A STUDY OF THE EFFECTS OF THE ARKANSAS RIVER CHLORIDE CONTROL PROJECTS AND THE NEED FOR A WATER QUALITY MONITORING SYSTEM

By

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Bachelor of Science

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Stillwater, Oklahoma

1961

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
July 1970

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Thesis Approved:

Thesis Adviser

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ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to the following people:

Dr. Don F. Kincannon, his major advisor, who provided encouragement and counsel during the course of research and thesis preparation.

Dr. Richard N. DeVries and Professor Quintin B. Graves, members of the Advisory Committee, for their valuable advice and suggestions.

Mrs. Margaret Morrison for her careful and accurate typing of the manuscript.

My wonderful and understanding wife of 22 years, Wanda, for her encouragement and patience from 1957 to 1961 while I worked on my first degree and during the subsequent years while I worked on my master's degree. Also to my wonderful sons, Robert, Jr., and Ronald, and my sweet daughter, Dawna, for their encouragement.

The U. S. Army Corps of Engineers for providing their financial assistance during much of the author's course work, and especially to Mr. M. W. DeGeer for his interest and encouragement.

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CHAPTER I

INTRODUCTION

A. General

The U. S. Public Health Service started a study of the Arkansas-Red River Basins in July 1957 under authority of the Federal Water Pollution Control Act, PL 660 (84th Congress), to determine the various factors which caused mineral degradation of the waters in the two basins and to suggest methods or measures which could be used to improve over-all water quality. Preliminary investigations by Public Health Service revealed that two mineral constituents, chlorides and sulfates, are the principal pollutants of the waters of the Arkansas and Red River Basins. Studies concentrating on abatement of natural and man-made brines were begun in 1958. Preliminary evaluations of the available data and general scope of the problem were made in cooperation with numerous Federal, State, and local agencies. The initial studies indicated that detailed basin-wide studies were required to more fully define the problem and develop plans for quality improvement in these two river basins. As a consequence, the Congress in August 1959 approved continuance of the Public Health Service study and in December 1959 authorized the Corps of Engineers' participation in the study. The results of this study indicate that structural means of controlling natural pollution are feasible and should be a Federal responsibility.

The water flowing in the Arkansas and Red Rivers is currently polluted by natural salt that finds its way into the stream system by way of springs and seeps located on tributaries. The concentration of chlorides, dissolved solids, and sulfates in general vary inversely with streamflow. The water stored in Keystone Reservoir, a few miles upstream of Tulsa, Oklahoma, on the Arkansas River, cannot be used for beneficial purposes because of mineral degradation of tributary inflows. Because of this, cities and towns along the Arkansas River go 60 to 100 miles to obtain water for municipal and industrial use. This report also studies the need for continuous water quality monitoring of the basin's streamflows.

B. Justification of this Research

A considerable amount of research has been done on monitoring organic pollution, and methods and means of controlling municipal and industrial effluents, but very little work has been accomplished for monitoring and control of inorganic or mineral pollution.

C. Objectives

The primary objective of this report is to study the magnitude and distribution of the natural salt pollution of the two stream systems and to evaluate the need for a continuous water quality monitoring system. Also, an estimate is made of what type data would give adequate information for future evaluation of the effectiveness of upstream structural controls.

It is anticipated that use of this information will aid in obtaining funds for a continuing program of water quality studies for the Arkansas River Basin and other similar river systems such as the Red River.

CHAPTER II

LITERATURE SURVEY

A. Water Quality Management

Kneese and Bower (1) stated that the problem of water quality management raises three main issues. First, how do we determine the quality of water we want to maintain in our watercourses; second, what is the best system of management measures for achieving the specified pattern of water quality; and third, what are the best institutional or organizational arrangements for managing water quality. All of these issues are related. For example, the choice of quality level must depend on the cost of achieving that level, and the cost largely depends on how effective the management agency is. Efficient water quality management can only be achieved with explicit consideration of other outputs from water resources systems including hydro-power, water supply, irrigation, navigation, water based recreation opportunities, and flood damage reduction.

According to McGauhey (3) the problems of water quality management stem from the inability of institutions and technology to respond quickly to changed conditions. This problem, no doubt, stems from the change from use-oriented goals to resource-oriented objectives of water quality control. Nevertheless, the concept of water quality management clearly seems to represent emerging public policy in relation to resources management and conservation.

The following paragraphs are aimed at wastes that are considered nondegradable. The reason for this approach is to show that the natural salt pollution of the Arkansas and Red Rivers is nondegradable. The only economical solution to the natural salt pollution is to remove, control, and hold this pollutant from the streams.

1. Nondegradable Wastes

The sources of nondegradable substances, mainly inorganic chemicals such as chlorides, synthetic organic chemicals, and inorganic suspended solids, are many and widespread. Industrial waste discharges frequently contain inorganic or metallic salts, synthetic organic chemicals, and other materials, which may be toxic or corrosive, may impart color or taste to the water, and also may produce odors. Domestic water use results in a small increase in the content of chlorides and other dissolved salts. The return flow from irrigation is generally significantly higher in dissolved salts than the applied irrigation water. The discharge of copper, zinc, uranium and other compounds in drainage from mine tailings is an acute problem in some of the major coal-producing areas. In the heavily industrialized sections of the country and in the major irrigated areas of the West, industrial operations and irrigated agriculture are, in some instances, major sources of chlorides and other dissolved salts.

Natural geologic formations, such as salt deposits, sometimes result in high concentrations of chlorides and dissolved solids in streamflows. Another instance of deterioration of water quality by a natural source is from seawater intrusion in groundwater aquifers near coastal areas. Similarly the quality of water in inland groundwater aquifers can be adversely affected by excessive pumping where there are hydraulic connections with brackish or saline aquifers.

The quality of water, as regards inorganic pollution, in storage in reservoirs and flowing in streams can be improved by reducing the pollution load at the source. Dilution of flows by storage of higher quality water is an alternative to reduction of loads or could be complementary to a reduction program.

B. Objectives of Water Quality Management

Water freezes at 32 degrees Fahrenheit (2), vaporizes at 212 degrees, and flows as a liquid anywhere between. It covers 70 percent of the globe, constitutes 70 percent of our bodies, and makes the earth hospitable to life. Water will dissolve more substances than any known liquid. Water, next to air, is man's most plentiful and precious resource. But he has blithely taken it for granted, using and misusing it with too little thought of the future. Only in recent years have conserving the world's water supply and developing water quality management programs become vital concerns. Development of an adequate framework for natural water pollution control in river basins should be concerned with national goals which give purpose to planning. Guidelines of comprehensive planning for water quality management are given in the following enacted Federal law, expressions by Department of Health, Education and Welfare representatives, the late President John F. Kennedy, former President Lyndon B. Johnson, and President Richard M. Nixon.

1. Federal Objectives

The policy of the Congress with regard to water pollution control activities of the nation is contained in Public Law 660, as amended by Public Law 87-88, approved July 20, 1961, and Public Law 89-234, approved October 2, 1965. The earlier amendment allows storage in federally constructed reservoirs for regulated release when needed to help control pollution by diluting treated municipal and industrial waste materials. Reservoir costs of water quality control features are nonreimbursable under provisions of this law when the benefits are widespread or national in scope. The purpose of the later amendment was to enhance the quality and value of water resources and to establish a national policy for the prevention, control, and abatement of water pollution and to require establishment of water quality criteria by the states. All 50 states have adopted water quality standards as required by law.

The Assistant Secretary of the Department of Health, Education and Welfare in 1961 stated that the Federal Government must take the lead in establishing a national policy on water pollution control which is comprehensive in its scope and uncompromising in its implementation. He said existing law actually authorizes the Federal Government to act with regard to interference with any and all legitimate water uses, whatever purposes they serve. He also said that any degradation of water which can interfere with a legitimate use is contrary to national policy. "No pollution control law, Federal, State, or local, should by its terms or by interpretation be held to require, permit or condone any type of water pollution." He further said that whatever may have been acceptable or unavoidable in years past, it is quite clear that the goal now and in the years ahead, in an age of vast industrial expansion and rapid urbanization, must be to prevent any sort of water pollution.

Referring to water resources in his conservation message to the Congress in 1962, the late President John F. Kennedy said:

> "Our goal, therefore, is to have sufficient water sufficiently clean in the right place at the right time to serve the range of human and industrial needs."

Former President Lyndon B. Johnson's 1965 State of the Union message gave promise of an expanded conservation program and gave first priority to cleanup and prevention of pollution. President Johnson stated in part, "We will seek legal power to prevent pollution of our air and water before it happens. We will step up our effort to control harmful wastes, giving first priority to the cleanup of our most contaminated rivers. We will increase research to learn more about control of pollution."

President Richard M. Nixon, in his January 1970 State of the Union message, proposed an action program to combat water pollution. President Nixon stated in part, "We still think of air as free. But clean air is not free, and neither is clean water. The price tag on pollution control is high. Through our years of past carelessness we incurred a debt to nature, and now that debt is being called. The program I shall propose to Congress will be the most comprehensive and costly program in this field in America's history."

2. Oklahoma Objectives

On July 26, 1967, Governor Dewey F. Bartlett submitted the "Water Quality Standards for the State of Oklahoma," (4) to the Secretary of the Interior for approval. The Standards were approved subject to minor exceptions on February 28, 1968. The Standards are complete and thorough regarding organic pollution objectives and inorganic or mineral pollution objectives for industry. The natural salt pollution is assumed to be a responsibility of the Federal Government. This is as it should be as the benefits from controlling natural pollution are widespread.

The water quality surveillance program consists of 56 proposed stations in the Arkansas and Red River basins in Oklahoma. The stations are located to monitor streamflow from the major basins as well as the smaller basins. In addition to the 56 continuous stations, intermittent measurements of stream water quality will be made at certain points as the need arises. New water quality data generated by this system may require additions or deletions of stations as time, funds, and needs may develop.

The water quality criteria, adopted by the State of Oklahoma for the Arkansas and Red Rivers, are based on the present and potential uses, and on existing quality data. The criteria will serve as guidelines to control pollution and to maintain the best quality which will result in an equitable balance of social and economic benefits to the State of Oklahoma.

C. Types of Mineral Pollutants

It cannot be said too often that fresh water is a critically important resource. Good water is the basic resource essential to the efficient use of most natural resources, as well as life itself. Regardless of how plentiful, water can neither assure survival nor create prosperity; a shortage of good quality water can threaten both. There is an abundance of water in the Arkansas-Red River basins to meet the short range demands for in-basin uses, with the significant volume potentials available for export to other basins of need. Scarcity of usable water in the basin region, as discussed in the following paragraphs, is largely caused by deterioration of water quality by mineral pollution and maldistribution of existing supplies.

In the Arkansas-Red River basins, the sources of pollution (other than municipal and industrial wastes) are rendering water resources unusable. These pollutants are salt (sodium chloride) and gypsum (calcium sulfate). The quality of water is determined by the magnitude of its mineral constituents. Mineral concentration is expressed as parts per million (ppm) or in milligrams per liter (mg/l). At a specific gravity of unity, one ppm is numerically equivalent to one mg/l. Water has the ability to absorb or dissolve salt until a concentration of 193,000 mg/l chloride is reached. If this concentration is exceeded, the solution is supersaturated and salt is deposited. The relationship between salt (sodium chloride) and the chloride ion is based on their atomic weights; therefore, salt loads may be converted to chloride loads by dividing by 1.65.

1. Chlorides

Two years of continuous mineral quality monitoring of streamflows by Public Health Service (5) (1961-1962) found a daily average of 20,000 tons of salt (as NaCl) in the Arkansas River (measured at

Van Buren, Arkansas) and 7,000 tons daily in the Red River (measured at Index, Arkansas). Approximately 15,000 tons of salt came from 15 primary natural source areas, while the remaining 12,000 tons were from man-made pollution sources and other minor natural source areas. The magnitude and effect of the natural chloride load emanating from the 15 defined source areas warranted separate study.

2. Man-made Brines

The brines entering the basins' streams as a result of man are primarily the consequence of petroleum and natural gas production. However, the Oklahoma Corporation Commission, in conjunction with the Oklahoma Water Quality Coordinating Committee, has reported that now over 95 percent of the brine resulting from petroleum activities is being reinjected into producing strata for pollution control or secondary petroleum recovery. The State of Oklahoma supports the concept that the enforcement and cost of controlling man-made pollution is a proper state responsibility. However, the Corps' studies correlate the downstream effects of natural and man-made chloride control measures.

3. Sulfates

In addition to chlorides, large volumes of surface and ground waters of these basins are polluted by sulfates originating in widespread gypsum deposits. The Public Health Service reports the total sulfate load in the basins approaches 9,600 tons per day, with approximately 500 tons measurable in the 15 major salt-source areas. Control of the chloride-emission areas would also control up to 20 percent of the sulfate load. In general, the sulfate concentrations at points of potential water usage are lower than chlorides. The Public Health

Service reports that the methods suggested for control of chlorides would not be effective for sulfate control and that the sulfate pollution problem should be the subject of further research.

CHAPTER III

METHODS OF STUDY

Much of the data developed during the course of the author's work on the Corps of Engineers' survey report "Arkansas-Red River Basins, Water Quality Control Study" was used to present the problem and potential solutions to control the mineral pollution of the Arkansas and Red River basins. The job of defining the origin of the brine is a very difficult and complex study of the geology of the areas and exceeds the scope of this report.

This study consists of three phases. The first phase revolves around the geologic origin of the salt deposits and the location of natural salt pollution areas. The second phase consists of research and summarization of engineering reports, manufacturing publications, and other references regarding pollution control structures and measurement equipment. The third phase involves studies for monitoring streamflow after structural measures are complete.

CHAPTER IV

RESULTS

A. Origin of Natural Salt Pollution

All of the important saline or salt producing rocks in the Arkansas and Red River basins are Permian in age. They are the marine deposits of 250 million years ago. At the time of their deposition, a salt water sea extended over the area that now comprises parts of western Texas, southeastern New Mexico, western Oklahoma and southern Kansas. Some of the sediments accumulated in deep basins that were separated by relatively shallow platforms, while others accumulated on the floors of the subsiding bays, lagoons and shallow inland seas. To the southwest in the Permian basin of Trans-Pecos, Texas, and southeastern New Mexico, the rock sequences reached thicknesses of over 12,000 feet with 7,500 feet of marine origin. All of the sediments were deposited under arid climatic conditions. The salt sequences of gypsum, anhydrite, and halite (rock salt) were produced by the chemical precipitation of salts from the sea water as evaporation increased the salt content of the water to the saturation point. Some basins of accumulation were fed periodically and others continuously with new water while evaporation and salt precipitation continued. (Volume 1, Public Health Service Report, 5.)

The Public Health Service located the mineral pollution source areas and measured their effect on the quality of water in the receiving streams. Results of their intensive two-year field study and stream quality monitoring program are incentives for planning measures to control brine emission. Delineation of the salt source areas was accomplished by a combination of different methods. Information on some of the natural salt water emission areas was obtained from published and preliminary reports. Air reconnaissance was made to pinpoint reported sources and this also helped in the location of other sources. Then followed a field reconnaissance of each source to locate and define specific springs, seeps and other brine drainage areas. Brine flows and concentrations were determined for each salt source area and, where possible, individual emissions in the area were measured.

B. Pollution Problems Resulting from Salt Emission

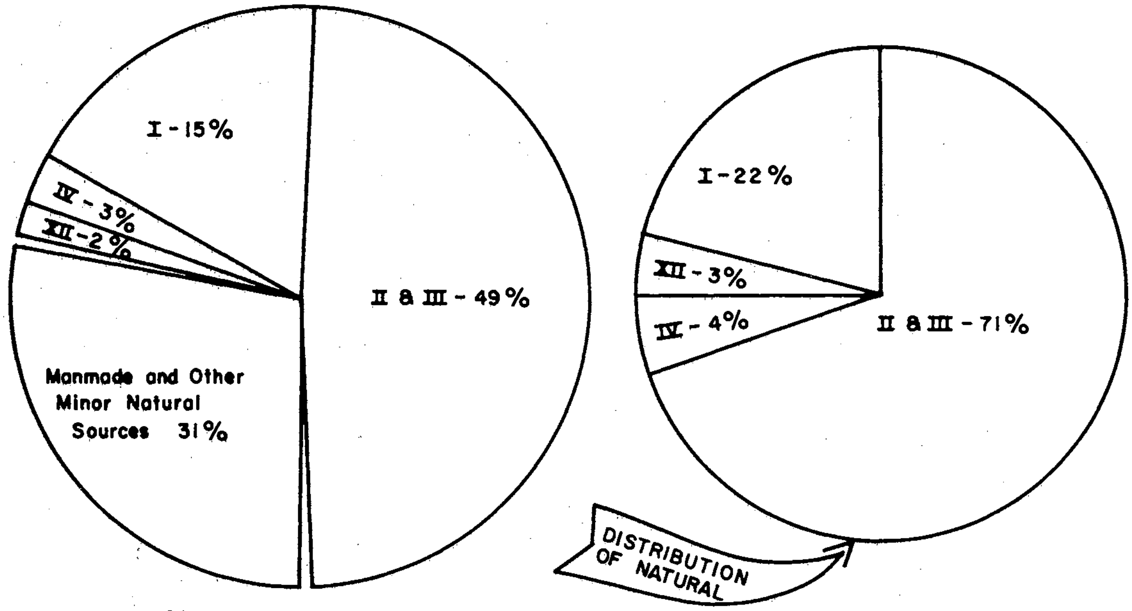
An average of 20,000 tons per day of salt (NaCl) enter the Arkansas River upstream from Van Buren, Arkansas, and 7,000 tons daily enter the Red River upstream of Index, Arkansas. Approximately 53 percent of the total salt load comes from primary and secondary natural sources, while the remaining portion comes from man-made and minor natural sources. The precise location of the man-made sources cannot always be determined; therefore, these salt loads are distributed over the reach of the river between the two identifying water quality measuring stations. In defining man-made salt sources, estimates of salt discharge from oil and gas operations, as well as information regarding disposal practices, were obtained from the state agencies responsible for pollution control and water resource development. The largest source of salt from man's activities is the brine associated with oil and gas production, which accounts for over 90 percent of the total salt. In new oil fields, little or no brine may be produced, but old, nearly depleted fields may yield as much as 100 barrels of salt water per barrel of oil. The remaining man-made salt pollutants are wastes from other industries such as salt manufacturing and chlorine-caustic plants. Figure 1 shows the chloride distribution from natural and man-made sources throughout the two-river basins upstream of Tulsa, Oklahoma, on the Arkansas River and above Lake Texoma on the Red River (2).

1. Arkansas River

Natural salt pollution in the Arkansas River basin begins in southern Kansas and western Oklahoma. Five major natural contamination sources: the Great Salt Plains on the Salt Fork of the Arkansas River, Area I; the Big and Little Salt Plains on the Cimarron River, Areas II-III; the Salt Creek tributary to the Cimarron River, Area IV - all in Oklahoma; and the Rattlesnake Creek, Area XII, in Kansas, account for about 70 percent of the total salt load carried past Tulsa, Oklahoma, each year. The Great Salt Plains on the Salt Fork of the Arkansas and Big and Little Salt Plains on the Cimarron River contribute 3,600,000 of the total natural salt load of 4,000,000 tons per year. Each year about 7½ million tons of salt in solution pass Van Buren, Arkansas.

