Quality of water; use and reuse effects and projections; significance, extent, and future with respect to pesticide, herbicide, and fertilizer applications.

7. Salt water; in the alluvial aquifer near Bald Knob, and at depth in the peripheral materials underlying the alluvial aquifer; extent, source, spread, and methods of control or use of salt water.

8. Effects of improvement and development of the water and related land resources as proposed in the comprehensive White River Basin study report.

## Bayou Bartholomew subsystem

Principal area.--

1. Alluvial aquifer and streams bordered on the east by Mississippi River, on the north by Arkansas River, on the south by Arkansas-Louisiana State line, and on the west by an outcrop of Tertiary deposits with a ground-water divide at the southern end (fig. 2).

2. Includes Chicot and parts of Desha, Ashley, Drew, Lincoln, and Jefferson Counties.

3. Includes the following streams: Right-bank tributaries to the Arkansas River below Red Bluff, right-bank tributaries to the Mississippi River below the mouth of the Arkansas River, Bayou Bartholomew, Bayou Macon, Boeuf River, Big Bayou, Crooked Bayou, Ables Creek, Consort Bayou, Choctaw Bayou, Oaklog Bayou, and Cypress Creek.

Peripheral area.--

1. Stream basins tributary to Bayou Bartholomew draining the Tertiary outcrop on the west.

2. Tertiary deposits underlying and bordering the alluvial aquifer.

Nature of subsystem boundaries.--

1. Arkansas and Mississippi Rivers form independent boundaries.

2. The Tertiary outcrop on the west forms a nearly impermeable boundary, laterally across which small insignificant amounts of seepage may occur.

3. Streams heading on the east side of the divide on the Tertiary outcrop flow into and affect the subsystem.

4. The ground-water divide from the south end of the Tertiary outcrop to the State line is a boundary of the aquifer across which there is no ground-water flow. However, the aquifer on each side of this boundary is subject to stress that can cause the position of the boundary to change.

5. The Arkansas-Louisiana State line is an arbitrary boundary across which streamflow and underground flow leaves the principal area. However, stress on the subsystem in the principal area could cause a reversal in the ground-water gradient, thus inducing movement of water across the State line into Arkansas.

6. The Tertiary deposits underlying the alluvium probably form a nearly impermeable boundary throughout most of the principal area across which negligible amounts of seepage may occur.

Description of principal area.--

1. The principal area comprises about 2,800 square miles.

2. Aquifer is composed of alluvium of the Arkansas and Mississippi Rivers as much as 180 feet thick and averages about 100 feet thick.

3. Transmissivity is as high as 300,000 gpd per foot and averages about 100,000 gpd per foot.

4. Water levels range from about 5 to 50 feet below land surface, but generally are less than 50 feet.

5. Major streams in the principal area are Bayou Bartholomew, Bayou Macon, and Boeuf River.

6. Natural recharge is by infiltration of rainfall and is estimated to be about 3 inches per year; average annual runoff is about 16 inches.

7. Natural discharge is by seepage to the Arkansas and Mississippi Rivers and Bayous Bartholomew and Macon.

8. The alluvial aquifer is major source of water for irrigation of rice and row crops, and for fish farming; to a lesser degree the aquifer is developed for municipal, industrial, and domestic supplies. Water also is withdrawn from streams for irrigation.

9. Ground-water use in the principal area was 108 mgd in 1965, surface-water use was 46 mgd; combined total use about 154 mgd. More than 90 percent of the ground water was withdrawn from the alluvial aquifer and used for irrigation.

10. Water in the alluvial aquifer is of good quality for irrigation; iron content is high (0.2-35 mg/l), water generally is hard (70-1,790 mg/l), chloride content generally is less than 100 mg/l but is as high as 1,490 mg/l in small area in Chicot County.

11. Salt water is present at depth in Tertiary deposits underlying fresh water. The high chloride content in water in the alluvial aquifer in Chicot County probably is caused by leakage into the alluvium from the Tertiary deposits.

12. Withdrawals of water from the alluvium have reversed the natural gradients in Lincoln County and water is being induced into the alluvial aquifer from the Arkansas River.

13. The streams in the principal area are not in perfect connection with the alluvial aquifer. However, the streams are regulated by direct withdrawal of water from the streams and by return irrigation water. Further regulation is caused where water levels in the alluvium are lowered below streambeds and recharge is induced from the streams.

14. Daily stage and flow data available for Bayou Bartholomew near McGehee and near Jones, La.

15. Bayou Bartholomew water-quality data available at Wilmot and near McGehee.

16. Stage data available on Arkansas River at Pine Bluff and Pendleton Ferry.

17. Arkansas River water-quality data available on daily basis at Little Rock.

18. Stage data on Mississippi River available on daily basis at Roseville and Greenville, Miss., and at Arkansas City in Desha County, Ark.

