TR-1
1967

Texas Water Resources Institute
make every drop count

A Study to Determine the Feasibility of Diverting a Portion of the Red River into the Trinity, Neches and Sabine River Basins

J.H. Cook

Texas Water Resources Institute

Texas A&M University

A STUDY TO DETERMINE THE FEASIBILITY OF DIVERTING A PORTION OF THE RED RIVER INTO THE TRINITY, NECHES AND SABINE RIVER BASINS

By

JOHN HENRY COOK

Water Resources Institute
Texas A&M University
May 1967

This investigation was supported by the Water Resources Institute, Project No. 5003 (A-004-TEX) Texas A&M University, College Station, Texas, and the Office of Water Resources Research, Department of the Interior.

ACKNOWLEDGEMENTS

I wish to acknowledge the assistance given to me in this study by Dr. Roy W. Hann, Jr. I extend appreciation to Professor William B. Davis and Dr. Robert A. Clark for their review and comments. Also, I am grateful for the financial assistance provided by the Department of the Interior, (Project A-004-TEX), Water Resources Research. This support was administered through the Water Resources Institute, Texas A&M University, Dr. Ernest T. Smerdon, Director.

Finally, I am especially grateful to my wife, Patricia, for her encouragement and assistance throughout my graduate studies, and to Mrs. Iris McKeen for typing the manuscript.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

This study involves four of the twelve major river basins of the state of Texas and is essentially a proposal to divert water from the Red River into the Trinity, Neches and Sabine River Basins. When first considered, it appears to be a rather unusual plan. It proposes to take water from the Red River at Lake Texoma, which is often of poor quality and in some areas of the basin scarce, and transport this water into a portion of the state that has an apparent abundance.

There are; however, numerous advantages to this plan. First, a dependable supply of water is made available to the upper reaches of the receiving basins without the cost of reservoir construction. It also creates a potential for peak period hydroelectric power generation and supplies the lower portion of the basins with an increased water supply which can be put to beneficial use. This may involve water quality control of municipal and industrial pollution, control of salt water intrusion, or redistribution.[1] In an age of grandiose water supply schemes, e.g., the California Water Plan [2] and the preliminary Texas Water Plan,[3] the cost of this proposal is very reasonable.

Some of the disadvantages of this proposal are discussed briefly in the following paragraph. The Red River is an interstate stream; consequently, division of its waters among the states included in the basin must be by compact. Compact Commissioners representing the states of Texas, Oklahoma, Arkansas, and Louisiana, with a chairman representing the Federal Government, have been negotiating a Red River Compact. Most of the details have been worked out and the draft of this agreement is being reviewed by federal and state agencies. The Red River Compact will then need approval by the legislatures of each of the states and by the Congress before it will become effective. Until final arrangements have been made concerning the allocation of water, the proposed diversion cannot legally be made. Since the quality of the Red River water has been poor much of the time, the Corps of Engineers has begun work to alleviate the natural salt pollution. The states concerned have agreed to aid the Federal Government by close control of manmade pollutants. The quality of the Red River water is dependent upon these control programs. Finally, the development of this plan would require revision of the master plans for the specific basins because a number of existing reservoirs would be affected. If for no other reason, this study and the evolved proposal have been valuable as a training program for use of the many recently developed water resources planning techniques.