2. Red River

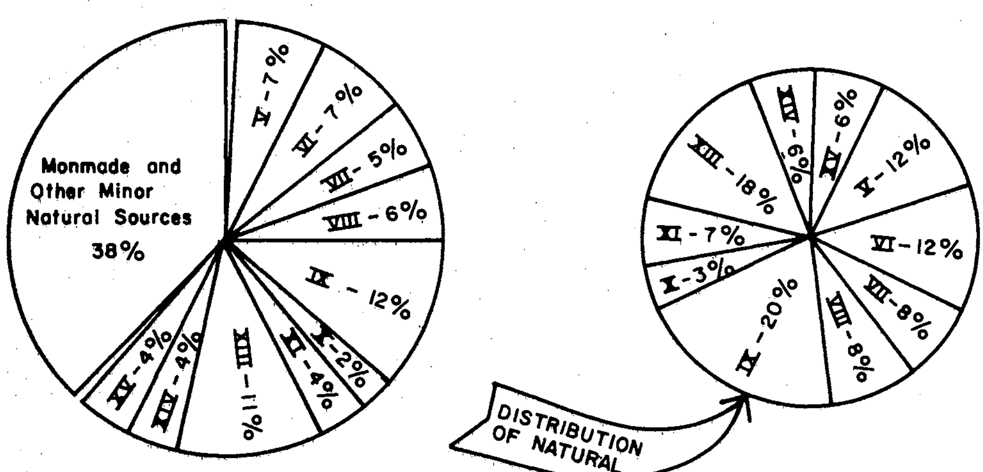
The Red River basin is presently polluted with salt from the Palo Duro Canyon in western Texas to its confluence with the Mississippi River. A large portion of the pollution originates from ten natural salt sources along the upper tributaries to Red River in Texas and



NATURAL AND MANMADE
(9450 TONS PER DAY)

NATURAL
(6500 TONS PER DAY)

ARKANSAS RIVER BASIN ABOVE TULSA, OKLAHOMA



NATURAL AND MANMADE
(4200 TONS PER DAY)

NATURAL
(2500 TONS PER DAY)

RED RIVER BASIN ABOVE LAKE TEXOMA

DISTRIBUTION OF CHLORIDE LOADS

FIGURE I

COURTESY U.S. ARMY CORPS OF ENGINEERS

Oklahoma. At Lake Texoma the total salt load entering the reservoir in one year is about 2½ million tons.

3. The Salt Emission Process

Under certain geologic and hydrologic conditions ground water percolates down and through salt bearing rocks where it dissolves the salt. Hydrostatic pressure of ground water at higher elevations forces the salt water to emerge as salt springs and seeps at lower elevations. In addition to the flow of brine from seeps and springs, ground water brings salt to the surface by capillary action. During dry periods or droughts evaporation of this water increases the concentration of the solution until a supersaturated condition is reached and salt flats and encrustations are formed in and adjacent to the streambed. High flows dissolve this solid salt which, along with the normal base flow, is washed downstream. Thus, large volumes of salt are transported during the early stages of a flood. Later, following a flushout period, the flood waters carry only the base salt load. The amount of salt in the flats depends upon the length of time between flushouts, the seasons of the year and the physical characteristics of the area such as type of soil, location and concentration of the ground water.

C. Streamflow and Salt Concentrations as Variables

In the Arkansas River basin the normal streamflow pattern near the salt sources is several months of low flows followed by short periods of flooding which produce the flushouts. The characteristics of this cycle are shown in Table I. The highest concentrations occur during periods of low flow when a small volume of water carries the base salt load.

TABLE I

ARKANSAS RIVER BASIN FLOW-LOAD DISTRIBUTION

% Time Flow is Equalled or Exceeded	Cimarron River		Arkansas River					
	Perkins, Okla.		Ark City, Kans.		Ralston, Okla.		Tulsa, Okla.	
	Average Daily Flow c.f.s.	% of Total Salt Load	Average Daily Flow c.f.s.	% of Total Salt Load	Average Daily Flow c.f.s.	% of Total Salt Load	Average Daily Flow c.f.s.	% of Total Salt Load
1	21,000	16	18,000	3	50,000	9	73,000	12
10	2,200	39	3,500	19	10,200	31	14,800	37
50	300	35	750	38	1,750	43	2,560	40
90	30	9.8	200	30	400	15.5	610	10
99	4	0.1	30	9	50	1.4	150	0.9

1. Distribution of Salt Load in Flows

About 16 percent of the total salt load measured at Perkins, Oklahoma, is carried by flows which are equalled or exceeded only one percent of the time as shown in Table I. Such high salt loading in a short time period is typical of a station located below a natural source area on an unregulated stream and receives the full impact of a flush-out. The Arkansas City, Kansas, station shows that a relatively small percent of the total load is carried in the flows equalled or exceeded one percent of the time. This indicates that there is little effect from flushouts on this particular reach of the stream. As the water flows from Arkansas City to Ralston, Oklahoma, it combines with Salt Fork water which carries large quantities of salt from the Great Salt Plains. On the average, about 80-90 percent of the total volume of water passes downstream each year within a four-month period leaving 10-20 percent of the water to pass in the remaining two thirds of the year. Figure 2 presents a picture of the normal distribution of the flow. Flood waters contribute so much of the total volume of water that the daily average flow nearly triples that which can be expected 50 percent of the time. Median flow is more indicative of the quality of the water. The average and median flows and salt loads at five of the stations in the Arkansas River basin are shown in Table II.

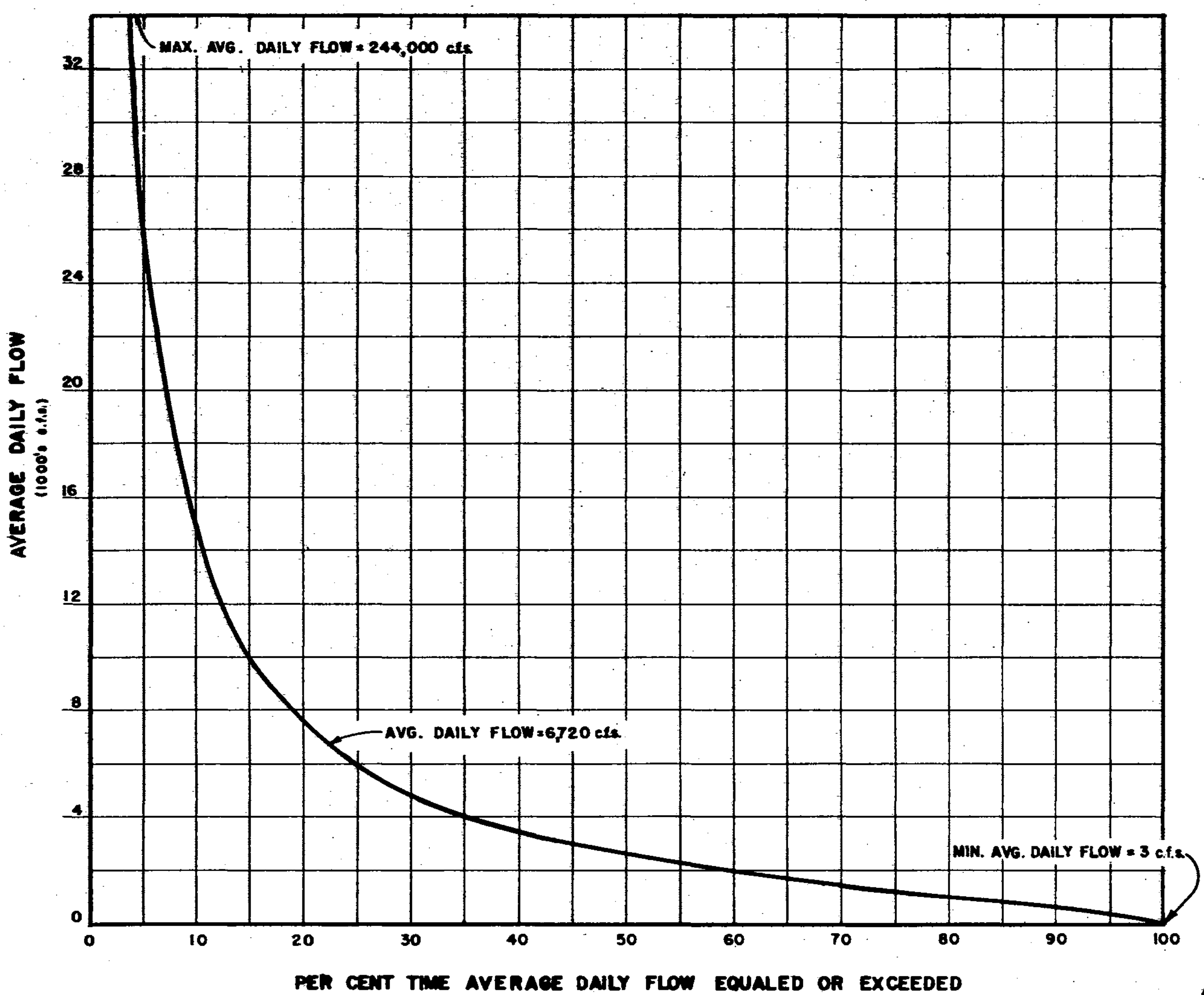
TABLE II

CHLORIDE REFERENCE STATIONS, ARKANSAS RIVER BASIN

Station	Average Daily Flow (c.f.s.)	Median Daily Flow (50% Time) (c.f.s.)	Average Daily Salt Load (tons/day)	Median Daily Salt Load (50% of Time) (tons/day)
Arkansas City, Kan.	1,741	730	2,100	1,100
Jet, Okla.	408	105	2,380	710
Ralston, Okla.	4,690	1,760	5,740	3,330
Perkins, Okla.	1,280	300	8,700	3,700
Van Buren, Ark.	29,990	11,500	20,400	13,900

2. Effect of Water Volume on Chloride Concentration

Figure 3 illustrates the effect the volume of water has upon chloride concentrations in the Arkansas River. The four stations shown are located at strategic points below the natural salt source areas.



NOTE:
1. Source of records: P.H.S.–U.S.G.S. Period of flow records: October 1925–September 1961.
2. Average daily flows for existing condition.

FIGURE 2

FLOW DURATION CURVE

ARKANSAS RIVER AT TULSA, OKLAHOMA
ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY TEXAS - OKLAHOMA - KANSAS
COURTESY U.S. ARMY CORPS OF ENGINEERS

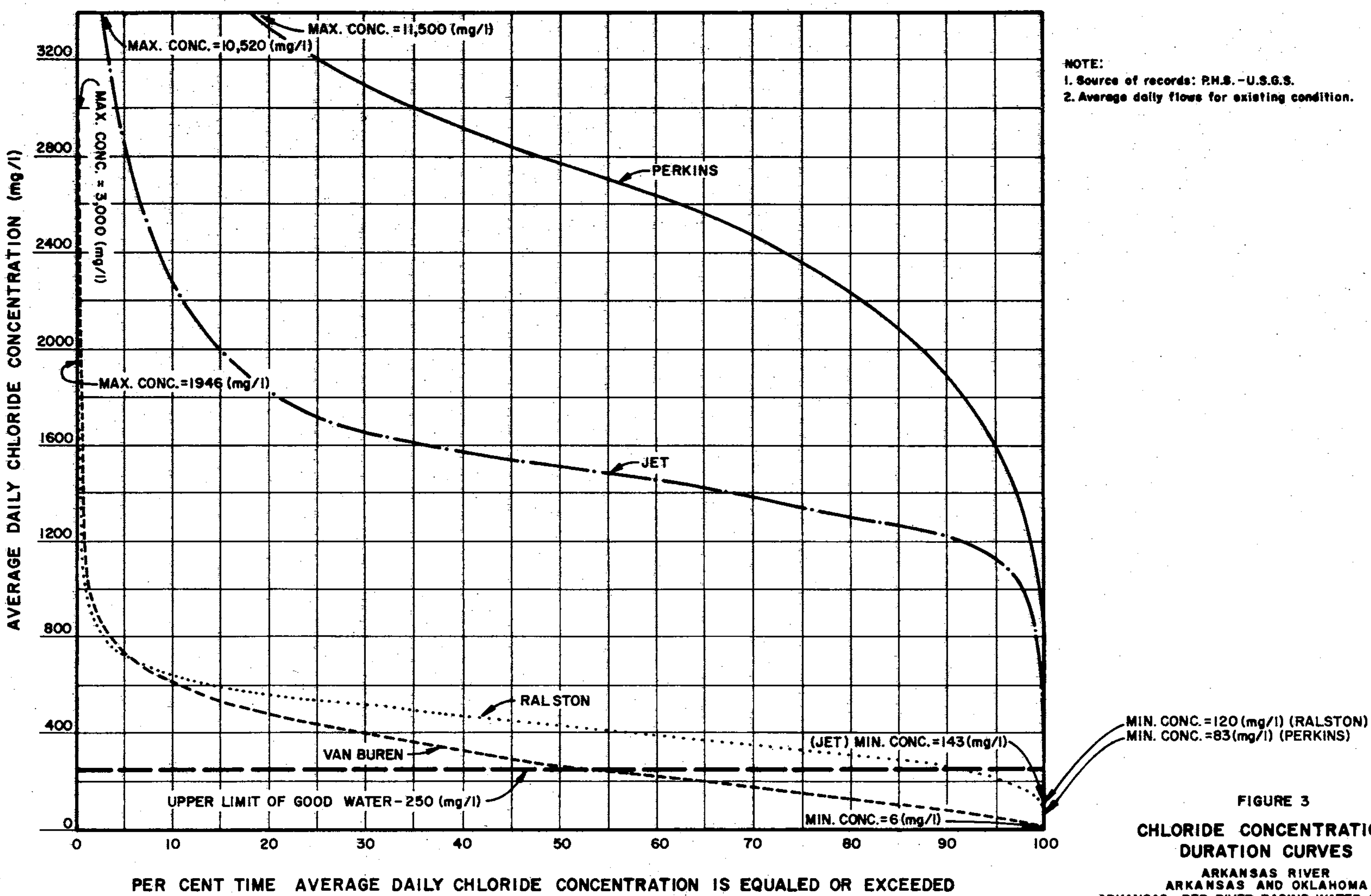


FIGURE 3

CHLORIDE CONCENTRATION DURATION CURVES

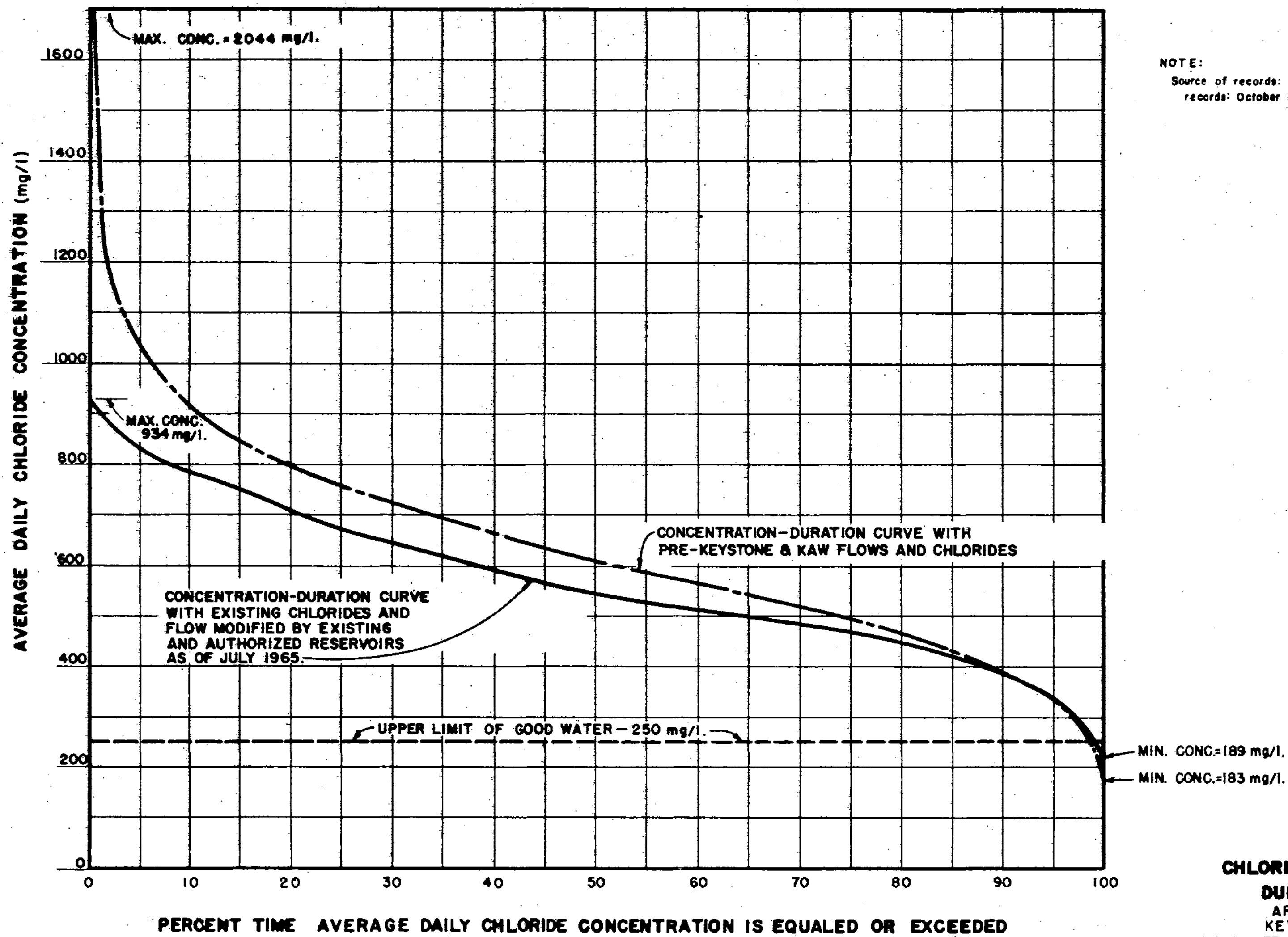
ARKANSAS RIVER
ARKANSAS AND OKLAHOMA
ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY TEXAS - OKLAHOMA - KANSAS

The curves show the concentrations at Jet, Oklahoma, on the Salt Fork of the Arkansas, and at Perkins on the Cimarron River, before substantial dilution by fresh water from downstream tributaries. The extreme left portions of the curves show the effect of droughts with low flows and high concentrations, such as the drought in the early 1950's. Statistical analyses of concentrations at various locations within the basin show this drought to be about a 50-year event over the mid-portion of the basin. The maximum chloride concentration of 3,000 mg/l at Van Buren, Arkansas, during the 1950 drought was three times higher than the concentration that could be expected to occur one percent of the time. Water supply reservoirs generally are designed to supply a dependable yield throughout a 50-year drought. This criterion requires adequate storage to allow long term withdrawal through droughts similar to one of the 1950's when the Arkansas River was highly concentrated with salt. The right hand side of the curves shows the dilution effect of flood periods on concentrations. Van Buren, Arkansas, has experienced a chloride concentration as low as 6 mg/l. This low concentration occurred during the 1943 flood, which has a once in 50 year chance of repetition. The 1943 storm centered in the lower region of the basin and did not cause a large flushout at any of the salt sources. About 55 percent of the time the chloride concentration of Arkansas River flows at Van Buren can be expected to exceed the maximum desirable (250 mg/l for domestic use). The curves of Figure 3 also show that Ralston has poor water 90 percent of the time while Perkins and Jet have good water only during the largest floods of record.