19. Mississippi River water-quality data available at Memphis, Tenn.

20. Stage and low-flow data are also available at other points in the subsystem.

21. Water-level data available in a few wells since 1950; potentiometric maps of area can be prepared for spring of each year since 1959.

22. In a general way, the hydrology of the principal area is fairly well known. However, quantification of the operation of the subsystem can be done only with a relatively extensive data-collection program. Total drainage from the area can be measured without technical difficulty except for drainage to Arkansas and Mississippi Rivers outside the levees.

Description of peripheral area.--

1. The peripheral area comprises about 200 square miles along the Tertiary outcrop on the west and the deposits of Tertiary age underlying the alluvial aquifer.

2. Hydrologic details in the peripheral area along the Tertiary outcrop can be easily ascertained. However, less is known about the hydrologic nature of the Tertiary deposits underlying the alluvial aquifer and data will have to be collected on an areal basis.

3. The peripheral area does not have major hydrologic effects on the subsystem and, although it cannot be ignored, extensive data collection will not be required in the area.

Basic considerations.--

1. A problem of management of streamflow, aquifer development, flood control, and surface and subsurface drainage requiring a complete knowledge of how the subsystem operates.

2. A management tool, such as a model, that can be used to project effects of various manipulations of any part of the subsystem.

3. Potential water yield of the subsystem.

4. Quantification of streamflow and underground flow into Louisiana, based on various stresses in either the surface or ground-water phase of the resources, thus permitting compact efforts to proceed on a factual basis.

5. Lake Chicot and Grand Lake; their environment, nature, and future; including quality-of-water considerations.

6. Salt-water contamination; its extent, source, spread, and methods of control, containment, or use.

7. Quality of water; use and reuse effects and projections; significance, extent, and future with respect to pesticide, herbicide, fertilizer applications.

## Description of Selected Cretaceous-Tertiary-Quaternary Aquifer-Stream Subsystems

### Red subsystem

Principal area.--

1. Cretaceous-Tertiary-Quaternary aquifers and streams bordered by the Arkansas-Oklahoma State line, the Red River, and the Arkansas-Texas State line on the west; the Arkansas-Louisiana State line on the south; by the topographic divide between the Red and Ouachita Rivers on the east; and by the Fall Line on the North (fig. 2).

2. Includes all or parts of Little River, Miller, Lafayette, Columbia, Nevada, Hempstead, Howard, and Sevier Counties.

3. Includes the following streams: Cossatot and Saline Rivers, Little River, and other right- and left-bank tributaries to the Red River, and Bodcau Creek and Bayou Dorcheat north of the Arkansas-Louisiana State line.

Peripheral area.--

1. Stream basins tributary to Little River draining Paleozoic rocks upstream from the Fall Line.

2. Subsurface deposits ranging in age from Cretaceous to Tertiary age.

Nature of subsystem boundaries.--

1. The Red River generally forms an independent boundary, but when under great stress probably acts as a partial boundary. Also, flow of the Red River may indirectly be affected by stress on the Cretaceous, Tertiary, or Quaternary aquifers where the river and aquifers are in hydraulic connection.

2. The State-line boundaries are arbitrary and streamflow and underground flow can enter and (or) leave the principal area across these boundaries. Water in the principal area can be altered by stress on the stream or aquifer on either side of these arbitrary boundaries.

3. The topographic divide between the Red and Ouachita Rivers is arbitrary, as ground water in the Cretaceous and Tertiary aquifers may move across the boundary.

4. Paleozoic rocks form a nearly impermeable boundary at the Fall Line.

5. The subsurface boundary of the subsystem is undefined. It probably is discontinuous with respect to any one geologic formation but probably is made up of relatively impermeable Cretaceous and Tertiary deposits.

Description of principal area.--

1. The principal area comprises about 2,000 square miles.

2. Aquifers are composed of Quaternary alluvium of Little and Red Rivers as much as 80 feet thick with an average of about 50 feet thick; Cockfield, Sparta, and Wilcox aquifers of Tertiary age; and Nacatoch, Tokio, and Trinity aquifers of Cretaceous age.

3. Transmissivity of the alluvium is as high as 60,000 gpd per foot and averages about 40,000 gpd per foot.

4. Water levels in the alluvium range from 5 to 20 feet below land surface.

5. Major streams in the principal area are the Cossatot, Saline, and Little Rivers, Rolling Fork, Sulphur River, McKinney Bayou, Bodcau Creek, Bayou Dorcheat, and the Red River.