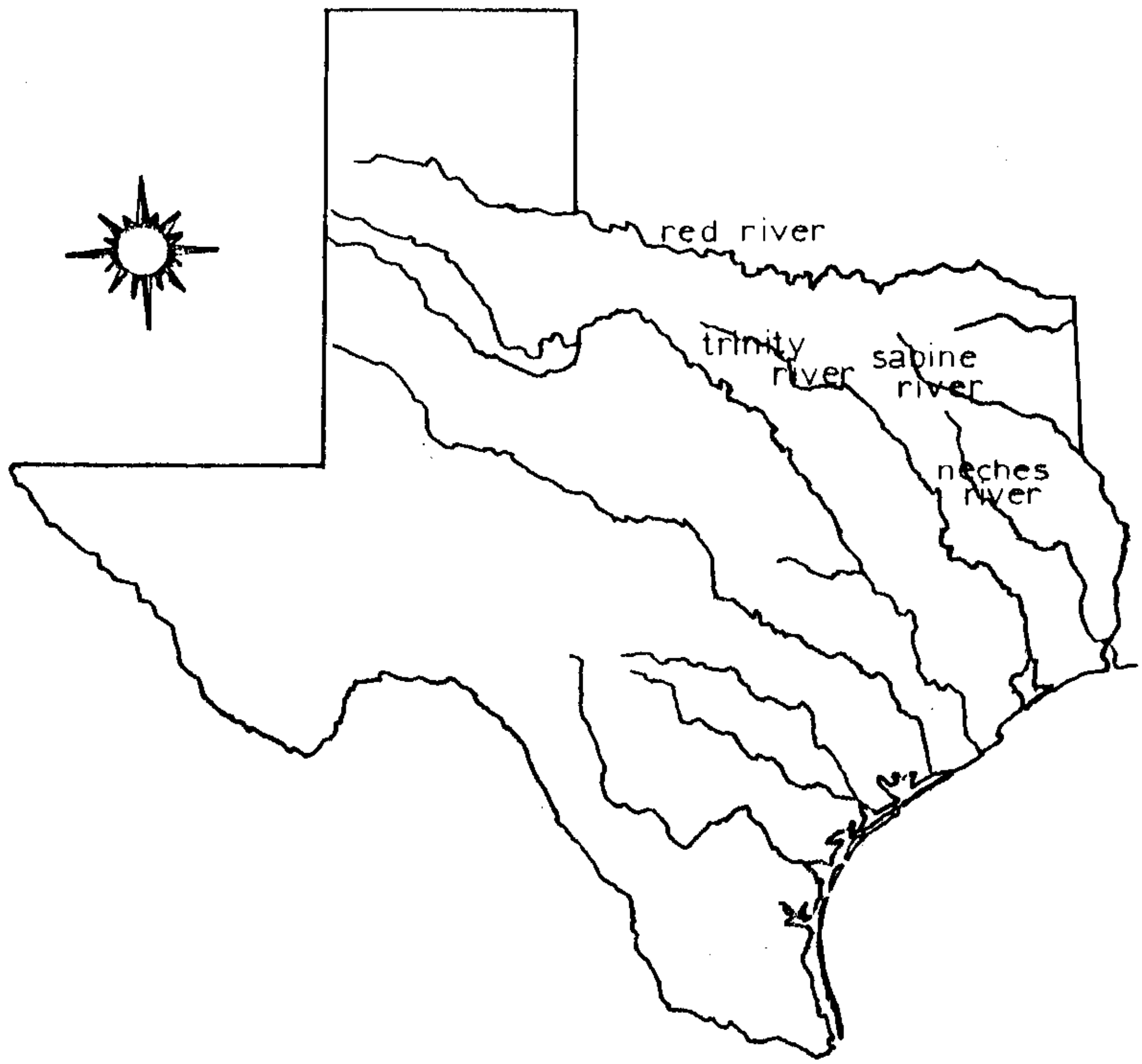
In order to insure a sense of direction, it seems apropos to present a brief outline of the study procedure.

Chapter II, entitled, "The Economic Development and Potential for the Red, Trinity, Neches and Sabine River Basins," is a general discussion of the economic factors as they are related to demand for water in each basin. In addition to a statewide outlook, a separate discussion for each basin is presented which includes future population projections. In closing this chapter, a table of the anticipated municipal and industrial water requirements is presented. Careful consideration of the information in this chapter is necessary for any type of water resources planning.

The largest section in this study is Chapter III, "The Water Resources of the Neches and Red River Basins." A comprehensive investigation of the water resources of all the basins in the proposal would have been desirable; however, the work required would have approached development of a master plan for a major portion of the state of Texas. Detailed examination and research of the donating basin and for a single receiving basin was considered adequate for the objectives of this study. The specific subtopics which were discussed are too numerous to list here and are available in the Table of Contents section.

Chapter IV, "The Proposed Physical Plan," contains a description of the diversion facilities required to transfer excess surface water from Lake Texoma in the Red River basin to the three recipient basins.

Chapter V, "Summary and Conclusions," contains a restatement of some of the major features of the proposal and suggestions for further research.



STATE OF TEXAS

FIGURE 1-1

CHAPTER II

THE ECONOMIC DEVELOPMENT AND POTENTIAL FOR THE RED, TRINITY, NECHES AND SABINE RIVER BASINS

The increasing demand for good quality water is directly related to the expanded economic productivity and population of a designated region. Any predictions of future water requirements for specific areas such as the Neches and Red River basins must be coordinated with the economic outlook for the entire state.

The potential for future economic growth and population increase of the state is based mainly on (a) utilization of the large undeveloped mineral, land, and water resources; (b) an expanding national market for the resultant products; and (c) the existing favorable environment for the industries which manufacture such products.

Texas offers many advantages to industries. Among these advantages are (a) a mild climate; (b) well developed rail and highway facilities; (c) low cost, year round harbor; (d) an adequate labor supply; (e) a favorable tax structure, and (f) public sentiment favorable to industrial growth.[4] In addition, the state has vast land resources whose productive capacity is only partially utilized. Finally, Texas has substantial water resources at its disposal.