D. Streamflow Regulation

Operation of the Federally authorized reservoirs in the Arkansas River basin generally will reduce the natural salt concentrations in the streams. On Figure 4 the maximum concentration in the Arkansas River of 2044 mg/l under natural conditions would have been reduced to 934 mg/l if Keystone Reservoir had been in place. Without the reservoir, flood waters with the low concentrations quickly pass downstream and the concentration of the stream soon returns to normal. With the reservoir in place, the low chloride flood waters mix with the stored water and by dilution reduce the reservoir concentration. One factor, evaporation and low flows, offsets this beneficial effect of reservoir storage on concentration. During the hot dry summer months the concentration of the low inflows are high and this, coupled with high evaporation rates, will increase reservoir concentrations. However, over a 12-month period the over-all effect of reservoir storage versus stream flows are beneficial. In hypothetical reservoir-chloride studies of Keystone Reservoir (2) the concentration of the water stored at the beginning of May 1957 would have been 700 mg/l. At the end of May the chloride concentration would have been reduced to 350 mg/l by the inflow of water having lower concentrations during the month. The May 1957 flows resulted from one of the largest known floods. Recurrence of such flood flows into Keystone Reservoir would provide better dilution water than normal inflows and consequent higher quality water for a longer period of time. The curves of Figure 4 show that the quality of water stored in Keystone Reservoir will be improved over the pre-project flows at the site. However, because of existing

NOTE:
Source of records: P.H.S.–U.S.G.S. Period of flow records: October 1937—September 1962.



COURTESY U.S. ARMY CORPS OF ENGINEERS

FIGURE 4

CHLORIDE CONCENTRATION DURATION CURVES
ARKANSAS RIVER AT KEYSTONE RESERVOIR
ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY TEXAS - OKLAHOMA - KANSAS

chloride inflow, the reservoir water is still unusable for municipal and industrial purposes more than 99 percent of the time.

E. Structural Measures for Control of Natural Salt Pollution

Foresight is essential to the development of plans for timely and adequate development of good water supplies. This section of the study presents the brine pollution problem and the proposed control plans for each major natural salt source in the Arkansas River basin. Specific plans of improvement were recommended by the Corps of Engineers for salt source Areas I, II-III and IV. A specific plan was not proposed for Area XII since its cost is out of proportion to achievable brine control on the Arkansas River.

1. Area I - Great Salt Plains, Salt Fork of the Arkansas River

Description

The Great Salt Plains is located in northern Alfalfa County, Oklahoma. Contained in the plains area is the existing Great Salt Plains Reservoir on the Salt Fork of the Arkansas River, near Jet, Oklahoma. This project has been in operation for flood control since 1941. It controls approximately 47 percent of the total drainage area of 6,800 square miles of the Salt Fork of the Arkansas River. The Bureau of Sport Fisheries and Wildlife, U. S. Fish and Wildlife Service, maintains the Salt Plains National Wildlife Refuge of about 32,000 acres adjacent to and including most of the reservoir area, and the Corps of Engineers manages about 800 acres at the damsite.

Salt Pollution Problem

The problem area is a large, low-lying, flat alluvial plain of about 30 square miles covered with a thin crust of salt. Slightly over 20 percent of the natural chlorides polluting the Arkansas River comes from the Great Salt Plains. Water flowing in the Salt Fork of the Arkansas River above the Great Salt Plains is generally of good quality. Ground water flowing from the higher terrain around the plains percolates down to the salt bearing strata and becomes a salt solution which flows into the reservoir or is drawn upward to the surface by capillary action. The average daily chloride ion load from the area is 1440 tons.

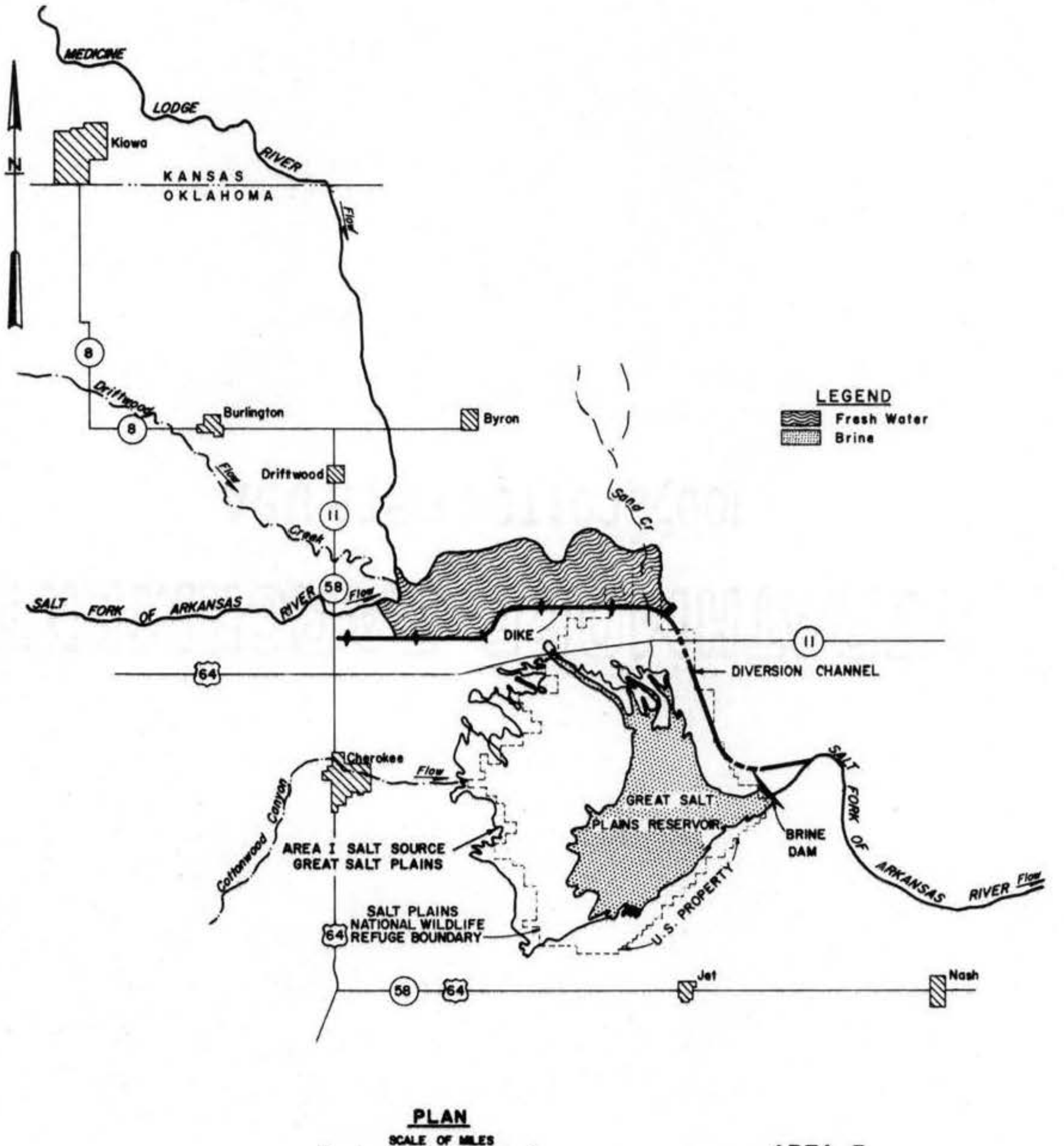
Plan of Improvement

Conversion of the existing Great Salt Plains Reservoir for brine storage and provision of a dike upstream from the salt plains with a diversion channel to pass fresh water flows is the most technically feasible plan for Area I as shown on Figure 5. The existing Great Salt Plains Reservoir would be converted into a brine reservoir. A dike starting 3.5 miles north of Cherokee, Oklahoma, and continuing around the northern perimeter of the salt plains for about 10.5 miles would form a fresh water reservoir. From the outlet works in the eastern end of the dike a diversion channel would extend about 7 miles to the river below the existing dam. About 90 percent of the 1440 tons per day of chlorides coming from Area I would be controlled. Impounded brine in the Great Salt Plains Reservoir would become saturated in about 25 years.

2. Area II-III - Big and Little Salt Plains of the Cimarron River

Description

Source Areas II and III are on the Cimarron River between river miles 280 and 301 near the Kansas-Oklahoma border. The Big Salt Plain



AREA I
CONTROL PLAN
ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY
TEXAS - OKLAHOMA - KANSAS

FIGURE 5

COURTESY U.S. ARMY CORPS OF ENGINEERS

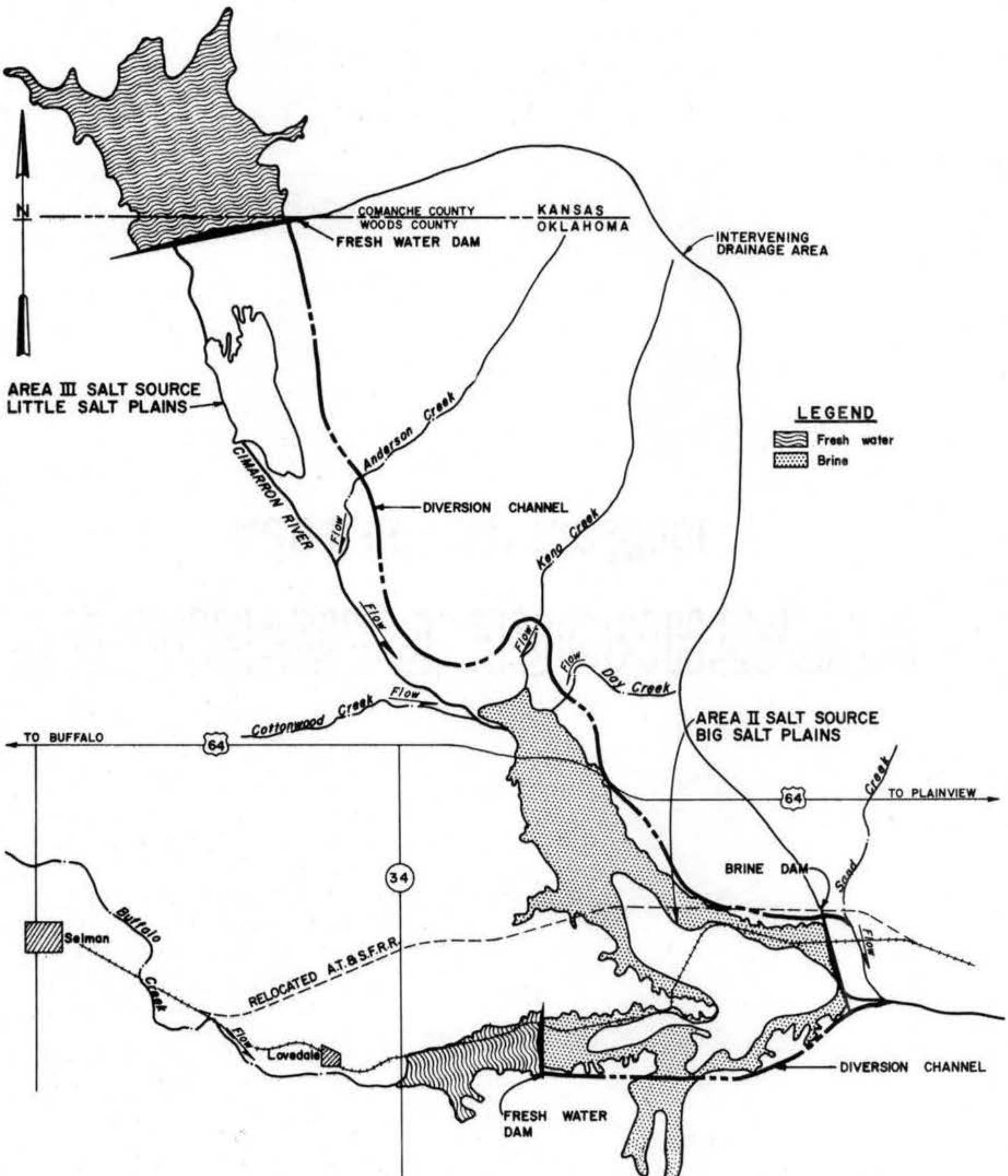
(Area II) occupies about eight square miles of the flood plain of the Cimarron River in parts of Woods, Woodward, and Harper Counties, Oklahoma. The Little Salt Plain (Area III) contains approximately two square miles in Harper and Woods Counties, Oklahoma, about two miles south of the Kansas border. The plain is located near river mile 298 of the Cimarron River upstream from the Big Salt Plain. The drainage area of the Cimarron River above Area III is 11,800 square miles, with 4,800 square miles noncontributing. The intervening area between the upper Area III and the lower Area II contains about 670 square miles, including 455 square miles drained by Buffalo Creek.

Salt Pollution Problem

Over 70 percent of the natural chlorides in the Arkansas River basin come from Areas II and III. The quality of the water is relatively good in the upper reaches of the Cimarron River basin; however, springs and seeps contribute near-saturated brine to the flow at Areas II and III. At Area II the plain is a broad, flat alluvial surface encrusted with crystallized salt varying from three to four inches in thickness. Small springs and seeps of saturated brine are found along the northern and southern margins of the plain and along the banks of Buffalo and Elm Creeks. Evaporation of these brines, during periods of dry weather, causes salt to accumulate on the surface of the plain. It is estimated that the accumulation of salt in the flood plain can amount to 125,000 tons before floods flush it downstream. Salt springs have not been observed in Area III. Salt water moves toward the river from the dune sand and terrace deposits on the north side and from the fractured shale and gypsum on the south side facilitating the downward flow of ground water to the salt-bearing strata and then into the alluvium. The alluvial fill in the Cimarron River valley ranges up to 80 feet in thickness and is saturated with brine waters of varying chloride concentration. The average daily chloride load from both plains is 4,600 tons.

Plan of Improvement

The plan selected for regulation of fresh water and control of brine at Area II-III is shown on Figure 6. A reservoir located downstream of the Area II salt source at Cimarron River mile 279.1 would contain brine flows from both areas. Fresh water reservoirs, on Buffalo Creek four miles upstream of the mouth and on the Cimarron River at river mile 301.5 above the Area III salt source, are required for fresh water detention and diversion. Diversion channels would convey the water stored in the fresh water reservoirs on Buffalo Creek and on Cimarron River (above Area III) around the brine dam. An uncontrolled spillway in the abutment of the Area III fresh water dam would pass the design flood and a conduit would pass flows up to and including the standard project flood. The fresh water diversion channel would intercept the outflow from the reservoir and runoff from the area north of the channel itself. A larger channel capacity is required as the drainage area increases. Small dams on tributary streams in the intervening drainage area north of this channel would decrease flood peaks and would aid in reducing the channel size. A similar diversion channel would convey fresh water from Buffalo Creek Reservoir to a point below the brine dam. The plan would control about 90 percent of the 4600 tons per day of chlorides from Area II-III.



AREA II-III
CONTROL PLAN

ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY
TEXAS - OKLAHOMA - KANSAS

COURTESY U.S. ARMY CORPS OF ENGINEERS FIGURE 6

3. Area IV - Salt Creek of the Cimarron River

Description

Area IV chloride pollution source is in Blaine County, Oklahoma, on Salt Creek, a right bank tributary to the Cimarron River. From its mouth, Salt Creek extends in a southwesterly direction, approximately 20 miles, to its source in Blaine County. Terrain in the area consists of moderately rolling sand hills that drain into canyons, some being 20 feet deep.

Salt Pollution Problem

Brine springs and seeps in the streambed of Salt Creek contribute approximately 250 tons per day of chlorides. Streamflow originates from surface runoff and wet weather springs, mainly in the overlying gravel and sand deposits that cover the uplands to the west. These deposits act as an aquifer supplying water to the formations below, where the soluble salts of the Permian are taken into solution. Small salt water springs and seeps emerge from all levels of the escarpment in the canyons of the upper three miles of the system and then merge to form Salt Creek. The drainage area above the salt source is 18 square miles.

Plan of Improvement

The control plan selected for Area IV is planned to contain all the surface runoff in addition to the brine flow from seeps and springs. A suitable dam would be located at mile 21.7 on Salt Creek as shown on Figure 7. The uncontrolled spillway designed for passing the design flood would be grass lined, with the crest elevation set by containing the 100-year event storm on a 100-year accumulation of brine. Control

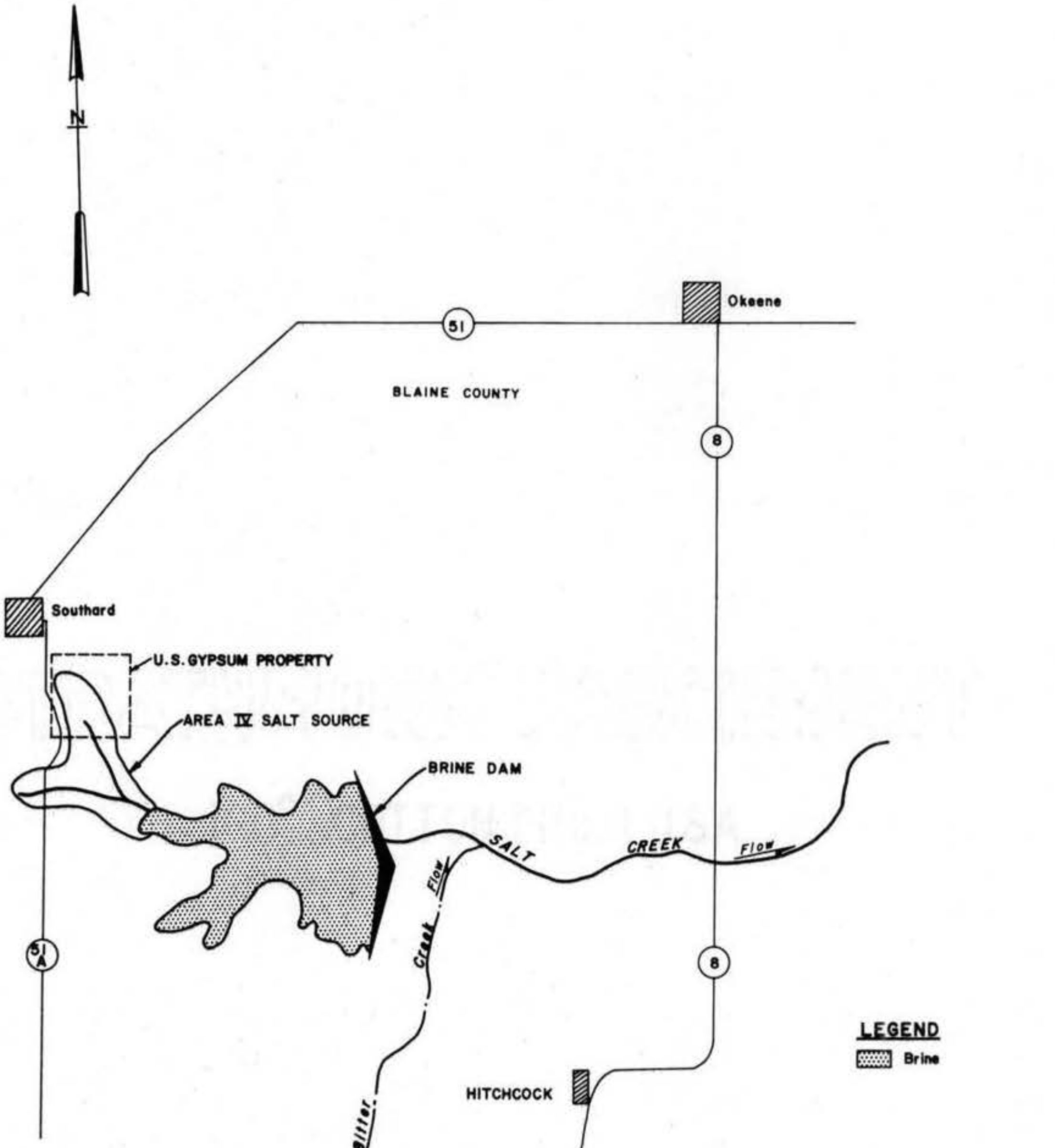


FIGURE 7

PLAN
SCALE OF MILES
1 0 1 2

AREA IV
CONTROL PLAN
ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY
TEXAS - OKLAHOMA - KANSAS

COURTESY U.S. ARMY CORPS OF ENGINEERS

of 90 percent of the 250 tons per day of chlorides would be realized with this plan in operation.