6. Natural recharge to all aquifers is by infiltration of rainfall and probably amounts to less than 3 inches per year; average annual runoff in the principal area is about 48 inches per year.

7. Natural discharge is principally by seepage to streams.

8. The alluvial aquifer is a source of water for irrigation of rice and row crops and is developed to a lesser degree for industrial, municipal, and domestic supplies. The Tertiary and Cretaceous aquifers are developed principally for industrial, municipal, and domestic use.

9. Ground-water pumpage from the alluvium (1965) in the principal area for all purposes was about 4 mgd.

10. Surface-water use (1965) in the principal area for all purposes was about 4 mgd.

11. More than 75 percent of the total water used in the principal area was for irrigation.

12. Water in the alluvial aquifer generally is of good quality for irrigation, iron content generally is high (as much as 14 mg/l), water generally is hard (as much as 800 mg/l, but generally less than 400 mg/l), chloride content generally is less than 100 mg/l, but in locations affected by oil-field wastes the chloride content may be as high as 45,000 mg/l. Water from aquifers underlying the alluvial deposits is of good quality; however, salt water is present downdip in Cretaceous rocks and at depth in Tertiary rocks.

13. Streamflow and (or) stage data and (or) water-quality data are available for the Red River at Fulton, Garland, Index, and Springbank, and near Hosston, La. Data are available for Little River near Horatio; for the Cossatot River near De Queen and Vandervoort; Bodcau Creek at Stamps and near Taylor; Bayou Dorcheat at Buckner and near Springhill and Taylor; McKinney Bayou near Garland; Saline River near Dierks and Lockesburg; and Sulphur River near Fort Lynn.

14. The Red River and Little River boundaries to and within the principal area in places are in hydraulic connection with the Cretaceous, Tertiary, and Quaternary aquifers. Other streams in the principal area probably are hydraulically connected with the aquifers but to a lesser degree than the Red and Little River.

15. Major regulation of water in the area is through pumpage from the alluvial aquifer for irrigation. Surface water also is pumped directly from streams. The Sulphur River is regulated by a dam in Texas.

16. In a general way, the hydrology of the principal area is fairly well known. An appraisal study of the water resources of Little River, Miller, Nevada, Lafayette, and Hempstead Counties now (1970) underway will add materially to the hydrologic knowledge of the principal area.

Description of the peripheral area.--

1. The peripheral area in the Interior Highlands comprises about 600 square miles and is made up of Paleozoic rocks.

2. Includes about 270 square miles of Polk County, none of which makes up any part of the principal area.

3. Hydrologic stress on the principal area from the streams draining the peripheral area can readily be obtained by point data. Some information already is available.

4. Details of the subsurface peripheral area are not known and will require some degree of resolution.

Basic considerations.--

1. A problem of management of aquifer development, streamflow, flood control, and quality-of-water control requiring a complete knowledge of how the subsystem operates.

2. Water quality involving high chloride content of the alluvial aquifer water caused by disposal of oil-field brines.

3. In some locations there are problems in developing a sufficient supply of water from any source. (Example, the Foreman, Ark., area.)

4. Potential streamflow pollution from oil-field wastes.

5. Hydrologic effects of drainage structures and land clearing.

6. Quality of water with relation to use, reuse, and future use with relation to pesticide-herbicide and fertilizer application.

7. Lakes, natural and artificial, and their relation to the subsystem.

8. Ground water-surface water relationships involving the Little Red and Red Rivers and Quaternary alluvium.

## Description of Selected Stream-Aquifer Subsystems

### Spring-Strawberry subsystem

Principal area.--

1. Bordered by the State line on the north; the topographic divide between the Spring and White Rivers, the Strawberry and White Rivers, and Spring Creek and the White River on the west; and by the Fall Line on the south and east (fig. 3).

2. Drainage basins of the Spring and Strawberry Rivers in Arkansas above their points of debouchment upon the Coastal Plain.

3. Includes the main stems of the Spring and Strawberry Rivers and their tributaries west of the Fall Line.

4. Tributaries to the Spring River include South Fork, Myatt Creek, Martins Creek, Janes Creek, and Eleven Point River.

5. Tributaries to the Strawberry River include Piney Fork, North Big Creek, Big Creek, and Cooper Creek.

6. Also includes adjacent small areas in the Interior Highlands whose drainage is not tributary to the Spring and Strawberry Rivers. Principal streams in these adjacent areas are Fourche River, Caney Creek, Curia Creek, Dota Creek, Sullavan Creek, Spring Creek, and Polk Bayou.