The urban and industrial growth has greatly increased the demand for good quality municipal and industrial water. The per capita use of water has followed the rising urban population. These factors, compounded by municipal and industrial degradation of many water sources, have created an unprecedented demand for good quality water throughout the state. The unretarded growth of industries relies on the assurance that a dependable supply of water will be available whenever it is needed. Since major new water supplies cannot be developed quickly because of the many engineering, economic and legal problems that are involved, maximum growth is contingent upon accurate prediction of and preparation to meet the future demands. Figure 2-1, obtained from the Texas Water Development Board, shows the projected population and municipal and industrial water requirements for the state of Texas. Table 1, located at the end of this chapter, shows the municipal and industrial water requirements for the Red, Trinity, Neches, Sabine, and related areas.

Red River Basin

Economic outlook. The economy of the Red River basin is centered around agriculture and light manufacturing. Dairy and cotton seed products, food processing, cotton gin machinery, and petroleum contribute to the income of major cities. Retailing and wholesaling comprise a significant part of the economy.

Wheat, cotton, and grain sorgums are the primary crops in the High Plains and in suitable lands on the Rolling Plains. The chief endeavor in the rolling hills area is the production of livestock. Agriculturally oriented production is the second greatest factor in

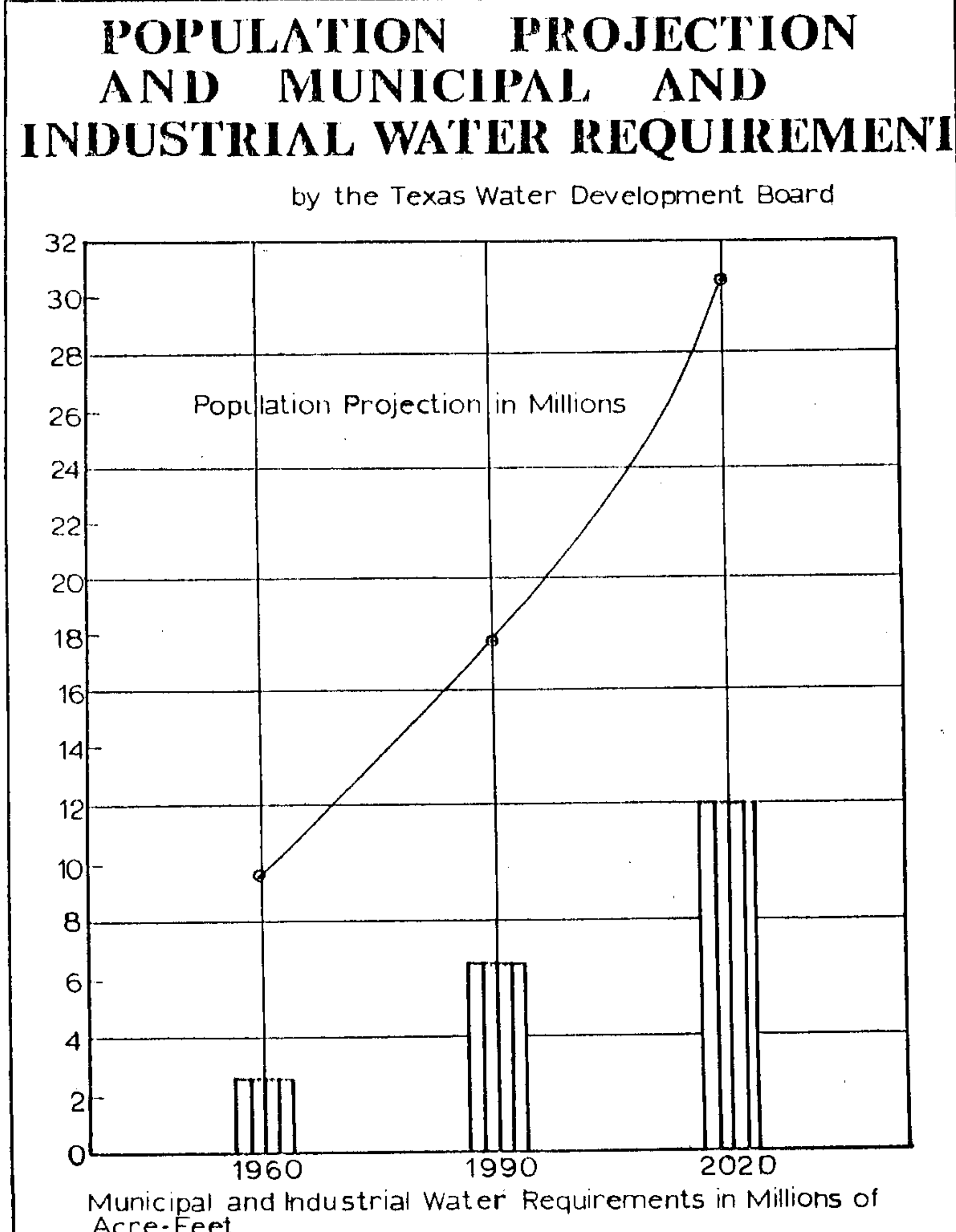

POPULATION PROJECTION AND MUNICIPAL AND INDUSTRIAL WATER REQUIREMENT
by the Texas Water Development Board
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Population Projection in Millions
1960
1990
2020
Municipal and Industrial Water Requirements in Millions of Acre-Feet

FIGURE 2-1

the economy of the region, following the oil and gas industry. The future of the oil industry seems to be well insured by statistics on reserves. There is no indication that large numbers of new people will be brought in by the oil industry, but there is also little reason to expect population losses due to oil depletion for the foreseeable future. The structure of the economy is not expected to change significantly, but should continue to grow with the expansion of the present types of industries in the basin.[5]

Population. The population of the Texas portion of the Red River basin is projected to grow from 463,900 in 1960 to 1,116,000 by the year 2020.[3] The urban portion of this projection is 949,000. This increase in population combined with a higher per capita water consumption will result in a water supply demand in the year 2010 that is approximately three times the 1960 demand. It should be noted that a large land area of the basin, the High Plains region, cannot economically utilize the water resource potential of the proposed diversion source (Lake Texoma).[3] Therefore, the High Plains area exerts no demand on the unappropriated waters of Lake Texoma.

Trinity River Basin