4. Area XII - Rattlesnake Creek of the Arkansas River

Description

Area XII is located on Rattlesnake Creek in northeastern Stafford County, Kansas. Rattlesnake Creek drains approximately 1,000 square miles above Area XII. The creek flows in a northeasterly direction and joins the Arkansas River approximately six miles southeast of Raymond, Kansas. Salt marsh land occupies most of the valley near the eastern side of Stafford County. Rattlesnake Creek is diverted by man-made structures to flow through the Little Salt Marsh. Downstream the Big Salt Marsh drains into Rattlesnake Creek. The Quivara National Wildlife Refuge encompasses both the Big and Little Salt Marshes as shown on Figure 8. Operation of wildlife refuge is dependent on Rattlesnake Creek flows.

Salt Pollution Problem

Brine seeps and springs occur in the creek bed for a distance of 20 miles upstream from the large salt marsh. The average daily chloride load from the area is approximately 200 tons. This chloride load, with secondary natural and man-made loads, makes water unusable in the Arkansas River near Wichita, Kansas.

Plan of Improvement

The plan that would give maximum control of Area XII chloride pollution would consist of a low flow dam on Rattlesnake Creek to collect brines which would be pumped north 31 miles to an impoundment dam on Deception Creek. The upstream fresh water flows in Rattlesnake

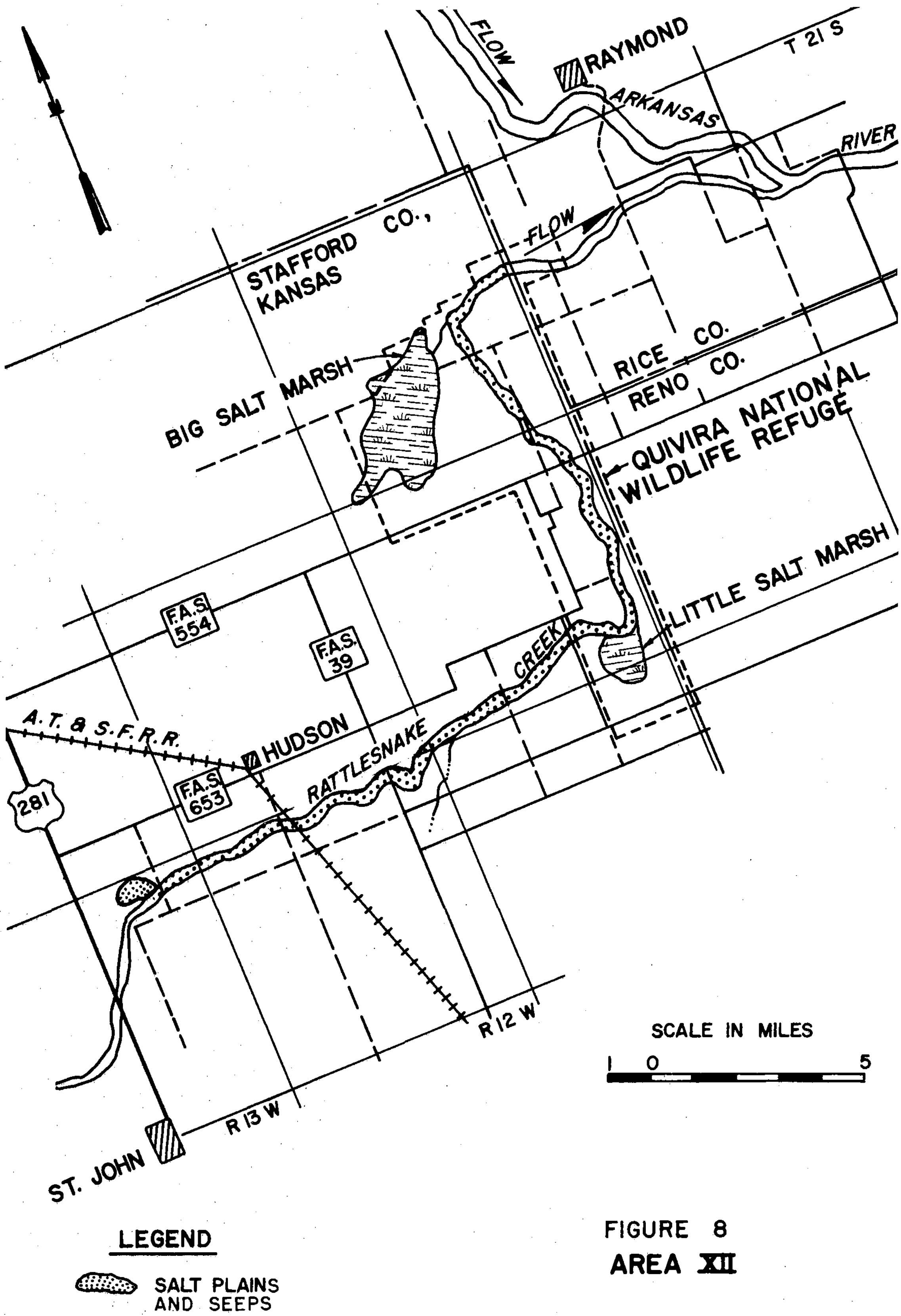


FIGURE 8
AREA XII

COURTESY U.S. ARMY CORPS OF ENGINEERS

Creek would be diverted to the North Fork of the Ninnescah River. This plan would control only about one half of the chloride load required to get good water at Hutchinson, Kansas, a checkpoint on the Arkansas River. The remaining salt water problem is caused primarily by secondary natural brine emission between Great Bend and Hutchinson, Kansas. Control of Area XII brine only is not sufficient for making usable water in the Arkansas River at Hutchinson or at Wichita, Kansas, which is a major demand center. The natural load from Area XII has only a minor effect on chloride concentration in the Keystone Reservoir near Tulsa, Oklahoma. Therefore the Area XII chloride control plan must be supplemented by control of the undefined secondary natural sources before its adoption by the Corps of Engineers as a part of the Arkansas River chloride control plan. Development of the Area XII control plan was not recommended by the Corps of Engineers because its costs are out of proportion to the amount of brine control achievable on the Arkansas River.

F. Mineral Water Quality Improvement

Associated with the Corps of Engineers' natural chloride control plans are possibilities for other water resources development. Maximum feasible control of brine emission from each source was of course the key objective of the solutions. Secondary values result in associated control of negligible quantities of sulfates. Added are the planning goals that the water quality improvements of the basin streams are in balance as to scale, sequence, and timing with other water use and control programs. Water resource planning has to anticipate the future requirements for land and water essential to economic growth.

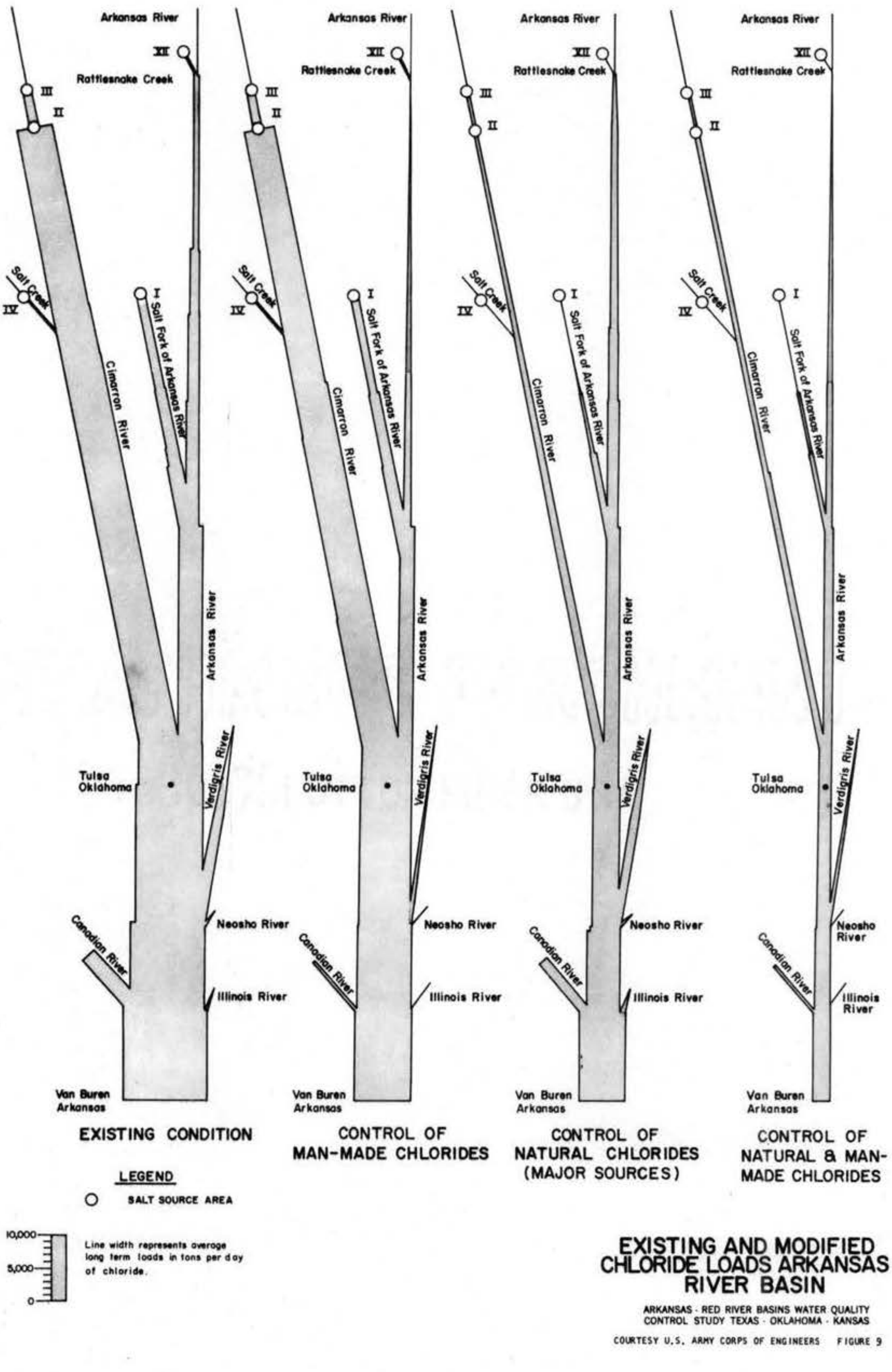
Therefore, knowledge is required of the physical and economic potentials of the natural salt control measures for comprehensive improvement of the river conditions.

1. Effects of Corps of Engineers' Chloride Control Plan

Appraisal was made of the physical effects of the chloride control plans for water quality improvement at key stations in the Arkansas River basin. The reference stations were selected on the basis of length of reliable flow records, their strategic location to man-made and natural chloride sources and to existing and authorized reservoirs. Figure 9 graphically illustrates the potential reduction in daily chloride load in the basin with various degrees of control of man-made and natural sources. With approximately 90 percent of the man-made chloride pollution in the basin coming from oil field brines, potential control of about three fourths of the entire man-made chloride load could be reasonably expected. The maximum possible control of the natural sources is estimated to be 90 percent (2). With such over-all control of brine the chloride concentration at downstream checkpoints can be maintained below 250 mg/l.

2. Chloride Ranges

A summary of the potential chloride concentration improvement in Keystone Reservoir attainable by 90 percent control of the five major natural salt sources is shown in Table III. Figure 10 shows chloride concentrations for the existing and potential water conditions in the basin. Data in Table III and Figure 10 would not significantly change by exclusion of the chloride control plan considered for salt-source Area XII on Rattlesnake Creek, Kansas. The chloride concentrations



EXISTING AND MODIFIED CHLORIDE LOADS ARKANSAS RIVER BASIN

ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY TEXAS - OKLAHOMA - KANSAS

COURTESY U.S. ARMY CORPS OF ENGINEERS FIGURE 9

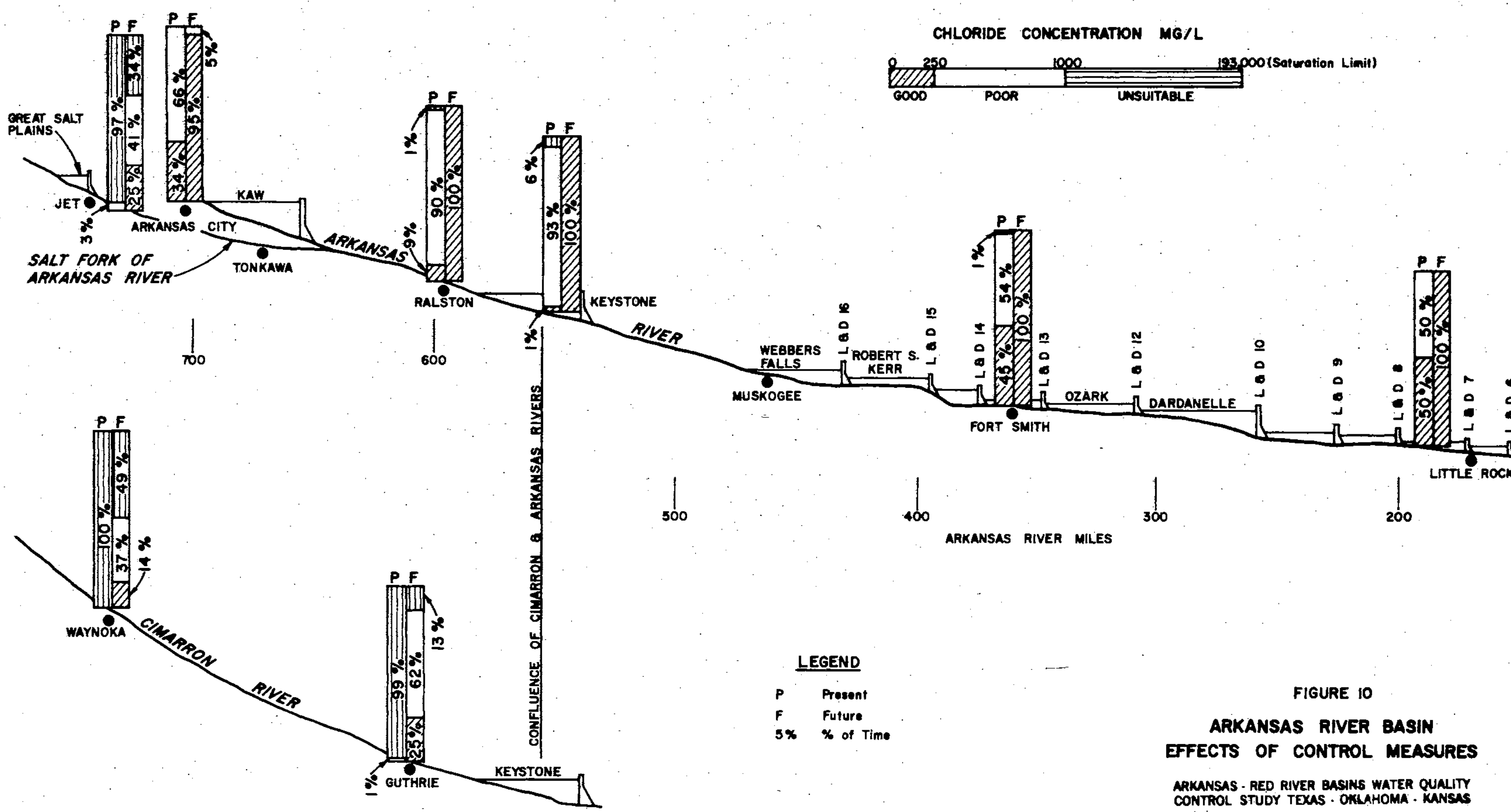


FIGURE 10

ARKANSAS RIVER BASIN
EFFECTS OF CONTROL MEASURES

ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY TEXAS - OKLAHOMA - KANSAS

COURTESY U.S. ARMY CORPS OF ENGINEERS

have ranges or suitability of use shown by hash lines. The upper ranges of 250 mg/l for good water and 1,000 mg/l for poor water were selected as limits to show desirability for municipal and industrial use. Above 1,000 mg/l the water is generally unsuitable for most uses, but in extreme drought conditions chloride concentrations in these ranges can be used for short periods of time. Figure 10 indicates that, under present conditions, the waters in the Arkansas River basin from Great Bend, Kansas, to Fort Smith, Arkansas, are unfit for most municipal and industrial uses. Should chloride improvements be implemented at the five major salt sources, the waters at major demand centers from the mouth of the Arkansas River to Arkansas City, Kansas, some 700 miles, would be suitable for municipal and industrial uses.

TABLE III

CHLORIDE CONCENTRATION, KEYSTONE RESERVOIR

Extent of Control of Natural and Man-Made Chlorides	Concentrations in mg/l Chloride Percent of Time Average Daily Concentrations are Equal to or Less Than		
	50%	90%	98%
Existing conditions	615	905	1200
Maximum anticipated control of man-made brines	460	635	680
Anticipated 90% control of the five major natural sources	210	295	325
Anticipated combined control of five major natural and man-made sources	105	145	180

3. Flow Depletions

Minor flow depletion would result at Keystone Dam on Arkansas River from implementation of the Corps of Engineers' control plans. Preliminary studies indicate an average reduction of 110 c.f.s. at the dam, which compares to 1.7 percent of average flows. The critical dry period flow reduction at Keystone Dam would be about 11 c.f.s. or 2 percent. This means that during the low flow periods losses would be insignificant.