7. Includes all or parts of Randolph, Fulton, Izard, Sharp, Lawrence, and Independence Counties.

Peripheral area.--

1. Limestone and dolomite deposits of Ordovician age immediately underlying the subsystem.

2. Deeper sandstones, cherts, and dolomites of Ordovician and Cambrian age.

Nature of subsystem boundaries.--

1. The State line is an arbitrary boundary across which streamflow and underground flow can enter and leave the subsystem. Streamflow can be greatly altered by regulation of the streams on the Missouri side of the boundary. Ground-water flow can be altered to some extent by stress on either side of the boundary with resultant but small effect on the streamflow.

2. The topographic divides are considered to coexist with ground-water divides and form boundaries wherein the ground-water divides can be shifted as a result of stress on either side of the boundaries. The topographic divides are unaffected by hydrologic stress; however, if the ground-water divide is significantly shifted, probably negligible effects will be noted in streamflow.

3. The boundary along the Fall Line is arbitrary, but confines the subsystem to an isogenous environment. Most of the subsystem is encompassed by the drainage basins of the Spring and Strawberry Rivers in Arkansas above the point at which they cross the Fall Line.

4. The limestone and dolomite deposits of Ordovician age immediately underlying the subsystem are hydraulically connected with the streams. The subsurface boundary of these deposits is undefined. Deeper rocks, consisting of older sandstone, chert, and dolomite of Ordovician and Cambrian age, may or may not be hydraulically connected with the surficial materials.

Description of principal area.--

1. The area comprises about 2,000 square miles.

2. Major streams are the Strawberry and Spring Rivers; their drainage areas comprise about 1,500 square miles in the subsystem.

3. The area is directly underlain by limestone, dolomite, and cherty dolomite of Ordovician age; well yields from these rocks are from 1 to 10 gpm (gallons per minute).

4. Many springs are located in the area: Mammoth Spring, located near the State line and one of the largest springs in Arkansas, has an average discharge of about 370 cfs (cubic feet per second).

5. The mean annual discharge of the Spring River above Imboden is about 1,300 cfs from a drainage area of 1,162 square miles.

6. The mean annual discharge of the Strawberry River is about 900 cfs from a drainage area of 811 square miles.

7. Surface water in the Spring River basin is very hard, of the calcium magnesium bicarbonate type, and normally contains less than 250 mg/l dissolved solids and less than 0.3 mg/l of iron.

8. Surface water in the Strawberry River basin is moderately hard to very hard, of the calcium bicarbonate type, and normally contains less than 300 mg/l dissolved solids and less than 0.3 mg/l of iron.

9. Ground water in the subsystem generally is moderately hard to hard, is of the calcium magnesium bicarbonate type, may contain as much as 600 mg/l dissolved solids, and normally is very low in iron.

10. Water use in the subsystem is estimated to be about 10 mgd, about equally divided between ground- and surface-water sources.

11. Most of the water is used for rural domestic purposes, with public supplies probably ranking second. A small amount of water is used for industrial purposes.

12. Streamflow data are readily available for most of the streams in the subsystem and coverage is adequate.

13. Chemical-quality data for the surface and ground water are not sufficient.

14. The geology of the area is not known in detail. However, broad grouping by lithologic and hydrologic character is possible and probably sufficient.

15. Perennial reaches of streams are not known and channel gain-loss studies are needed.

16. Major regulation of water in the area is through pumpage for use and storage in small, shallow farm ponds.

17. In a general way, the hydrology of the subsystem is well known.

18. Reports are available for most of the subsystem in the form of hydrologic atlases and a comprehensive White River basin report.

Description of peripheral area.--

1. The limestone and dolomite deposits immediately underlying the subsystem are underlain by sandstone, chert, and dolomite of Ordovician and Cambrian age.

2. These deeper rocks yield from 10 to 75 gpm to wells and constitute the best aquifer in the Interior Highlands.

3. In places the deeper rocks yield as much as 450 gpm.

Basic considerations.--

1. A problem of management, principally of the surface-water resources.

2. A management tool or tools that can be used to project effects of various manipulations of any part of the subsystem, particularly surface water. Includes withdrawals, diversion, storage, and other flow regulation.

3. Pollution of the ground and surface water. Includes chemical, biological, and physical stresses.

4. Quantification of geologic factors affecting runoff and streamflow.

5. Quality of water; use and reuse effects and projections; significance, extent, and future with respect to pesticides, herbicides, and fertilizer application.

6. Surface water-ground water relationships.

7. More detailed qualitative-quantitative information that will more readily permit evaluation of ground-water development.