Economic outlook. The dominant center of the economic activities is the Dallas-Fort Worth Metropolitan Area, located in the northern portion of the basin. The major economic endeavors include aerospace research, aircraft manufacturing, petroleum production, and assorted light manufacturing such as oilfield equipment. The Dallas-Fort

Worth Area is also a leading center of banking, finance, insurance, and meat packing.

It is expected that the Dallas-Fort Worth Area will contribute much to the basin's growth with expansion of its commercial center and diversification of the manufacturing interests.

The center portion of the basin is mainly engaged in agriculture, including the production of livestock and lumber. Navigation could increase the importance of this area as a distribution center; however, the basic industries are expected to remain agriculturally oriented. The southern portion is involved in the production of petrochemicals and plastics. The increased distribution ability created by the proposed navigation project would be especially beneficial to these industries. While the Houston Metropolitan Area is not located in the Trinity River basin, considerable influence could be exerted on future water requirements of the lower basin area.

Of all the basins in the state, the Trinity River basin will probably experience the most drastic changes in population and water requirements. In addition to the consumptive requirements of industries and municipalities, there is a demand for a dependable supply to aleviate the pollution problem, maintain a minimum flow for navigation, insure the protection from salt water encroachment, produce hydroelectric power, and many other needs which can arise.[3, 6, 7]

Population. The population of the Trinity River basin, currently approaching two million, is projected to double in the next 30 years and to exceed six million by the year 2020. The urban population of the projected figure is expected to be about 90 percent.[3]

Neches River Basin

Economic outlook. The economic activity of the Neches River Basin is centered about petroleum production and processing. Beaumont, a deep water port, provides an outlet for petroleum products as well as a base for commercial banking and light industry. The total national demand for refinery products is expected to more than double by 1975 and to double again by 2010.[6] This increased national activity should be reflected in the economy of the basin.

Much of the basin contains good timber land, and lumbering is the major agricultural activity. Livestock, fruits, and vegetables are also important to the agricultural economy.

The economic future of the southern portion of the basin seems very good because of the growing importance of petrochemicals and plastics. The northern part of the basin is growing in importance as a marketing and light manufacturing area. The central portion of the basin probably will continue to rely mainly on lumbering and agriculture.

The major economic acitvities of this basin, i.e., petroleum, petrochemicals, and lumber, are water oriented and water demanding. To insure the projected growth and uninhibited development, the supply of good quality water is a necessity.[6]

Population. The population of the Neches River basin is projected to grow from 379,200 in 1960 to 1,303,300 by the year 2020. This represents more than a threefold increase which can be expected to augment the demand for water about 3.5 times that of the 1960 period.