G. Stream Water Quality Monitoring Systems

1. Objectives

The four basic objectives (7) behind the almost limitless number of possible reasons for water quality surveillance are: determination of chemical character of the streamflows, determination of quality variations by time, procurement of data on waste loads, and calculation of flow-load relationships. The location of water quality monitoring stations should be selected on the basis of available flow recording stations and at certain points downstream of known sources of pollution. Another factor involved regarding selection of a location for the station would be the relationship to points of use or water diversion from the stream. The location for water quality data collection would not necessarily be in agreement with existing flow measurement stations. Accessibility to the station is also a consideration in selecting station locations. See figure 12 for a map showing the recommended water quality monitoring station locations.

2. U.S.G.S. Water Quality Information

Water resources investigations of the U. S. Geological Survey (8) include the collection of water quality data on the chemical and physical characteristics of surface and groundwater supplies. The chemical quality includes concentrations of individual dissolved constituents and certain properties or characteristics such as hardness, sodium-absorption ratio, specific conductance, and pH. These data are available for selected stations from 1941 and are continuing on a yearly basis as funds are available. The work in Oklahoma is done under a cooperative agreement between the U. S. Geological Survey, the Oklahoma Water Resources Board, and the Oklahoma State Health Department. Assistance in the form of funds is given by the Bureau of Reclamation and the Corps of Engineers. The installation cost of a conductivity meter and flow measurement device installed by the U.S.G.S. is estimated at $3,400. The annual cost of data collection, correlation, and reporting is estimated at $3,700.

The surface water samples for analysis usually are collected at or near points on streams where flow discharge stations are maintained by the U.S.G.S. Samples are collected daily at some sites and less frequently at other sites. Solute data on samples collected daily at surface water sites are usually "average" chemical characteristics and are determined by the analysis of a "composite sample" prepared in the laboratory from the daily samples collected during a "composite period." The methods of collecting and compositing water samples are those set forth by Rainwater and Thatcher (1960).

3. Water Quality Parameters

The development and use of instrumentation for the measurement of water quality and surveillance of water pollution is proceeding at an ever accelerating pace. The concept of an integrated automatic instrumentation system for monitoring water quality of a natural waterway system was first explored and applied by the Ohio River Valley Water Sanitation Commission. This instrumentation system used multiple electrode sensors and analyzers in modular packages for integrated recording and transmitting of water quality data. Basic variables measured included temperature, pH, conductivity, dissolved oxygen, chloride ion, oxidation-reduction potential, turbidity, and solar radiation intensity. This concept of an integrated water quality monitor system has been generally adopted by various governmental enforcement agencies and by industry. As water quality standards and enforcement plans are established and appropriations become available under the terms of recent water quality legislation, the need for accurate, dependable multi-parameter water quality monitoring systems has greatly expanded.

Eight Basic Parameters

A multi-parameter water quality system can be designed to make any number of various water quality measurements. The following basic parameters generally receive primary consideration:

pH.--pH is a measure of the active hydrogen ion concentration in an aqueous solution which determines whether the solution is acidic or basic. Measurement of pH does not identify any particular pollutant but does indicate whether acid or alkaline impurities predominate. In addition to the strictly corrosive aspect, pH is of great importance to the capacity of water to biologically assimilate organic wastes. Bacteria will grow in a pH range from about 5.0 to 9.0 but thrive best in the range from 6.5 to 8.5. A high pH can cause precipitation of phosphates and trace metallic oxides creating turbid conditions.

Oxidation-Reduction Potential (ORP or Redox).--ORP is an electrical property existing in a solution as a result of the respective concentrations of oxidants and reductants present. Hence, ORP is not specific to one ionic specie and the potential related to any given set of conditions will vary with temperature, and may vary with pH or total dissolved solids (conductivity). The ORP measurement as applied to water quality analysis is normally useful only to determine the relative degree to which highly active oxidizing or reducing agents are present.

Chloride Ion (Dissolved Chlorides).--The measurement of dissolved chloride ion may be applied in water quality analysis to determine specific chloride pollution by natural salt emissions or by wastes from chemical and food processing plants, or the oil industry.

Temperature.--Water temperature is a highly important measure of water quality. Temperature directly affects the rate of chemical and biological reaction. The rate of metabolism of the various microorganisms is quite temperature sensitive. Too high a temperature can kill certain species. Dissolved oxygen concentration is also related to temperature. An increase in stream temperature decreases the concentration of dissolved oxygen. Therefore, a pollution load is more likely to deoxygenate a receiving water in summer than in winter or if the water is subjected to temperature rise due to discharge of high temperature effluents.

Turbidity.--Turbidity measures the amount of solid material suspended in water. It is an expression of the optical property of the sample of water which causes light energy to be scattered rather than transmitted through the water. In addition to its usefulness in spotting large amounts of insoluble pollution, turbidity measurement is also indicative of the amount of light entering the water which has a direct effect on the growth of algae. Through photosynthesis, algae bloom releases oxygen which dissolves in the water.

Solar Radiation Intensity.--Solar radiation intensity is not a direct measure of water quality but the measurement of an external environmental characteristic affecting water quality. Solar radiation may be correlated with the amount of dissolved oxygen in natural waters. This correlation is the result of the photosynthetic reaction in which plant life undergoing the catalytic effect of sunlight releases oxygen during the day, thereby increasing the oxygen content of the water.

Dissolved Oxygen.--Dissolved oxygen is perhaps the one most critical measurement of water quality. The presence of sufficient dissolved oxygen is essential to the direct oxidation of many pollutants and to the life of micro-organisms which biologically degrade organic pollution. Dissolved oxygen is also necessary for the life of fish and other marine life which play a vital role in the over-all ecology of natural waters.

Conductivity.--Solution conductivity as applied to water quality is essentially a measurement of total dissolved solids. While it again is a nonspecific measurement and does not identify any particular substance, conductivity is useful in determining gross contamination from industrial plant spillage, natural salt pollutions, or sea water intrusion. High dissolved solids concentrations can reduce the solubility of oxygen in water.

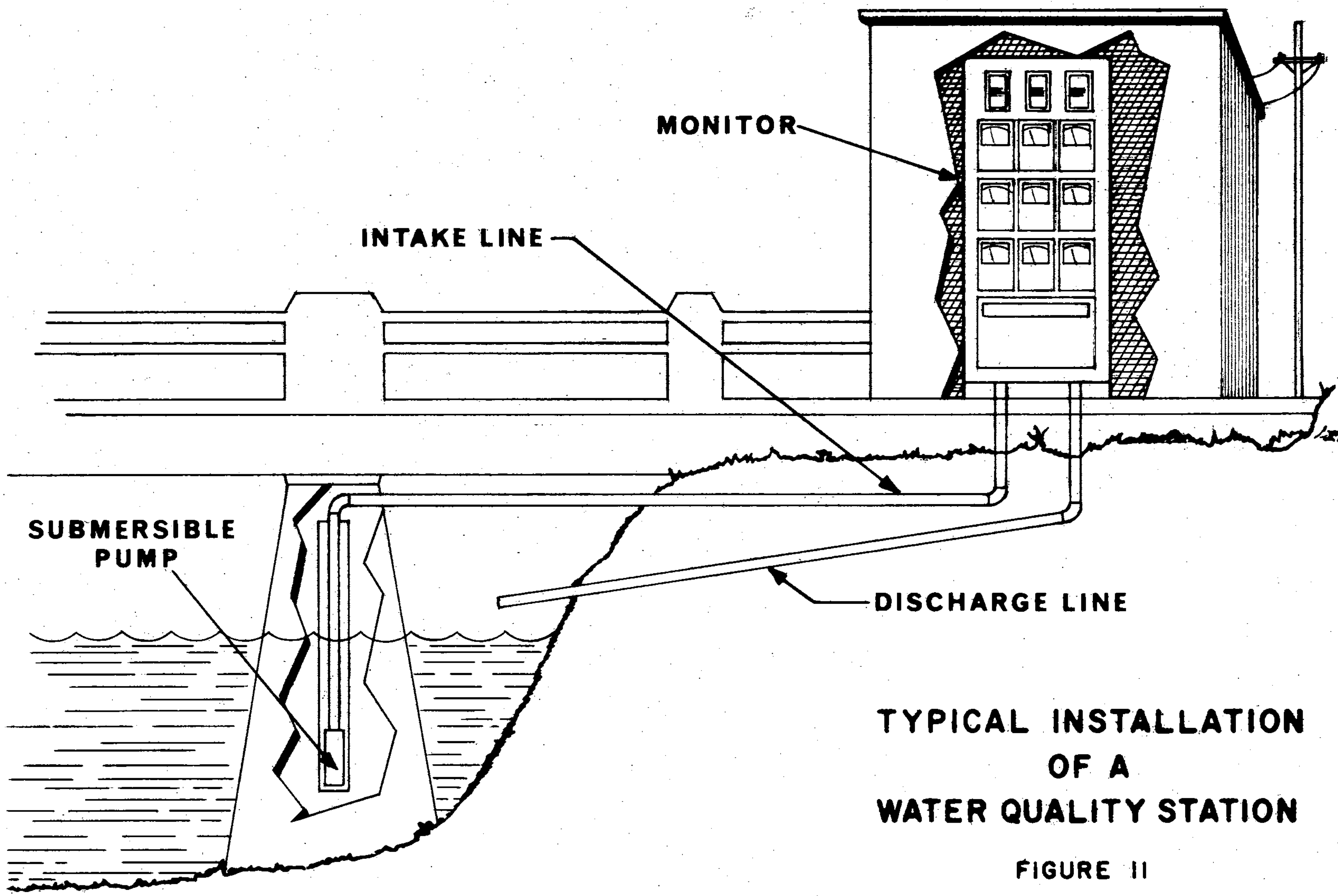
There are, of course, many other variables which are important to the determination of water quality. Those listed above are the ones which are presently of primary interest and which lend themselves to automatic continuous measurement by relatively simple means.

4. The Beckman Model 9500 Water Quality Monitor

This report is not designed to promote the Beckman product; it is only used here as an example of the types of equipment that are on the market today.

Continuous monitoring serves to alert those concerned to sudden changes in water quality as well as to more gradual, yet still significant, trends. Often analyzers to measure several different parameters have been incorporated into a single monitoring system. The new Beckman Model 9500 Water Quality Monitor is a natural outgrowth of these analyzer systems. It not only brings several different analyzers into a single system, but also incorporates many new and exclusive features which make it a superior monitor for the continuous and simultaneous analysis of multiple water quality parameters including pH, oxidation-reduction potential (ORP), chloride ion, temperature, conductivity, dissolved oxygen, turbidity, and solar radiation intensity.

A sample stream of water for analysis by the sensing devices in the sensor module is continuously pumped from beneath the surface of the water source. See Figure 11. The sample stream is piped to the



TYPICAL INSTALLATION OF A WATER QUALITY STATION

FIGURE II

monitor which is located in a shelter as close to the sampling point as possible. The sample stream enters the sensor module through a one-inch polyvinyl chloride pipe at the bottom rear of the module. At this point, if turbidity is to be measured, a portion of the flow is diverted to a surface scatter turbidimeter flow cell. The elevation of the turbidimeter overflow establishes a constant head pressure on the main inlet line supplying sample to the other individual sensor chambers. If turbidity is not being measured, an overflow standpipe is installed in place of the turbidimeter cell to establish constant head pressure.

The main inlet flow line continues to the front of the sensor module where a vertical manifold parallel feeds individual sensor flow chambers. The sample streams are fed to the sensing devices in transparent, flexible plastic tubes which run in parallel, each independent of the other. This eliminates any chances of cross contamination. The constant head of the flow control system is designed so that sensors may be removed from the flow chambers without overflow or spillage of sample. This feature makes it possible to service any individual sensor without having to shut down any other part of the monitor. The pH, ORP, dissolved oxygen, temperature, and chloride ion sensors are contained in parallel "see-through" flow chambers. These chambers are made of transparent lucite which permits the water flow and condition of the sensors within the chamber to be easily checked without interrupting the measurement.

The turbidimeter, also located within the sensor module, utilizes a windowless surface scatter overflow-type chamber. The conductivity sensor is an inductive-type flow-through cell located in the sensor module. The sensor module utilizes a sensor standardization bowl. This bowl allows the probe-type sensors to be conveniently immersed in standardizing solution. When standardization is completed the bowl may be lifted off two retainer pins for dumping. A grab sample bottle is built into the overflow system. This permits convenient taking of a fresh sample for separate analytical determinations.

The analyzers required to measure the output signals from the sensors for transmission to a recorder or telemetering system may be contained in one, two, or three modules stacked above the sensor module. Since each analyzer module can contain one, two, or three amplifiers, the water quality monitor may accommodate as many as nine amplifiers. If seven, eight, or nine parameters are to be monitored, all three analyzer modules are required. If only four, five, or six parameters are to be monitored, only two analyzer modules are required. If three or less are to be monitored, only one analyzer module is required. Each sensing device requires an amplifier. The connecting cables from the sensors meet at a common tie point in the sensor module so that only a minimum amount of wiring is required between the sensor module and the analyzer module. On the front of each amplifier is a large, accurate indicating meter. The indicating meters permit easy on-site calibration and simplify trouble-shooting procedures.

5. Estimated Cost of Water Quality Data Collection

The cost of water quality data is a variable that must be considered in setting up a stream monitoring system for a water quality management program. Should the responsible agency have unlimited funds, there is no problem; the most sophisticated equipment should be used. However, this is not the case; limitation of funds is the constraint that makes the management team of a study or survey for water quality data use statistical procedures for estimating pollution loads. The following tables (IV and V) contain cost estimates of equipment similar to that used by the Ohio River Valley Water Sanitation Commission.

TABLE IV

WATER QUALITY DATA EQUIPMENT COSTS

Item	Cost per Station	Cost for System with ten Remote Stations
	$	$
1. Remote Station		
Instrumentation - 8 parameters	12,000	
Shelter	2,500	
Land	1,000	
Pumping System	1,500	
Recorder (Multipoint)	2,000	
Digital Conversion	6,000	
Total	25,000	250,000
2. Central Station		
Encoder	4,500	
Transmitting	3,000	
Receiver	2,500	
Logger	25,000	
Display	6,000	
Total	41,000	41,000
Total Installation Costs		291,000

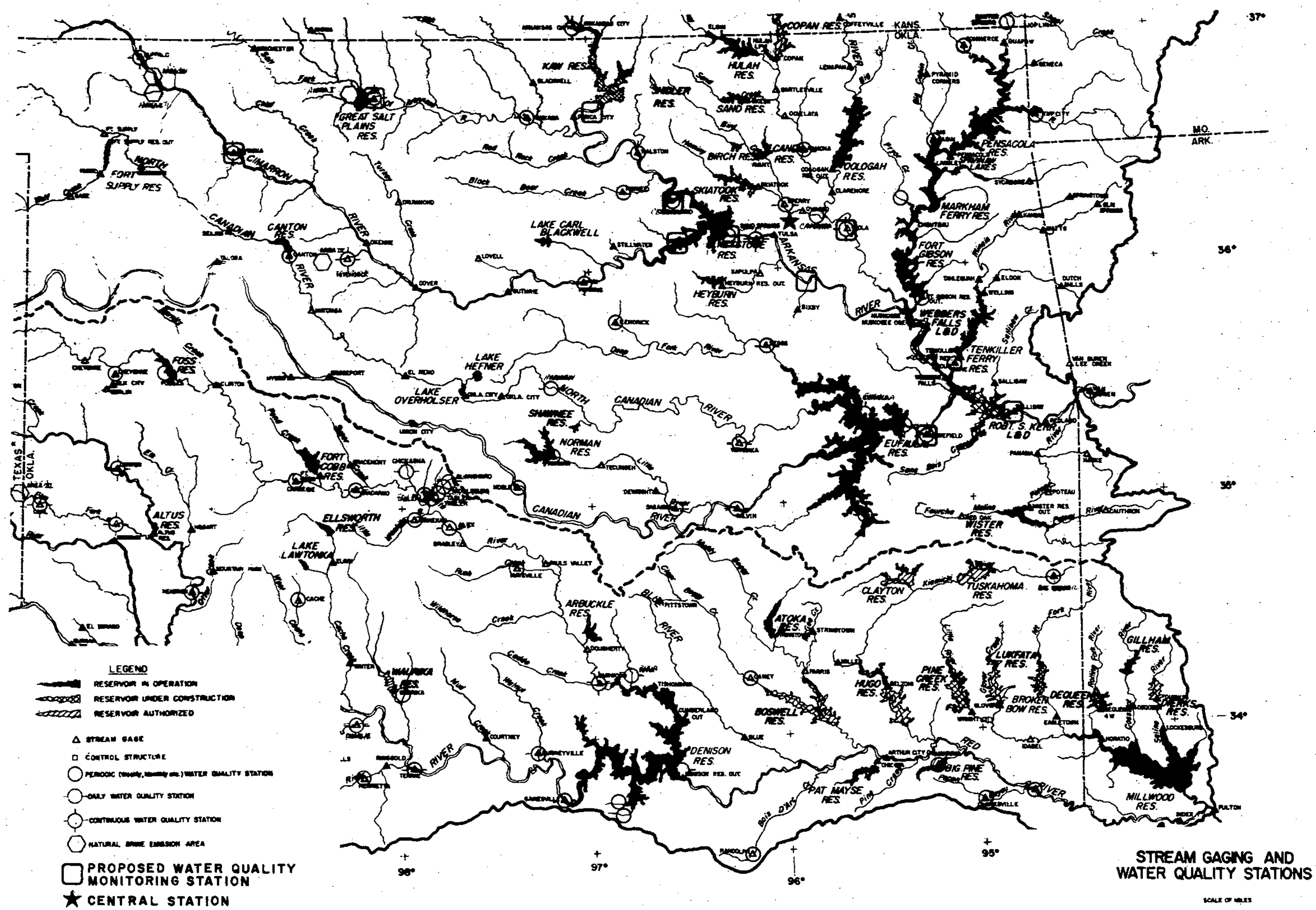
TABLE V

ANNUAL COST

	Cost per Station	Cost for Ten Stations
	$	$
Operation - Maintenance & Data Collection		
Power	500	
Service	1,000	
Supplies	1,200	
Specialist	500	
Travel	500	
Overhead	200	
Total	3,900	39,000

6. A Proposed Plan for Continuous Water Quality Monitoring of the Arkansas River

The location of the ten continuous water quality monitoring stations (see Figure 12) should be such as to give the best indication of the effectiveness of the salt control structures. It would be desirable to install these stations about 3 years before the control structures are complete and continue after the salt control works are operable. The first station should be located on the Cimarron River at Waynoka. The Waynoka station is below the Big and Little Salt Plains and would measure the percent control of those structures. The station located on State Highway 48 on the Cimarron River would determine salt reductions from Salt Creek of the Cimarron. This station would also give information on the eight parameters for this arm of Keystone Reservoir. A station located below the Great Salt Plains Reservoir and one below Kaw Reservoir would give reductions from the control works on



COURTESY U.S. ARMY CORPS OF ENGINEERS **FIGURE 12**

the Salt Fork of the Arkansas and would measure contributions from the Arkansas River upstream of Kaw Reservoir. A station at Cleveland on the Arkansas arm of Keystone Reservoir would give data of inflows to the reservoir. The station immediately below Keystone Reservoir would give information on outflows from the reservoir and give a comparison check of the data collected at the Bixby station. These data would allow studies of pollution in the Tulsa reach of the Arkansas River. The station at Inola, on the Verdigris River downstream of the Port of Catoosa, would give valuable information on the pollution problems in the port area. The Whitefield station downstream of Eufaula Reservoir would yield data on the Canadian River system pollution. The data obtained from Sallisaw station downstream of Robert S. Kerr Lock and Dam would be the most downstream station to measure the effects of not only the salt control measures but also industrial pollution from the port of Catoosa. The central station could be located at Tulsa for ease of monitoring and data collection and subsequent analysis. This system of ten water quality stations would not be recommended as the final plan but only as a starter plan. The stations would no doubt be moved somewhat to obtain the best data for critical evaluation of pollution problems of the Arkansas River. Also, this ten-station network should be expanded as funds become available and as the needs warrant.