## Upper Arkansas subsystem

Principal area.--

1. Bordered on the north by the divide between the Little Red River and the Arkansas River basins and the divide between the White and Arkansas River basins to near Winslow; on the west by the divide between tributaries of Lee Creek and Frog Bayou to the confluence of Lee Creek with the Arkansas River, and thence to and along the State line near Fort Smith; on the south by the north boundaries of James Fork Poteau River and the Petit Jean River basins and the divide between tributaries to the Arkansas River and tributaries to the Ouachita and Saline Rivers (fig. 3).

2. Drainage basin includes the Arkansas River and tributaries in Arkansas above the Arkansas River's point of debouchment upon the Coastal Plain at Little Rock exclusive of tributary drainage basins of the Neosho, Poteau, Petit Jean, and Fourche Rivers, and Lee Creek .

3. Principal tributaries in the subsystem are Frog Bayou, Mulberry River, Piney Creek, Illinois Bayou, Point Remove Creek, Cadron Creek, Six Mile Creek, Big Shoal Creek, and Maumelle River.

4. Includes all or parts of White, Pulaski, Faulkner, Cleburne, Van Buren, Conway, Perry, Pope, Searcy, Yell, Newton, Johnson, Logan, Franklin, Madison, Washington, Sebastian, and Crawford Counties.

Peripheral area.--

1. The Hartshorne Sandstone and Atoka Formation, shale and sandstone deposits of Pennsylvanian age, make up most of the subsurface peripheral area in the subsystem.

2. These deposits have great thickness throughout the subsystem; thus, deeper lying rocks have little or no bearing on flow conditions in the subsystem other than their action as an impermeable boundary. In a sense, there is no subsurface peripheral area.

Nature of subsystem boundaries.--

1. The State line is an arbitrary boundary across which streamflow and underground flow can enter and leave the subsystem. Streamflow can be greatly altered by regulation of the streams on the Oklahoma side of the boundary. Ground-water flow can be altered to some extent by stress on either side of the boundary with resultant but small effect on the streamflow.

2. The topographic divides are considered to coexist with ground-water divides and form boundaries wherein the ground-water divides can be shifted as a result of stress on either side of the boundaries. The topographic divides are unaffected by hydrologic stress; however, if the ground-water divide is significantly shifted, probably negligible effects will be noted in streamflow.

3. The boundary along the Fall Line is arbitrary, but confines the subsystem to an isogenous environment. Most of the subsystem is encompassed by the drainage basin of the Arkansas River in Arkansas above the point at which it crosses the Fall Line.

4. The shale and sandstone deposits of Pennsylvanian age immediately underlying the subsystem may or may not be hydraulically connected with the streams. Furthermore, the subsurface boundary of these deposits is undefined.

Description of the principal area.--

1. The area comprises about 5,000 square miles.

2. Alluvium in a narrow band along the Arkansas River is hydraulically connected with the river and will yield as much as 500 gpm. These deposits and the river are treated as a separate subsystem in the alluvial aquifer-stream subsystem category.

3. Lake Maumelle, formed by a dam on Maumelle River, serves as a water supply for Little Rock.

4. Most of the tributaries to the Arkansas River in the subsystem cease to flow at times during most years.

5. Average annual runoff of the subsystem is about 14 inches near Fort Smith and in the subsystem increases to about 20 inches in all directions away from Fort Smith.

6. Ground water in the subsystem generally is hard and has a high iron content.

7. Surface water in the tributaries to the Arkansas River generally is of very good quality and tends to improve the quality of Arkansas River water.

8. The quality of Arkansas River water is variable; chloride content may be as low as 85 mg/l and as high as 800 mg/l.

9. Water use in the subsystem is estimated to be about 100 mgd (1965) with about four-fifths of the water drawn from surface-water sources.

10. With the exception of Franklin County, most of the water is used for public supplies and domestic-rural purposes. The water use in Franklin County in 1965 was 32.03 mgd, of which 30.16 mgd was used for fuel-electric purposes.

11. Streamflow data for most of the larger streams in the subsystem are available.

12. Water-quality data for ground and surface water are not sufficient.

13. The geology of the area is not known in detail. However, broad grouping by lithologic and hydrologic character is possible and probably sufficient.

14. Major regulation of water is through locks, dams, and reservoirs on the Arkansas River.

15. An analog model of the alluvial aquifer-stream flow system is available for the Arkansas River and its adjacent Quaternary deposits. Reports and data on postconstruction hydrologic conditions are available.