CHAPTER V

DISCUSSION

A. General Discussion

Demands placed upon our water and related land resources are many and varied. Water alone serves an array of domestic, municipal, industrial, agricultural and other human activities; and demands may occur in almost any combination and degree of urgency. Interest in the problem of water quality is at a high pitch. As Kneese (9) has said, the whole nation is suddenly aware of the problem.

We don't always get water in exactly the right amounts, in the right places, and at the right times. This statement is particularly true of the upper Arkansas and upper Red River basins where months of little or no rainfall are interrupted by heavy precipitation and flash floods. These flash floods carry tremendous loads of salts and sulfates downstream to pollute streamflows and reservoir storage to excessive concentrations.

1. History of the Basins

For centuries a large section of the watersheds of the Arkansas and Red Rivers was covered with grasses and forests (2). These areas afforded food for buffalo and other game on which the Indian inhabitants depended. The region became part of the United States with the Louisiana Purchase in 1803. Accounts in 1810, 1814, and 1821 of the explorations of Pike, Lewis and Clark, and Stephen H. Long reported the country as being hostile wasteland except for portions along streams, and generally popularized the idea of the great American Desert. However, realization of the region's potential and population pressures in the East generated gradual settlement of the area. Texas was annexed in 1845 and additional land to the west was ceded to the United States after the Mexican War.

Railroads made possible the occupation of these semi-arid regions by wheat and livestock farmers. In the late 19th century, the production of crops began to dominate the economy and railroads encouraged settlement along their lines. The Homestead Act of 1862 stimulated settlement and the concurrent creation of the Department of Agriculture encouraged agricultural activities. Favorable farming weather gave further impetus to settlement. Drouth and meager production in the 1880's with some consequent land abandonment led to development of new techniques of "dry land" farming and interest in irrigation. Farms became larger, more specialized, and more mechanized.

The Federal Government's initial legislative effort in support of reclamation and conservation began in 1894 with the Carey Land Act, which provided public lands to certain states for the promotion of irrigation. The Carey Act, however, did not prove satisfactory, and it was not until passage of the Reclamation Act of 1902 that truly effective conservation legislation came into existence. Interest in conservation had begun, and the Agricultural Extension Service and the National Park Service were formed in 1914 and 1916. In the 1920's the Boulder Canyon Project was authorized and Muscle Shoals was bitterly contested as the pattern of conservation measures began to emerge. The "black blizzards," the dust storms of the 1930's, impressed upon the nation once more the need for conservation. The Flood Control Act of 1936 authorized construction of four multiple purpose dams and a number of local flood protection projects in Oklahoma and Kansas, thus augmenting the expanding conservation philosophy.

Discovery and production of oil, gas, and other minerals occurred concurrently with development of roads and the auto industry. The trend of population concentration in towns and cities became apparent. The area developed small processing industries with accompanying expansion of suppliers, wholesalers, retailers, and service industries. This development did not include as a prime requirement an abundant quantity of high quality water. Development occurred despite the rather poor quality of water in many streams of the area. Sufficient quantities for drinking and other requirements have been obtained from ground water and clean tributary streams. However, during drouth periods, some cities have been forced to use generally unsuitable water from the Red and Arkansas Rivers with people in some cases buying distilled or imported water for drinking purposes.

2. Economy of the Basins

The Public Health Service's report (5) states that in 1960 over 9,300,000 people lived in the 302,000 square mile study area. The report further states that population trends in the study area closely resemble the national condition - rural decline and urban increase. During the decade 1950-1960, major metropolitan areas such as Dallas, Fort Worth, Oklahoma City, Shreveport, Tulsa, and Wichita indicated a population growth rate of 3.25 percent compounded annually as compared to the average growth rate of 2.625 percent for similar areas throughout the nation. Sixty-seven percent of the total labor force of

3,370,000 is concentrated in metropolitan areas with only 9 percent being in agriculture in 1960. Of the remainder, 17 is in manufacturing, 3 percent in mining, and the remaining 4 percent is unemployed. Between 1939 and 1958, value added by manufacture, based on 1960 constant dollars, increased approximately 3.4 times as compared to 1.7 times for the nation. Other measures of the regional economy are per capita personal income, mineral resources, agriculture, recreation, and transportation, discussed as follows.

Per Capita Personal Income and Mineral Resources

Constant 1960 dollar per capita personal income in the study area has increased 180 percent during the 1930-1960 period as compared to only a 100 percent increase for the nation as a whole during the same period. However, the 1960 per capita income of $1,822 for the study area is still less than the national average of $2,223. The petroleum industry has played a major role in development of the area, producing about one fourth of the nation's oil and gas in 1960. In the same year, petro-chemical production was nine percent of the U. S. total, having expanded from two to over 45 plants from 1940 to 1960. Estimated recoverable coal reserves in Oklahoma and Arkansas total about 2.8 billion tons. Many other minerals are prevalent in the area. In 1960, the study area produced over $2.6 billion (1960 constant dollars) worth of minerals, over 14 percent of the nation's total.

Agriculture

With a wide range in soil and climatic conditions, agricultural production varies from beef cattle and wheat in the western part to beef cattle, dairy cattle, and truck crops to the east. In 1959, livestock production was valued at $1.3 billion. Approximately 35 percent of the U. S. wheat production was grown in Kansas, Oklahoma, Texas, Missouri, and Arkansas.

Recreation

The recreation industry of the region has grown in the last 20 years. The climate and transportation facilities are such as to permit continued expansion. However, because of lack of access, terrain conditions and other factors, many of the streams are unsuited for some recreational purposes. Thus, development of the recreation industry is related to control of water resources. The Corps of Engineers' (2) annual Public Recreation Use report indicated attendance at 47 Federal reservoirs in the eight-state study area totaled 58,528,000 in 1963. Future expansion of recreation attendance will also be related to the degree to which the streams are controlled and developed for recreation purposes.

Transportation

The study area is traversed by 12 major railroad systems, a network of national, state and county highways, transcontinental bus and truck systems, transcontinental air routes and numerous major oil and gas pipelines.

Industry

Major heavy industry has not developed for various reasons, of which one major reason is inadequate water supplies in terms of quantity and quality. Some improvement has resulted from construction of multi-purpose reservoirs, and completion this year of the Arkansas River navigation project to the vicinity of Tulsa, Oklahoma, will further enhance industrial growth. Low cost transportation will place present industries in a more comparative position with other areas and also encourage development of new industries. Currently, the area has grown in production of a variety of sophisticated space-age hardware and electronic equipment.

3. Future Potential for Economic Growth

At least four major factors affect the economic growth prospects of the study area. These factors are the condition of the national economy, available natural resources, geographic location and transportation, and the development and availability of good quality water.

National Economy

Since World War II the United States has enjoyed the greatest economic expansion since the post Civil War era. In view of the wave of national independence sweeping the world and the accompanying struggle for social and economic improvement of lower income nations, the pressure will be unrelenting for a continuing world-wide economic expansion. The United States will continue to play an increasing role in this expansion. Many agricultural products have been exported to Europe. Asiatic demands will likely exceed those of Europe in the future. Increasing U. S. population will also require increasing quantities of food and fiber. Thus, output of food and fiber is expected to increase about 3½ times by 2020. Such an increase will require changes in production methods and stable supplies of good quality water.

The Public Health Service in their report (5) on Water Quality Conservation estimates that population of the two-basin region will increase from 9.3 million in 1960 to about 24.5 million in 2020. Considering natural resources, labor force and other economic conditions the output of the study area is assumed to equal or exceed that of the nation, as it has over the past 30 years.

Available Natural Resources

Production of petrochemicals, forest products, food and fiber, and minerals are expected to continue to increase in the study area. The petrochemical industry is expected to increase more than five times by 2020 (Oil and Gas Journal, September 15, 1960). Oil and gas will be supplied from local reserves for some time; then, navigation facilities on the Arkansas River in conjunction with pipelines should be available for import of crude oil and export of finished products. Output of forest products, which account for about 3.5 percent of the total value added by manufacture in the U. S., is anticipated to increase by about 3½ times by 2020. About a three-fold growth in agricultural production of the area is expected during the same period, but requiring only half the people employed in 1960. More equipment and fertilizer will be needed. Processing of many of these products, requiring large quantities of suitable water, will be done locally if sufficient water is available.

Minerals (except petroleum) such as stone, sand, gravel, clay, coal, etc., in the various states of the study area increased production volumes from 3.75 to 9.0 percent during the period 1949-1960 (source: Minerals Yearbook "Area Reports"). A continued increase in production volumes is anticipated up to the year 2000. An improved economic marketability of coal reserves and other ores, rocks, and minerals should result following the completion of waterway transportation in the study area.

Geographic Location

Geographic location is among factors favoring the study area, resulting from improvements in transportation and relative shifts in population. The shift and its expected continuance is contributing to the growth of population and markets, particularly large urban and metropolitan areas. Much of the new and expected growth is within one day's trucking or rail distance from centers within the basins.

Availability of Good Quality Water

Growth and development of urban areas and accompanying industries require large amounts of good clean water. Generally, suitable water has been available from ground sources or streams in amounts sufficient for the smaller municipalities, but some already have felt the pinch of drought. Many large cities of the basins are now obtaining water from distant sources to satisfy demands. With diminishing potential sources of supply and anticipated increased future demands, scarcity of good water will become a major factor hindering the basin's development.

4. Upper Limits of Chloride Concentrations

Development of an area is dependent upon a supply of water of quality suitable for the purpose for which it is to be used. About 310 billion gallons of water were used per day in the nation in 1960. Projections by the U. S. Senate Select Committee on National Water Resources suggest a daily over-all water requirement around 600 billion gallons for the nation by 1980. This is a large increase in demand for water from a resource which is not unlimited in quantity. All states have water problems and these will increase. The Arkansas-Red River region is no exception. The problem of providing the quantity and quality of water necessary for this region to contribute to the nation's production and welfare to the extent needed may be different from and more difficult than that of other regions. As demonstrated from the Public Health Service study (5), irrigation may well continue being a high water user. Also, water of sufficient quality and quantity is needed to supply process industries. Many industries can tolerate only a small percentage of chlorides. Following is a tabulation of the acceptable maximum chloride concentration for certain industries and irrigation.

Water Use	Maximum Cl Concentration (mg/l)
Paper Making	
Groundwood pulp	75
Soda pulp	75
Kraft pulp	200
Steel Manufacturing	175
Textile Processes	100
Carbonated Beverages	250
Food Equipment Washing	250
Brewing (NaCl)	275-500
Ice Manufacturing	300
Food Canning & Freezing	750
Irrigation	250*

*Varies as to soil classification and crop type.

5. Disadvantages of High Cloride Waters

Many industries would be unable to operate or establish in the area if the primary source of water was the Arkansas and Red Rivers in their present salt contaminated condition. Maintenance expenses increase because chlorides corrode evaporative coolers, cooling towers, automobile radiators and plumbing fixtures. Lawns and shrubs die or are stunted when watered with salt water. Living habits of many residents are affected by their physical inability or unwillingness to accept water with a high salt content. While high salt concentration may have little effect on the health of normal people, the taste becomes perceptible by the average person when the concentration reaches 250 mg/l. Since the chloride ion is generally associated with sodium as found in common table salt, this can become a problem to people suffering from cardiac, renal, and circulatory diseases requiring a low sodium diet.

B. Available Stream Records - Arkansas River Basin

Several flow measuring stations, hereinafter called reference stations, were chosen in each basin (2) to study the chloride pollution problem. Subsequent discussion will demonstrate how the control of man-made and natural chlorides will affect the chloride concentrations at the selected reference stations. In addition, these discussions will show how the existing chloride concentrations will be modified by reservoirs existing and authorized to July 1, 1965, under the following conditions: With the maximum anticipated control of man-made chlorides only; with the maximum anticipated control of natural chlorides only; and with the maximum anticipated control of both man-made and natural chlorides.

1. Reference Stations

The reference stations shown in Table VI were selected (2) as checkpoints on the basis of length of reliable records (both flow and chloride) and their strategic location within the basin with reference to man-made and natural chloride load sources as well as reservoirs existing and authorized to July 1, 1965. The records at these stations indicate the magnitude of natural salt pollution and the amount of

TABLE VI

ARKANSAS RIVER BASIN REFERENCE STATIONS

Reference Station	Existing or Federal Authorized Reservoirs (July 1, 1965) Which Will Modify Concentration Duration	Are There Many Man-Made Chloride Loads Above Reference Stations Which Will Modify Concentration Duration	Will Corps of Engineers' Proposed Salt Control Structures Modify Concentration Duration
Raymond	None	No	No
Waynoka	None	No	Yes
Perkins	None	Yes	Yes
Hutchinson	None	Yes	No
Arkansas City	Cheney	Yes	No
Jet	None*	No	Yes
Ralston	Kaw	Yes	Yes
Keystone Reservoir	Kaw, Keystone	Yes	Yes
Van Buren	**	Yes	Yes

*The existing Great Salt Plains Reservoir was in place when period of flow records began.

**Kaw, Keystone, Locks and Dams 14, 15, 16, 17, and 18, Tenkiller and Eufaula Reservoirs. Other structures on tributary streams will also have a minor effect.

chloride reduction necessary to obtain water of suitable quality for municipal and industrial use. The records also help delineate the vicinity of the river reach in which salt emissions occur. Table VI shows which control structures will have an effect on the concentration of the selected reference stations.

2. Stream Records Usable for Chloride Studies

U. S. Geological Survey Chloride Records

The U. S. Geological Survey has published chloride records for many of the selected reference stations. Samples for chemical analysis were usually collected at or near points on streams where gaging stations were maintained for measurement of water discharge. Composite samples were made by mixing volumes of collected samples. The volume of each sample contributing to the composite sample was made proportional to the product of the flow and the time interval represented by each sample. Table VII contains the period of U.S.G.S. chloride record for the selected reference stations within the Arkansas River basin.

Public Health Service Chloride Records

In July 1960, the Public Health Service established approximately 37 chloride stations in the Arkansas River basin. These stations were strategically located to measure the pollution resulting from natural and man-made sources. In order to obtain the most complete and precise measurements possible in a short period of time, continuous monitoring was essential. The most suitable instrument to obtain continuous monitoring was the electrical conductance recorder. These recorders measure the specific conductance of the solutions. Chemical analyses of samples at monitoring stations showed a reasonably good degree of

TABLE 7

CHLORIDE AND STREAMFLOW RECORDS
ARKANSAS AND RED RIVER BASINS

Reference Stations	P.H.S. Chloride Records (Period)	U.S.G.S. Chloride Records (Period)	Other Chloride Records (Spot Samples)	U.S.G.S. Flow Record (Period)
Raymond	1 Jul 60 - 30 Sep 63*	None	-	July 60 - Sep 63*
Arkansas City	1 Jul 60 - 30 Sep 62	Jan 07 - May 07 Oct 51 - Sep 57	A	Sep 02 - Sep 06 Sep 21 - Sep 62*
Hutchinson	1 Jul 60 - 30 Sep 62 (Haven, Kansas)	None	-	June 95 - Dec 05 Oct 59 - Sep 62*
Jet	1 Jul 60 - 30 Sep 62*	1 Oct 54 - 31 Oct 54 Feb 55 - Sep 55	A, B,	Oct 37 - Sep 62*
Ralston	1 Jul 60 - 30 Sep 62	Jan 50 - Sep 57	A	Oct 25 - Sep 62*
Waynoka	1 Jul 60 - 30 Sep 62	Feb 51 - Sep 55	B	Oct 37 - Sep 62*
Perkins	1 Jul 60 - 30 Sep 62*	Oct 52 - Sep 57	A	Jun 39 - Sep 62*
Keystone Reservoir	1 Jul 60 - 30 Sep 62	Synthetic from Ralston and Perkins	-	Synthetic Oct 37 - Sep 62
Van Buren	1 Jul 60 - 30 Sep 62	1 Oct 45 - 30 Sep 57	-	Oct 27 - Sep 62*

A - Chemical Character of Surface Waters of Oklahoma, "Oklahoma Planning and Resources Board," Oklahoma City, Oklahoma

B - Chemical Analysis of Surface Waters in Oklahoma, September-December 1944, "U. S. Department of Interior, Geological Survey," Austin, Texas

* Operations continuing.

NOTE: Hutchinson, Kansas has no U.S.G.S. chloride records.

correlation existed between chlorides, total dissolved solids and conductance. Samples were collected bi-weekly throughout the period of record in order to obtain the correlation between conductance and water quality. The results of the laboratory analyses for conductance, chloride, sulfate, and dissolved solids were used in computing the correlations of continuous conductance records at the various reference stations. Table VII shows P.H.S. water quality records for selected reference stations in the Arkansas River basin.

Other Chloride Records

The following additional sources of chloride records were utilized:

> "Chemical Character of Surface Waters of Oklahoma," Oklahoma Planning and Resources Board, Oklahoma City, Oklahoma.
>
> "Chemical Analysis of Surface Waters in Oklahoma, September-December 1944," U. S. Department of the Interior, Geological Survey, Austin, Texas.

Streamflow Records

The U. S. Geological Survey streamflow records at the selected reference stations in the Arkansas River basin are listed in Table VII. These records are of a substantially long duration and are presented in the U.S.G.S. publications for various water years. The average daily flows from these publications were used to develop flow-duration curves.

C. A Method for Estimating Long Term Chloride Records

The reliability of any hydrologic record is directly related to the length of the record and the accuracy and frequency of the measurements. The chloride records available in the Arkansas and Red River basins are not adequate for long term records but were considered sufficient for the feasibility study by the Corps of Engineers of the chloride control projects. Concentration-duration curves of chlorides were selected to illustrate water quality as it is more desirable to know the length of time the streams or reservoirs can be expected to be of a certain quality than the frequency that a given quality will be exceeded. Peak concentrations downstream from the reservoirs can be drastically reduced by the use of storage. The Van Buren reference station shows the effects of many reservoirs on concentration and duration. Keystone Reservoir's effect in reducing the existing maximum concentration of chlorides from 2,044 mg/l to 934 mg/l is a good example of the effect of one reservoir on water quality. (See Figure 4.) The synthetic development of concentration-duration curves will be described in more detail in subsequent paragraphs.

1. Extension of Chloride Records

Prior to the establishment of the Public Health Service continuous conductivity recorders, it was necessary to develop estimated flow-chloride load relationships from U.S.G.S. composite samples. Recorded samples at many reference stations indicated large variations in the flow and load relationships. Many stations show a definite build-up of natural chlorides in a stream channel or source area during drought conditions and a definite flushing action during periods of high flow. The magnitude of this build-up varies with the length of time between the flushout periods and length of the drought or semi-drought periods. Those stations with heavy man-made loads have very little correlation between load and flows. Stations such as Waynoka on the Cimarron River had small variations in the flow-load relationship and a high correlation coefficient when using the method of least squares to determine the flow-load correlation. The flow and load relationships were used (2), for those reference stations that had good correlation, in the extension of their short-term records to long-term records. One procedure utilized in extending the short-term records to long-term records made use of the log-log plot of the short-term records. Since load is proportional to the flow for certain stations, a flow-duration curve was made from the long-term flow records. A long-term load duration curve was computed by utilizing the flow from the long-term flow-duration curve and reading loads from the log-log plot which correspond to the flow. Concentrations in mg/l were computed from the flows and loads. The percents of time corresponding to the flow were subtracted from 100 percent and plotted against the corresponding concentration, thus developing a concentration-duration curve.

2. Flow-Duration

The procedure selected to present a picture of the existing salt pollution and expected clean-up was to show the percent of time that the water at the reference stations would be of good quality. In order to obtain the curves, it was necessary to know the distribution of flows that would be expected to pass the reference stations under various conditions. An electronic computer program was developed by the Corps of Engineers to compute a flow-duration curve or the percent of time that a gaged flow is equaled or exceeded. The concentration-duration curves were developed from the flow-duration curves and the flow-load curves.

3. Composite Duration Program

The U.S.G.S. chloride records consist of weighted samples, representing variable periods of time. Concentration-duration curves were developed for the period of time that each sample represents. The results showed conditions for the short period of record analyzed (12 years or less) and are not necessarily representative of long-term conditions. The relatively short periods of flow records which corresponded to the chloride records are not representative of the long-term records. In most instances where the complete chloride record was 5 years or less, 2 years of the period were under drought conditions; consequently, the flows and chloride loads were low and the chloride concentrations were high. The concentration-duration curves developed from this computer program were helpful in the over-all salt study, but they had to be corrected for long-term flow records to be representative for all flow conditions.

4. <u>Flow-load Correlation</u>

In the development of the flow-load relationship for each station, it was necessary to analyze the 27 month record (1 July 1960 - 30 September 1962) collected by Public Health Service (5). A computer program (2) was developed to produce an average flow-load relationship. The average flows and corresponding average loads were computed for each group of flows and loads in the listing. The flows were arranged in descending order of magnitude and groups of 25 consecutive values were used for each point in this correlation. These average values were plotted and a best fit line was drawn through the plotted points to represent the average flows and corresponding loads.

5. <u>Reservoir Chloride Routing</u>

A computer program, "Reservoir Chloride Routing," was developed by the Corps of Engineers primarily for the purpose of determining the effect of reservoirs on water quality. This program was used to determine the concentration of outflows from reservoirs under past and future conditions, and with the proposed control structures in place. The basic assumptions made in this program were that the chlorides in the reservoir had a uniform concentration throughout the reservoir, and that the average concentrations of the outflow from the reservoir were equal to the average concentration of the reservoir. A comparison of the monthly values of chloride concentration of Lake Texoma, based on a monthly reservoir chloride routing using loads at Durwood and Gainesville stations, with the chloride concentration of the U.S.G.S. gaged monthly outflows at Colbert, Oklahoma, supports this assumption. These monthly comparisons normally show close agreement even under extreme conditions. In July 1953, the Lake Texoma chloride concentration was 304 mg/l as compared to a chloride concentration of 320 mg/l for outflow measured at Colbert (2).

The phenomenon of density currents and stratification was recognized. Memorandum Report No. 63-01, Texas Water Commission, February 1963, entitled "Brazos River Basin Reservoir Studies Progress Report, May 1962, Chemical Quality and Stratification of Belton, Whitney, and Possum Kingdom Reservoirs," reported that reservoir stratification is not constant, but is continually changing from a thoroughly mixed state to a state having a recognizable chloride stratification. It appears the stratification tends to cycle and is due to seasonal changes (temperature variations). When the reservoirs are noticeably stratified, the stratification appears to be more pronounced longitudinally than vertically. In most cases, density currents occur due to temperature variations, but may also rise from other variations, such as chemicals, waste, or suspended sediment. Based on the above-mentioned memorandum, and from comparing the average monthly concentrations with the concentration of the actual gaged outflows, it appears stratification and density currents do not materially affect the results of the reservoir chloride routings. A more conclusive investigation of the effects of density currents and chloride stratification needs to be done.

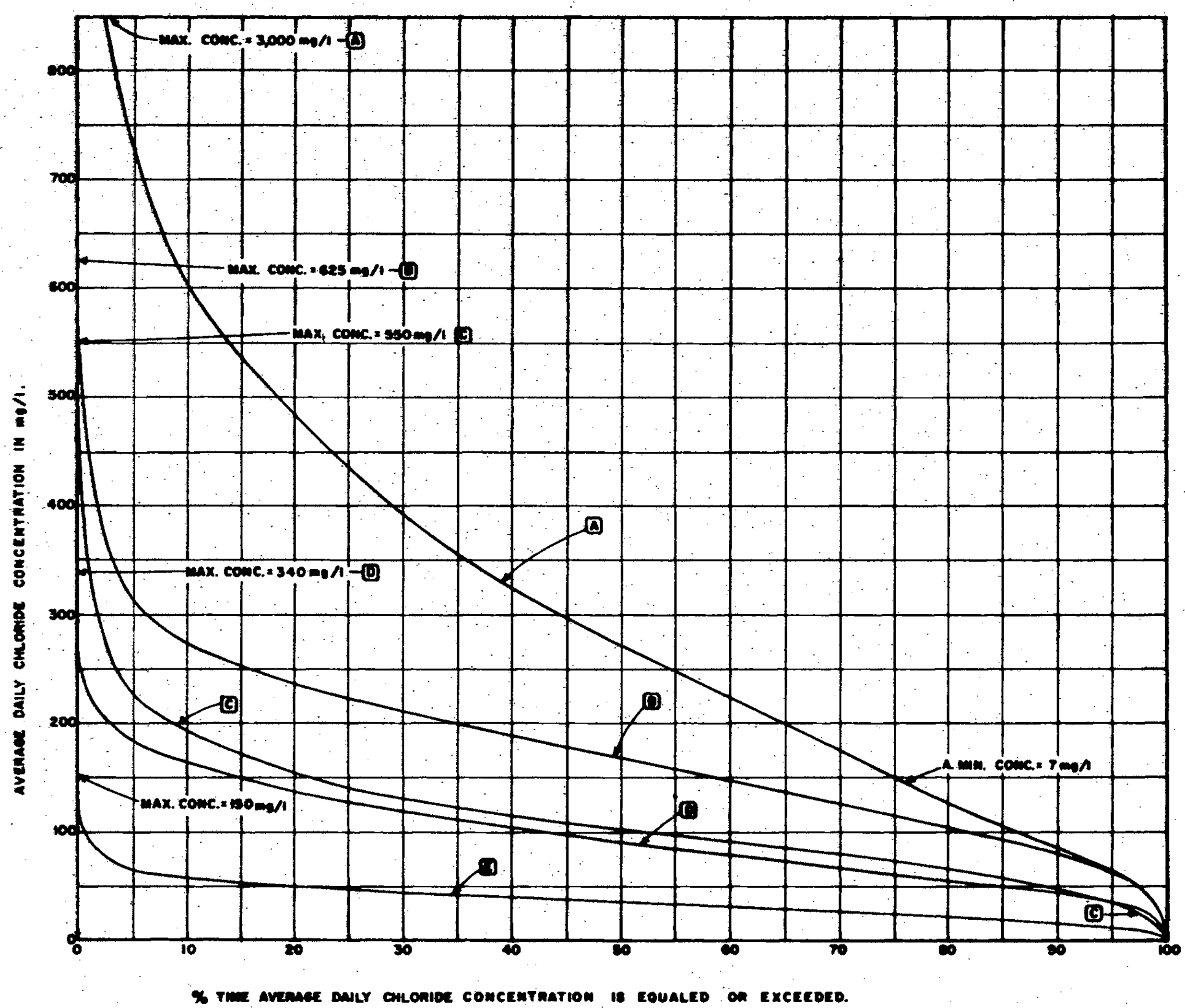
D. Estimates of Existing Chloride Loads - Arkansas River

Considering estimates of chloride loads is a hypothetical condition which represents a basic balance of chlorides. The chloride loads in this balance are estimated long-term averages based on past records. The Public Health Service (5) furnished the average daily chloride load in tons per day for their period of record of 1 September 1960 - 30 September 1962. A comparison of records of the Public Health Service (continuous monitoring for the water years 1961-1962) with the U.S.G.S. record at Hutchinson and Arkansas City, Kansas, and Jet and Ralston, Oklahoma, were found to agree closely, and the loads reported were assumed to be representative of long-term conditions. Since there were no long-term flow or chloride records at the Raymond Station, results are based on 39 months of P.H.S. records.

The remainder of the selected reference stations in the Arkansas River basin are affected by the large load carried by the Cimarron River. A study of the average daily chloride loads, consisting of U.S.G.S. and Public Health Service records, indicates a daily average chloride load at Waynoka, Oklahoma, to be significantly higher than the Public Health Service values. The Public Health Service records of

1 September 1960 - 30 September 1962 indicate a daily average chloride load of 3760 tons per day compared to 4800 tons per day for the average long-term load. The average daily chloride load at Waynoka was low during the Public Health Service sampling period since the average daily flow was only 58 percent of the long-term flow record. The result is a relatively low load contribution from the Cimarron River during the Public Health Service period of record which is not considered representative of the long-term average daily chloride load. Consequently, the average daily chloride load for all selected reference stations downstream of Waynoka on the Cimarron River and downstream of the Cimarron-Arkansas River confluence is higher than the Public Health Service period of record (2).

Long-term load-duration curves were computed from the long-term flow-duration curves for all reference stations in the Arkansas River basin except for the Raymond station. From these load-duration curves, concentration-duration curves were computed by the procedure discussed in paragraph C 1, except for the Van Buren and Raymond stations. The chloride concentration-duration curve of the Van Buren reference station was computed by utilizing concentration-duration curves from P.H.S.'s 2 years of continuous records and the U.S.G.S.'s 12 years of composite sample record. The chloride concentration-duration curve for the Raymond station was computed using the available record (30 continuous months of P.H.S. monitoring record). The results of the existing and modified chloride concentration-duration curves for the reference station at Van Buren, Arkansas, in the Arkansas River basin are shown in Figure 13. The existing average daily chloride load for the Arkansas River basin above Van Buren shows the large pick-up in



LEGEND

- A CONCENTRATION - DURATION CURVE WITH EXISTING FLOWS AND CHLORIDES
- B CONCENTRATION - DURATION CURVE WITH EXISTING CHLORIDES AND FLOWS MODIFIED BY EXISTING AND AUTHORIZED RESERVOIRS
- C CONCENTRATION - DURATION CURVE WITH FLOWS MODIFIED BY EXISTING AND AUTHORIZED RESERVOIRS AND WITH MAXIMUM ANTICIPATED CONTROL OF MAN - MADE CHLORIDES
- D CONCENTRATION - DURATION CURVE WITH FLOWS MODIFIED BY EXISTING, AUTHORIZED, AND PROPOSED WATER QUALITY STUDY STRUCTURES AND WITH MAXIMUM ANTICIPATED CONTROL OF NATURAL CHLORIDES
- E CONCENTRATION - DURATION CURVE WITH FLOWS MODIFIED BY EXISTING, AUTHORIZED, AND PROPOSED WATER QUALITY STUDY STRUCTURES WITH MAXIMUM ANTICIPATED CONTROL OF NATURAL AND MAN - MADE CHLORIDES

SOURCE OF RECORDS: P.H.S. — U.S.G.S
PERIOD OF FLOW RECORD: OCT. 27 — SEPT. 62

ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY OKLAHOMA - TEXAS - KANSAS

VAN BUREN, ARKANSAS

ARKANSAS RIVER, ARKANSAS

CHLORIDE CONCENTRATION DURATION CURVES

COURTESY U.S. ARMY CORPS OF ENGINEERS **FIGURE 13**

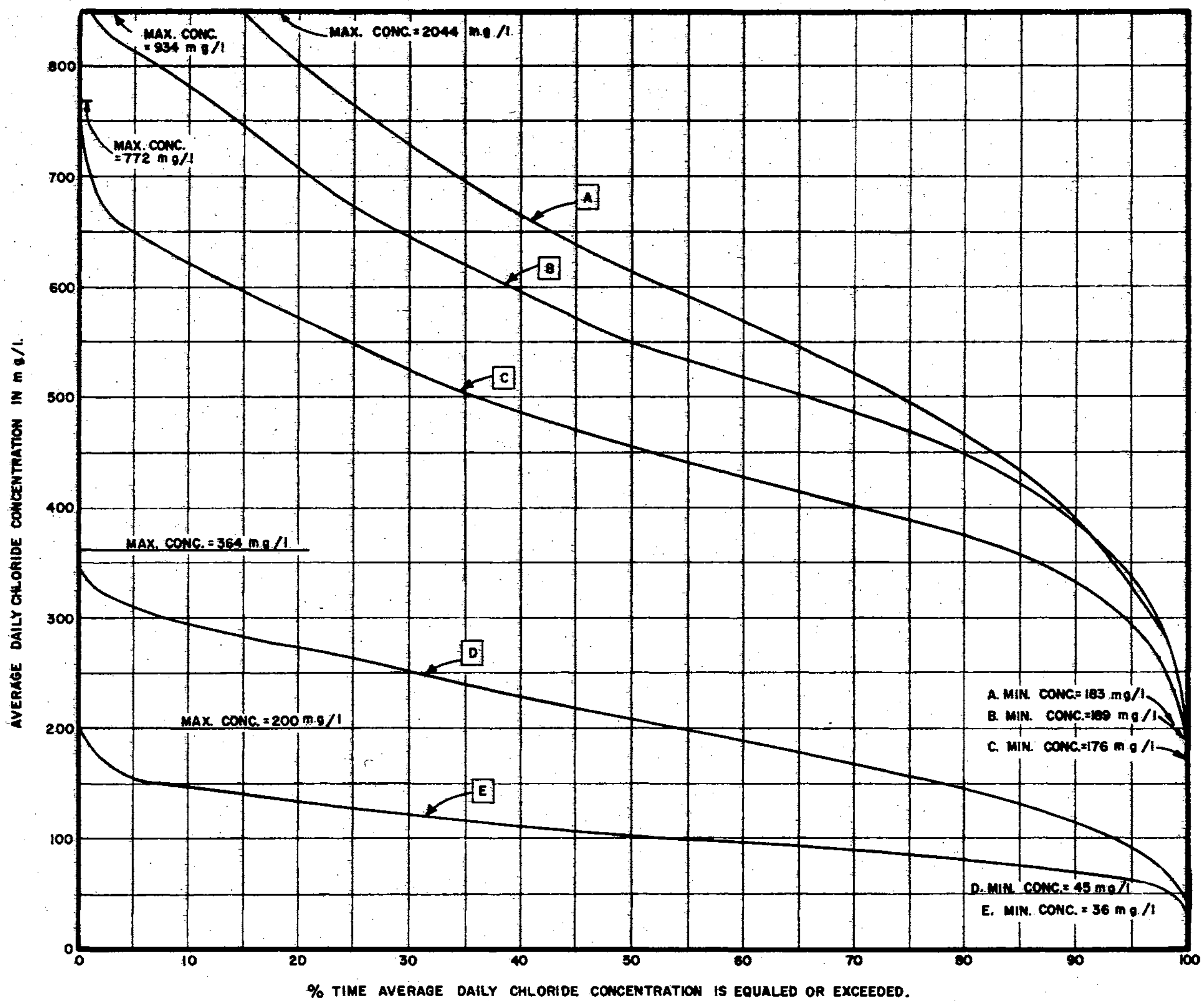
average daily chloride loads from the upper reaches of the basin to Van Buren.

E. Reservoir Storage Effects on Chlorides - Arkansas River

The natural peak flows which normally would pass the Van Buren station are significantly reduced due to the flood control capabilities of the upstream reservoirs. The low flows will be increased by releases from upstream reservoirs and will reduce the existing concentrations of chloride. Reservoirs authorized to July 1, 1965, which will materially affect the existing water quality in the Arkansas River basin above Tulsa, Oklahoma, are the Kaw and Keystone Reservoirs. The only reference station that will be affected by authorized reservoirs (not under construction) above Keystone is the Ralston station. The peak flows which normally pass the Ralston station will be reduced and the low flows will increase due to the operation of Kaw Reservoir. The effects on Keystone Reservoir by upstream structures are shown on Figure 14. The importance of low flow augmentation for dilution of wastes from six downstream municipalities was evident in the 1950's when releases from the Fall River Reservoir in Kansas were made (10). These releases also prevented the shutdown of three refineries and other industries.

F. Water Quality Monitoring Responsibility

Currently there are several State and Federal agencies responsible for water quality control. For instance, there are five Oklahoma State agencies (4) that have separate and distinct responsibility for water pollution enforcement. The Oklahoma agencies are: the Department of Health, the Water Resources Board, the Corporation Commission, the



LEGEND

A CONCENTRATION - DURATION CURVE (1) WITH EXISTING FLOWS AND CHLORIDES

B CONCENTRATION - DURATION CURVE WITH EXISTING CHLORIDES AND FLOWS MODIFIED BY EXISTING AND AUTHORIZED RESERVOIRS

C CONCENTRATION - DURATION CURVE WITH FLOWS MODIFIED BY EXISTING AND AUTHORIZED RESERVOIRS AND WITH MAXIMUM ANTICIPATED CONTROL OF MAN - MADE CHLORIDES

D CONCENTRATION - DURATION CURVE WITH FLOWS MODIFIED BY EXISTING, AUTHORIZED, AND PROPOSED WATER QUALITY STUDY STRUCTURES AND WITH MAXIMUM ANTICIPATED CONTROL OF NATURAL CHLORIDES

E CONCENTRATION - DURATION CURVE WITH FLOWS MODIFIED BY EXISTING, AUTHORIZED, AND PROPOSED WATER QUALITY STUDY STRUCTURES WITH MAXIMUM ANTICIPATED CONTROL OF NATURAL AND MAN - MADE CHLORIDES

SOURCE OF RECORDS: P.H.S.—U.S.G.S.
PERIOD OF FLOW RECORD: OCT. 37—SEPT. 62

(1) NATURAL FLOWS PAST THE KEYSTONE DAM SITE.