Description of peripheral area.--

1. The shales and sandstones of Pennsylvanian age (principally Hartshorne and Atoka) are very poor aquifers.

2. Well yields are unpredictable, undependable, and seldom exceed 10 gpm.

Basic considerations.--

1. A problem of management, principally of the surface-water resources.

2. A management tool or tools that can be used or project effects of various manipulations of any part of the subsystem.

3. Pollution of ground and surface water.

4. Quantification of geologic factors affecting runoff and streamflow.

5. Ground-water development guidelines for best location, drilling depth, and yield; what characteristics are peculiar to those few known areas where well yields are several times greater than average yields in the subsystem.

6. Time-travel information on the Arkansas River.

7. Operation of current-purpose data stations (quality of water and surface water) on the Arkansas and principal tributaries.

Upper Saline-Upper Ouachita subsystem

Principal area.--

1. Bordered on the east by the Fall Line from Little Rock to near Caddo Valley, on the south by the divide between Caddo River and the Ouachita River from the Fall Line to near Big Fork, on the west by the divide between tributaries to Cossatot River and Mountain Fork and the Ouachita River to near Rich Mountain, on the north by the divide between Arkansas River basin and the Ouachita River basin to near Ferndale, and thence to Little Rock along the divide between the Arkansas River and McHenry and Fourche Creeks (fig. 3).

2. Drainage basins of the Ouachita and Saline Rivers above their point of debouchment upon the Coastal Plain; includes small adjacent areas west of the Fall Line that drain to the Ouachita, Saline, and Arkansas Rivers.

3. Principal tributaries in the subsystem are Irons Fork, Mazarn Creek, Glazypeau Creek, Alum Fork, and Middle Fork.

4. Also includes adjacent small areas in the Interior Highlands whose drainage is tributary to the Arkansas, Saline, and Ouachita Rivers. Principal streams in these areas are McHenry and Fourche Creeks tributary to the Arkansas River, Hurricane and Francis Creeks tributary to the Saline River, and Prairie Bayou tributary to the Ouachita River.

5. Includes all or parts of Pulaski, Saline, Perry, Yell, Scott, Polk, Montgomery, Garland, and Hot Spring Counties.

Peripheral area.--

1. Sandstone, shale, chert, and novaculite deposits, Mississippian to Cambrian in age, underlying the subsystem.

2. These deposits are underlain by older rocks that probably do not affect the subsystem. In this sense, no subsurface peripheral area exists.

Nature of subsystem boundaries.--

1. The boundary along the Fall Line is arbitrary, but confines the subsystem to an isogenous environment. Most of the subsystem is encompassed by the drainage basin of the Ouachita River upstream from the point at which it crosses the Fall Line.

2. The topographic divides are considered to exist with ground-water divides and form boundaries wherein the ground-water divides can be shifted as a result of stress on either side of the boundaries. The topographic divides are unaffected by hydrologic stress; however, if the ground-water divide is significantly shifted, probably negligible effects will be noted in streamflow.

3. The sandstone, shale, chert, and novaculite deposits ranging from Cambrian to Mississippian in age immediately underlying the subsystem may or may not be hydraulically connected with the streams. Furthermore, the subsurface boundary of these deposits is undefined.

Description of principal area.--

1. The area comprises about 2,000 square miles.

2. The Ouachita River is extensively regulated by three dams forming Lakes Ouachita, Hamilton, and Catherine.

3. Alum Fork, a tributary to the Saline River, is dammed to form Lake Winona, which serves as a water supply for Little Rock. Use of this water in Little Rock represents a diversion of water from the Saline River basin to the Arkansas River basin.

4. The famous hot springs are located in the subsystem at Hot Springs, in Garland County.

5. At gaging stations on South Fork Ouachita River at Mt. Ida, and Saline River at Benton, no-flow conditions have been observed.

6. Average annual runoff of the subsystem is about 24 inches in the west part, diminishing eastward to about 20 inches.

7. Average annual precipitation in the subsystem ranges from 52 inches in the east to 54 inches in the west and is the highest in the State.

8. Ground water in the subsystem generally is hard and has a high iron content.

9. The chemical quality of water in the Ouachita River is excellent. A maximum dissolved-solids content of 283 mg/l and a minimum of 26 mg/l have been noted. Hardness has been noted to range from 85 to 10 mg/l and specific conductance from 550 to 27 micromhos. Iron content ranging from 0.26 mg/l to 1.1 mg/l was noted during the 1967 water year.

10. Water use in the subsystem is estimated to be about 250 mgd (1965). This high use is attributed to 209.40 mgd use (1965) for fuel-electric power in Hot Spring County. Most of the other use was for public supply; the rest was used for industrial and domestic-rural purposes. Ground-water use in the subsystem is less than 10 percent of the total and is used principally for domestic-rural purposes.