ARKANSAS - RED RIVER BASINS WATER QUALITY CONTROL STUDY OKLAHOMA - TEXAS - KANSAS

KEYSTONE RESERVOIR

ARKANSAS RIVER, OKLAHOMA

CHLORIDE CONCENTRATION DURATION CURVES

COURTESY U.S. ARMY CORPS OF ENGINEERS **FIGURE 14**

Department of Wildlife Conservation, and the Department of Agriculture. However, these agencies are primarily concerned with man-made pollution. Man-made pollution includes that pollution that is a result of the oil and gas industry, municipal and domestic wastes, agricultural production, and other minor industrial pollution. These agencies are doing a good job but do not have the capability to seek out natural pollution and initiate an action program for correction.

The Federal Water Pollution Control Administration, created in 1965, took over responsibility from the U. S. Public Health Service for water pollution problems. The Corps of Engineers has responsibility for construction of structures needed for natural pollution control. The U. S. Geological Survey has the primary responsibility for collecting streamflow and quality records to be used by all other State and Federal agencies in determination of mineral pollution problems.

G. The Cost of Water Quality Management Programs

Section 16 (a) of the Federal Water Pollution Control Act, as amended, directs the Secretary of the Interior to conduct a comprehensive analysis of the national requirements for and the cost of treating municipal, industrial, and other effluent to attain water quality standards under the Act. The first report (6) on this subject was submitted to Congress on January 10, 1968, and covered the fiscal years 1969 to 1973 regarding the cost of clean water.

This study (6) is extremely important because, although there is widespread agreement that water pollution is a significant and growing problem which must be dealt with, there are no firm estimates as to what the national requirements are or what it will cost to achieve a satisfactory abatement level. Several cost estimate studies of municipal needs have been conducted in the past but they have not been sufficiently comparable in geographical coverage, time phases covered, cost criteria, types of facilities included, or in cost estimate technique to provide a meaningful guide to the national requirements and costs involved.

1. Summary of National Cost Estimates for Pollution Control

The following paragraphs were taken from the report (6) on the cost of clean water. Initial estimates of the national requirements for and the cost of treating municipal, industrial, and other effluent during fiscal years 1969-73 to meet water quality standards established under the Act (7) and comparable levels for intrastate and coastal waters were made. The findings were as follows:

The cost of constructing municipal waste treatment plants and interceptor sewers is estimated at $8 billion, exclusive of land and associated costs. This total includes $2.7 billion to provide adequate treatment to the urban population whose wastes do not receive any treatment at present; $1.9 billion to upgrade service to secondary treatment for the urban population whose wastes now receive primary treatment (excluding areas where primary treatment is likely to be adequate to meet water quality standards); $2.2 billion for urban population growth; and $1.2 billion for replacing facilities.

By 1973 the urban population required to be served will comprise about 75 percent of the total U. S. population. The estimated costs represent the capital outlays required to provide secondary treatment, or other appropriate treatment levels contained in the water quality standards, to all of this 1973 urban population (162.6 million people). Currently, only 55 percent of the urban population is receiving adequate treatment. It is estimated that, to meet water quality standards by 1973, 90 percent of the urban population will require secondary treatment and 10 percent primary treatment.

There may be significant opportunity for reducing the costs, as well as for contributing to more effective pollution control, through establishment of intermunicipal sewage treatment and disposal systems and districts. In many cases, however, it will be necessary to overcome existing institutional obstacles to develop effective arrangements for such systems.

Operation and maintenance costs for the required treatment works are estimated at $1.4 billion for the 5-year period. Unlike annual construction costs, which can be expected to level off after the initial backlog has been eliminated, operation and maintenance costs will continue to rise as more sewage treatment plants are placed into operation.

There will be substantial additional costs incurred during the 1969-73 period for the control of overflows from combined sewers. It is anticipated that a variety of control methods will be initiated depending upon individual circumstances and, as a result, the full extent of these costs cannot be estimated at this time.

Construction of sanitary collection sewers will require an estimated $6.2 billion over the next 5 years. These costs will be an integral part of necessary expenditures for waste disposal by the communities involved.

Initial estimates indicate that the cost of treating industrial wastes to a level comparable to secondary treatment of municipal wastes will be in the range of $2.6 to $4.6 billion. This includes $1.8 to $3.6 billion for new industrial treatment works and $0.8 to almost $1 billion for replacing equipment. However, these estimates are based upon the minimal levels of control generally considered necessary to comply with water quality standards. Should implementation of the standards involve establishing industrial requirements calling for higher levels of waste reduction, these cost estimates could rise sharply.

There are significant opportunities for meeting industrial waste abatement requirements more efficiently through better in-plant controls and process changes, and joint municipal and industrial treatment systems.

Estimated costs of operating and maintaining industrial waste treatment facilities will range from $3 to $3.4 billion over 1969-73. As in the case of sewage treatment works, these costs will continue to rise with increases in plant in place.

Costs for constructing, operating, and maintaining heat dissipation equipment will be considerable. However, it is not possible to estimate the costs required to comply with water quality standards because of lack of information on the application of temperature criteria and the effect of heat discharges on existing water temperatures. Some indication of the upper limits of such outlays is the estimate of costs to reduce cooling water after use to its original temperature. Capital outlays in the 1969-73 period to attain complete temperature restoration would be $1.8 billion. This includes $1.6

billion for new cooling facilities and $0.2 billion for replacing equipment. Operation and maintenance would amount to an additonal $0.9 billion over the 5-year period. In actual practice, a lesser over-all temperature reduction - and a portion of the cost - may well prove adequate.

Other effluents will increase in significance as municipal and industrial wastes are brought under control. Additional costs for controlling a wide range of other pollutants, such as sediment, acid mine drainage, and animal feedlot runoff, will be incurred during the 5-year period, but these costs cannot be estimated accurately at this time. Over the long run, these sources will require heavy expenditures for pollution control.

The above projected costs are expressed in constant dollars. "Constant 1968 dollars" were developed by using July 1967, the beginning of fiscal year 1968, as the base. "Current dollars" were developed by multiplying the 1968 "constant dollar" estimates over the fiscal year 1969-73 time frame by projected cost indexes for each year.

Assuming a continuation of past cost increases, the dollar costs would be proportionally higher. Costs of municipal waste treatment works could rise from $8 to $8.7 billion; industrial waste treatment facility costs could rise from the $2.6 to $4.6 billion range to the $2.9 to $5.1 billion range. Operation and maintenance costs in current dollars would also rise: municipal waste treatment from $1.4 to $1.7 billion and industrial waste treatment from the $3 to $3.4 billion range to the $3.2 to $3.6 billion range.

H. Distribution of Cost of Chloride Control Structures - Arkansas River Basin

The distribution or allocation of costs among project purposes is principally to determine reimbursement to the Federal Government for specific facilities or products. When more than one water use or purpose is involved, an allocation of costs for each project function is generally made in accordance with the Separable Costs-Remaining Benefits Method. An allocation of costs among multiple water use benefits is not practical for the Arkansas River Chloride Control Projects. Specific storage for purposes other than water quality control was not planned. The reservoirs with outlet channels for passing fresh water around salt sources are formulated to prevent flushing of stored brine. Other brine reservoirs with small drainage areas were designed to store both fresh water and brine without release. Incidental flood protection benefits, and minor fish and wildlife conservation benefits would be realized at certain projects and benefits are also credited to outdoor recreation facilities planned for public use and fish and wildlife enhancement of project lands and fresh water pools. Based on foregoing reasons (2), a cost allocation for project functions was not applicable, especially for determining reimbursable costs, for the Arkansas River Chloride Control Projects.

1. Cost Sharing for Chloride Control Projects

The provisions of the Federal Water Pollution Control Act Amendments of 1961, while not stated in specific terms were determined (2) applicable for assigning responsibility for control of natural and man-made chloride pollution of the Arkansas River basin streams.

Pre-enactment discussion of the 1961 legislation was in terms of low flow augmentation rather than withholding of pollutants. However, both are forms of streamflow regulation, to which the legislation refers without differentiation. Accordingly, it seems reasonable to apply the cost-sharing standards of the legislation to the Arkansas River chloride control projects. Section 2(b)(4) of the 1961 Act reads, "Costs of water quality control features incorporated in any Federal reservoirs or other impoundment under the provisions of this Act shall be determined and the beneficiaries identified and if the benefits are widespread or national in scope, the costs of such features shall be nonreimbursable." This Act also provides that inclusion of storage for regulation of streamflow for the purpose of water quality control shall not be as a substitute for adequate treatment or other methods of controlling waste at the source. Discussion follows of the widespread effect of the chloride control plans, identification of beneficiaries and views of State water resource agencies regarding cost sharing for natural and man-made chloride control.

2. <u>Widespread-national Scope of Improvements</u>

As outlined below, the water quality control services to be rendered by the Arkansas-Red River chloride control plan would be classified as widespread under all of the guidelines developed to reflect the Corps of Engineers' understanding of the legislative history of the 1961 legislation.

<u>Interstate Considerations</u>

Natural salt pollution in the Arkansas and Red River basins, together with other natural sources of pollution in the basin, affects the quality of water available from the two major rivers and tributaries in Kansas, Texas, Oklahoma, Arkansas, and Louisiana. Classification of the problem as widespread is indicated under the guidelines for this factor.

Geographical Considerations

The water quality impairment by chloride extends over more than 1,000 miles of streams in each basin. Widely separated cities in Texas, Oklahoma, Arkansas, and Louisiana would benefit from improvement in quality of water available from the Arkansas and Red Rivers. The natural brines causing degradation of water originate from sources in a wide band across three states existing prior to establishment of any present-day uses of water in the region. Classification of the problem as widespread is indicated under the guidelines for this factor.

Type of Pollutants

The pollutants involved here are of natural origin and of a type not benefited significantly by the self-purification capability of the streams which carry them. Under the guidelines for this factor classification of the problem as widespread is indicated.

Availability of Solution

Technology has not developed an economical method of reducing or removing the natural salt pollution at points of use or of handling it effectively before it reaches surface water courses. In the terms of the legislation under discussion there is no base of "adequate treatment or other methods of controlling waste at the source" which storage operations might supplement. In the absence of practicable direct waste control measures the guidelines referred to above indicate the problem should be classified as widespread.

Distribution of Costs

The Arkansas-Red River chloride control plan would supplement widespread, costly local programs for water supply and direct waste control. It is probable, also, that unit local costs for these programs will be substantially larger than the entire cost of that plan. A widespread classification is indicated under the referenced guidelines.

Number and Diversity of Beneficiaries

The potential uses of the improved water are widespread municipal, industrial, and agricultural activities now existing in the Arkansas and Red River basins, and subject to expansion because of the improved water source. Also, this improved water may serve expanding needs of urban areas in adjacent basins. Classification of the problem as widespread is indicated under the guidelines for this factor.

Federal Interest Areas

There are no National Parks in the basin but several Federal reservoirs in the two basins receive extensive recreational use. The Arkansas River navigation project now under construction is expected to have a major impact on the national economy. Thus, there is some project-oriented basis for classifying the problem as of national significance.

3. Identification of Beneficiaries

All project benefits must have some point of incidence. That is, they must accrue to one or more beneficiaries, whether specifically identified or not. Thus, all benefits, whatever the evaluation device, are aggregations of benefits to individuals. Evaluation of benefits in terms of alternative water supply costs does not imply any greater or lesser degree of specificity in incidence than would evaluation in other terms. This method was used by the Public Health Service and the Corps of Engineers in the Arkansas-Red River study for lack of a more definitive evaluation device. While the legislation calls for identification of beneficiaries, this is not understood to require pinpoint identification. Instead, indication that a given project would reduce pollution damage to water supplies along an extended reach of stream would appear to comprise acceptable identification (recognizing that quantification would require some identification of use by specific communities). However, regardless of the specific identification of beneficiaries, the cost-sharing device provided relates to over-all patterns of benefit incidence rather than to detailed rosters of beneficiaries.

4. Division of Responsibility for Natural and Man-Made Chloride Control

A reasonable division of responsibility for controlling chloride pollution would be to assign the construction and operation costs of natural chloride control to the Federal Government and have the non-Federal interests bear full responsibility and costs of man-made chloride control. Pertinent to the cost-sharing decisions for water quality improvements is that the natural chloride control projects are dependent on local interests' control of man-made salt pollution from oilfields and other mining and industrial operations as recommended by the U. S. Public Health Service (5). Such parallel participation by local interests is essential to the success of Federal chloride remedial works. Today, approximately $67.73 million are being spent each year by municipalities and industries for pollution control in the

Arkansas-Red River basins according to information developed by the Federal Water Pollution Control Administration. Approximately $34.28 million are spent in the Arkansas River basin, including $19.0 million for municipal controls, $0.5 million for industrial controls, and $14.78 million for brine injection controls. Of the $33.45 million annual cost in the Red River basin $14.95 million are for municipal controls, $0.5 million for industrial controls, and $18.0 million are for brine injection controls. The combined $32.78 million expenditures yearly in the two basins for salt brine injection are about four times greater than the annual cost of the projects proposed by the Corps of Engineers for control of natural brines in both basins. Such pollution control programs under State government direction constitute real local contributions to solving the over-all pollution problem in the Arkansas and Red River basins. Therefore, the Corps of Engineers feels that the construction and annual operation costs of the natural chloride control projects should be considered nonreimbursable.

5. Views of State Agencies Regarding Pollution Control

Following are summarized views of State agencies of Texas, Oklahoma, and Kansas contained in letters to the Corps of Engineers. These states are in agreement as to division of responsibility for control of natural and man-made salt pollution. The logic of these views generally advocates that the Federal Government should be responsible for the construction and operation costs of projects for control of natural salt pollution when benefits obtained are widespread or national in scope. The states agree that the costs of programs needed to control man-made salt pollution are a proper non-Federal responsibility.

Texas Water Commission

The Commission considers that water quality improvement is, in fact, a salvage of water for beneficial use. They note an appropriate Federal cost guideline is the 1948 authorization of a joint Corps of Engineers-U. S. Bureau of Reclamation series of projects for the Middle Rio Grande, New Mexico. One of these authorized projects was the channelization of the Rio Grande for water salvage on nonreimbursable construction cost and operation and maintenance cost bases. Similar projects are noted to have been subsequently approved in New Mexico and Arizona.

Determination of beneficiaries for flood control reservoir projects which benefit large areas are noted to be difficult if not impossible. It appears to the Commission that, since there are no repayment requirements of local interests for a flood control reservoir, the same repayment criterion would apply to a single-purpose water quality improvement project. The Commission believes that nonreimbursable provisions of the 1961 Water Pollution Control Act amendments for multipurpose projects are applicable to single-purpose salinity alleviation projects.

While natural pollution occurs in definable areas in the upper portions of the Arkansas-Red River basins, the quality of the water is affected at distant locations downstream from the points at which natural pollution occurs. The length of these major interstate streams and large widespread areas benefited by salinity alleviation projects indicate very definite problems if repayment provisions are required of local interests. In addition, The Texas Water Commission supports the foregoing views by a resolution dated April 17, 1964.

Oklahoma Water Resources Board

The Board considers that, until such time as a definite and firm policy can be worked out, the cost of controlling man-made pollution should be the responsibility of the State, and that natural pollution should be the responsibility and at the cost of the United States.

The Board reports that the State of Oklahoma is making a diligent effort to control its man-made pollution. Four state agencies have formed a coordinating committee to better prosecute their respective responsibilities and are vigorously pursuing a program of pollution abatement throughout the state.

Kansas Water Resources Board

This Board and the State Department of Health firmly support the concept that enforcement and cost of control measures for man-made pollution is a proper state responsibility and would not favor any change in this procuedure. The adopted control measures have and are being financed by non-Federal interests with the enforcement being carried out by the State Department of Health.

As to cost sharing for control of natural pollution sources, the two Kansas agencies consider the provisions of the 1961 Federal Water Pollution Control Act would generally be applicable.

I. Federal Cost of Chloride Control Structures - Arkansas River Basin

The first cost of the Arkansas River basin chloride control plan would be $177,500,000. This program would include three fresh water reservoirs with outlet diversion channels, one on the Salt Fork of the Arkansas River, and two on the Cimarron River. There would also be three brine reservoirs, one a modification of the existing Great Salt

Plains Reservoir, one on the Cimarron River, and one on Salt Creek, a tributary to the Cimarron River.

CHAPTER VI

CONCLUSIONS

Development and initiation of a water quality management program in the Arkansas and Red River basins at Federal expense is warranted based on the following conclusions:

1. The Arkansas and Red Rivers are currently being polluted by natural and man-made chlorides to the extent that the flow is not usable for municipal and industrial purposes.

2. Fifteen major sources of natural chloride have been identified as the primary cause of mineral degradation of waters in the two basins. Effective control of the natural chloride pollution in the Arkansas and Red River basins can best be accomplished by brine collection systems and brine retention reservoirs at 10 of the 12 major natural sources as proposed by the Corps of Engineers.

3. Adequate water quality data collection is necessary to monitor existing mineral pollution, as well as organic pollution, for use in future water quality management programs.

4. The outlook is favorable for continued economic growth in the Arkansas and Red River basins region. Projected population growth, increased personal income, and other output gains are expected to parallel or exceed those of the nation. Adequate land is available for urban growth and for increased output of food and kindred products by agriculture. Natural resources of petroleum, natural gas, coal,

minerals, and forest reserves are available to sustain accompanying increased industrial supply and service activities. Trends toward urbanization and industrialization which will influence the future use of land and water resources are well established in the basins.

5. The abundant stream yields from the upgraded Arkansas and Red Rivers at urban localities would ensure nonmineralized water for long-range supplies. By reduction of natural and man-made chlorides, regulated flows would be available for use by municipalities, industries, and agriculture. At urban centers and other points along the now-polluted rivers a new water resource would be created for door-step water withdrawal. By meeting chloride tolerance standards, there is promise for development of many new and expanding industries along the streams. Irrigated lands in the two basins (projected 50-100 years hence) are estimated at 5,250,000 acres. Therefore, the prospects are favorable for large irrigation use from the improved waters of the Arkansas and Red Rivers.

6. The control of the natural brine pollution of the Arkansas and Red Rivers is considered a Federal responsibility. It is concluded that control of the man-made brines should be a state responsibility. Therefore, it would not be unreasonable to consider that the Federal Government maintain water quality monitoring stations at certain key checkpoints on the two basins' streams. This responsibility is a followup of the effectiveness of the chloride control works proposed for the two basins.

7. Recent technological advances in automated water quality monitoring systems have given leaders of water quality management

programs a choice between continuous monitoring and the grab sample and corresponding laboratory analysis for data collection.

8. A comprehensive system of water quality monitors should be installed in the Arkansas River to develop records on the quality of our water comparable to our records on flow.

CHAPTER VII

SUGGESTIONS FOR FUTURE WORK

The following suggestions are made for future research concerning the natural pollution of the Arkansas and Red Rivers and the long-range effects of the Corps of Engineers' chloride control plans.

1. Continuing study of the occurrence, mode of transmission, and origin of the brines now polluting the Arkansas and Red Rivers. This would involve a general geology study.

2. That a study similar to the chloride control study be made in the two basins regarding sulfates. This would be a study of the magnitudes and occurrence of sulfate pollution with possible remedial works for control.

3. A model study of the existing water quality of the two basin streams relating all natural mineral pollution to existing municipal, industrial, and agricultural pollution.

4. A field installation of a continuous monitoring system to determine the effectiveness of additional water quality data.

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