11. Streamflow data for the larger streams in the subsystem are available but are lacking on the smaller tributaries except for South Fork Ouachita River at Mount Ida.

12. Water-quality data for ground and surface water are not sufficient.

13. The geology of the area may not be known in the detail required. Broad grouping by lithologic and hydrologic character is possible and may be sufficient.

14. Major regulation of water in the subsystem is through reservoirs and dams, three on the main stem of the Ouachita River and one on Alum Fork, a tributary to the Saline River.

Description of peripheral area.--

1. Well yields from the deposits immediately underlying the subsystem are low, rarely exceeding 10 gpm.

2. Peripheral rocks at depth may influence the subsystem, but the nature and extent of influence probably is local (for example, hot springs in Garland County).

Basic considerations.--

1. A problem of management, principally of surface-water resources.

2. A management tool or tools that can be used to project effects of various manipulations of any part of the subsystem.

3. Pollution of surface and ground water; one notable example being pollution of Lake Hamilton from septic tanks and sewage disposal.

4. Quantification of geologic factors affecting runoff and streamflow.

5. Ground-water development guidelines for best location; drilling depth and yield.

6. Time-travel information on the Ouachita and Saline Rivers.

7. Operation of current-purpose data stations (quality of water and surface water) on the Ouachita and Saline Rivers.

## Description of Selected Aquifer Subsystems

### Sparta-Memphis subsystem

Principal area.--

1. Areal limits of Sparta Sand and Memphis aquifer within Arkansas.

2. With the exception of Sevier, Howard, Little River, Pike, Randolph, and Independence Counties, includes all or parts of all counties in the Coastal Plain of Arkansas (fig. 4).

3. Area bordered on the south by the State line, on the east by the Mississippi River, on the north by the State line and St. Francis River, and on the west along a line from the northeast corner of the State to the southwest corner that coincides with the westward areal limits of occurrence of the Sparta Sand and Memphis aquifer.

Peripheral area.--

1. Stream drainage basins upstream from the point of debouchment of the stream upon the outcrops of the Sparta Sand and Memphis aquifer. Principal streams crossing the outcrops are the Little Missouri, Saline, and Ouachita Rivers.

2. Quaternary deposits immediately overlying the Sparta Sand and Memphis aquifer.

3. Tertiary deposits immediately overlying and underlying the Sparta Sand and Memphis aquifer.

Nature of subsystem boundaries.--

1. The Mississippi and St. Francis Rivers and the State lines are arbitrary boundaries across which flow conditions must be known.

2. The areal limits of occurrence of the Sparta Sand and Memphis aquifer on the west are undefined as to exact location but terminate the subsystem, constituting an independent boundary where the formations abut other impermeable rocks.

3. The Tertiary deposits overlying and underlying the Sparta-Memphis subsystem are low in permeability, but probably allow leakage to or from the Sparta Sand and Memphis aquifer.

4. Quaternary deposits immediately overlie a part of the Sparta Sand and Memphis aquifer and are hydraulically connected with the subsystem.

5. Stress on either side of any of the subsystem boundaries, except the boundary at the termination of areal occurrence, will alter flow conditions in the subsystem.

Description of principal area.--

1. The principal area comprises about 25,000 square miles in the southeastern half of Arkansas.

2. The Sparta Sand is composed principally of very fine to medium sand, but also contains clay and silt lenses and lignite.

3. Thickness of as much as 800 feet.

4. Transmissivity for the Sparta is as high as 130,000 gpd per foot.

5. Recharge to the Sparta is from precipitation on the outcrop, leakage from overlying and underlying deposits, and underflow from the Memphis aquifer. Recharge from streams occurs only where streams cross the outcrop.

6. Discharge is principally by pumping; withdrawals for industrial, irrigation, and municipal use in Arkansas were about 125 mgd in 1965.

7. Water in the Sparta generally is soft and is a sodium bicarbonate type.

8. Dissolved-solids content of water in the Sparta ranges from 20 to 1,510 mg/l, but a median of 218 mg/l indicates only moderate mineralization.

9. The Memphis aquifer is a northward-extending sand facies equivalent to the Carrizo Sand, Cane River Formation, and Sparta Sand in the southern part of the subsystem.

10. The Memphis aquifer is principally made up of sand, but contains some argillaceous, micaceous, and lignitic materials.

11. Clay layers constitute only a small part of total thickness of the Memphis aquifer, but layers as much as 20 feet thick may be extensive enough locally to hydraulically separate the sand.

12. The principal source of recharge to the Memphis aquifer in the subsystem is from leakage from Quaternary deposits.

13. Discharge from the Memphis aquifer is principally by pumpage; withdrawal in Arkansas in 1965 was about 15 mgd.

14. The Memphis aquifer is comprised of sand as much as 800 feet thick.

15. Transmissivity of the Memphis aquifer is as high as 50,000 gpd per foot.

16. Water in the Memphis aquifer in the subsystem is a calcium magnesium bicarbonate type. This is caused by leakage into the aquifer from Quaternary deposits.

17. Water in the Memphis aquifer generally is of good quality.

Description of peripheral area.--

1. Detailed geologic maps of the surface and subsurface peripheral areas are not available. However, the Mississippi embayment study provides regionalizations that probably are sufficient.

2. Stream-gage data for the Little Missouri and Saline Rivers at their points of debouchment upon the outcrop of the Sparta Sand are lacking.

3. Leakage to the Sparta Sand and Memphis aquifer from Tertiary and Quaternary deposits has been inferred from analog-model studies of the subsystem on a regional basis.

Basic considerations.--

1. A problem of management of the subsystem requiring a complete knowledge of how the subsystem operates.

2. Local severe lowering of water levels in the El Dorado, Magnolia, Pine Bluff, and Grand Prairie areas.

3. Heavy pumpage (140 mgd in the Memphis area in 1965) and lowered water levels.

## Roubidoux-Gunter subsystem

Principal area.--

1. Areal limits of Roubidoux Formation and the Gunter Sandstone Member of the Van Buren Formation in Arkansas (fig. 7).

2. Includes all or parts of Benton, Washington, Crawford, Carroll, Madison, Franklin, Boone, Newton, Johnson, Marion, Searcy, Pope, Baxter, Stone, Van Buren, Fulton, Izard, Cleburne, Randolph, Sharp, Lawrence, and Independence Counties.

3. Bordered on the west and north by the State line, on the east by the Fall Line, and on the south by the limits of occurrence of the Roubidoux Formation and the Gunter.

Peripheral area.--Deposits overlying and underlying the subsystem.

Nature of the subsystem boundaries.--

1. The State line is an arbitrary boundary across which underflow can enter the principal area. Extreme stress on either side of the State line can alter the water regimen in the subsystem.

2. The areal limits of occurrence of the Roubidoux Formation and the Gunter on the south are undefined as to exact location but terminate the subsystem, constituting an independent boundary where the formations abut other impermeable rocks.

3. The surface and subsurface boundaries of the subsystem are undefined.

Description of principal area.--

1. The principal area comprises about 12,000 square miles in the northwestern part of Arkansas.

2. The Roubidoux Formation is composed principally of dolomite, sandstone, and chert. The sandstone consists of fine-to-medium, angular-to-rounded, frosted quartz grains, loosely to well cemented by silica or calcareous material.

3. The Gunter Sandstone Member of the Van Buren is mainly sandstone consisting of fine-to-coarse, subangular-to-rounded quartz grains, generally cemented by silica or calcareous materials.

4. The Roubidoux is as much as 455 feet thick.

5. The Gunter is as much as 100 feet thick.

6. The transmissivity of the Roubidoux and Gunter is poorly known and at most locations probably is less than 5,000 gpd per foot.

7. Recharge to the Gunter and Roubidoux is from precipitation on the outcrop areas in Missouri outside the subsystem. Streams crossing the outcrops also may provide recharge or may receive water from the aquifer. Leakage from overlying and underlying deposits may supply small amounts of recharge, as well as provide a means of discharge.

8. Discharge in the principal area is primarily by pumping for municipal and industrial use.

9. Withdrawal from the Roubidoux-Gunter aquifer in 1965 in the principal area probably was as much as 15 mgd.

10. Water from the Roubidoux-Gunter aquifers generally is of good quality and is of the calcium bicarbonate type.

11. Saline water may be present in the Roubidoux-Gunter below 1,000 feet.

Description of peripheral area.--Hydrologic details of the relationship of rocks overlying and underlying the Roubidoux Formation and Gunter are not well known. However, there probably is little exchange of water between the aquifers and contacting rocks because the water in the aquifers is under artesian pressure.

Basic considerations.--

1. A problem of knowing good well spacing.

2. Better control on locations of aquifer tops and bottoms.

3. A problem of management with respect to long-term maximum development that can be expected without seriously lowering water levels.

4. Probably best considered as a regional subsystem throughout areal extent rather than confining study to Arkansas.

5. Probably saline water at depth, location, extent, effects of fresh-water withdrawals.