Sabine River Basin

Economic outlook. The Sabine River basin shares many economic activities of the Neches River basin. Similarly, the chief industry is petroleum production, which is centered around Longview. Orange is the location of refining industry, heavy steel works, and ship building. Light manufacturing such as aircraft, mobile homes, and rocket engines is located in the north and central parts of the basin.

It is expected that the production of primary metals, paper, and natural gas will play a prominent part in the economy of the basin in future years.

The expansion of chemical, glass, and plastic production should stimulate growth around the Orange Area. The easy access to marketing and distribution centers should increase the productivity of the Longview - Marshall Area. Paper manufacturing in the northern forest region should continue to increase if economical, good quality water is maintained in adequate supply.

The central portion of the basin should experience more limited growth and industrial expansion, but increased productivity of this area is also anticipated.[6, 8]

Population. The population of the Texas portion of the Sabine River basin is projected to grow from 296,500 in 1960 to 886,800 by the year 2020.[8] It is anticipated that the urban portion of this population will be nearly 631,400.

TABLE 1

MUNICIPAL AND INDUSTRIAL WATER REQUIREMENTS

in Acre-Feet[3]

	1960			1990			2020		
	M	I	Tot	M	I	Tot	M	I	Tot
RED	43,240	26,212	69,452	94,200	78,800	173,000	172,100	118,700	290,800
NECHES	30,047	120,852	150,899	88,000	353,200	441,200	202,000	668,000	870,000
NECHES TRINITY	16,324	96,695	113,019	47,200	341,000	388,200	108,600	703,100	811,700
TRINITY	282,830	119,887	402,717	728,900	196,500	925,400	1,394,300	300,300	1,695,100
SABINE	23,301	69,168	92,469	55,200	346,100	401,300	131,200	755,600	886,800
TRINITY	5,677	42,367	48,044	12,400	75,300	87,700	29,600	122,500	152,100
SAN JACINTO	176,999	248,801	425,600	445,300	792,600	1,237,900	914,600	1,522,800	2,437,400

CHAPTER III

THE WATER RESOURCES OF THE NECHES AND RED RIVER BASINS

Neches River Basin

General description. The Neches River is bounded on the north and east by the Sabine River basin, on the west by the Trinity River basin, and on the south by the Neches-Trinity coastal basin. It rises in southeastern Van Zandt County, Texas, at an elevation of about 600 feet above mean sea level and flows southeasterly for an airline distance of 220 miles to Sabine Lake, which is an estuary of the Gulf of Mexico. Throughout most of the basin, the width varies from 50 to 60 miles. The basin contains approximately 10,000 square miles or 3.8 percent of the area of Texas.

The largest tributary to the Neches River is the Angelina River. The drainage area of the Neches above the mouth of the Angelina is 3,808 square miles. The other important tributaries to the Neches River enter from the west, downstream from the Angelina River. Village Creek, drainage area 1,113 square miles, enters the river channel 10 miles upstream from the city of Beaumont. Another tributary, Pine Island Bayou with a drainage area of 657 square miles, enters the river channel five miles upstream from Beaumont. The topography of the Neches River basin ranges from hilly in the upper portion to gently rolling in the middle portion and flat in the coastal area.[9]

Rainfall and evaporation. The average annual rainfall in the Neches River basin is 48 inches, and the average annual net lake-surface evaporation loss is 13 inches. The rainfall ranges from 40 inches in the northern part of the basin to 50 inches in the southern part, while the net evaporation loss ranges from three inches in the southern to 23 inches in the northern areas.[10]

Ground water. Approximately 560,000 acre-feet of ground water is available annually from the known major and minor aquifers in the Neches River basin. The basin's major aquifers are the Carrizo-Wilcox and the Gulf Coast. Its minor aquifers are the Queen City and the Sparta.[10]

Surface water.

Runoff. The average annual runoff in the Neches River basin ranges from a maximum of about 1,000 acre-feet per square mile near the mouth of the Neches River to 400 acre-feet per square mile along the northwestern boundary of the basin in Van Zandt, Henderson, and Anderson Counties.

Data from three key gaging stations show that the Neches River at Rockland, with a drainage area of 3,637 square miles, had an average annual runoff of 1,667,000 acre-feet, a maximum year in 1941 of 3,578,000 acre-feet, and a minimum year in 1925 of 164,000 acre-feet, during the 61-year period 1904-64.

The Angelina River near Lufkin, with a drainage area of 1,600 square miles, had an average annual runoff of 896,300 acre-feet, a maximum year in 1932 of 1,790,000 acre-feet, and a minimum year in 1925 of 107,000 acre-feet, during the 36 years 1924-34 and 1940-64. The Neches River at Evadale, Jasper County, with a drainage area of 7,951 square miles, had an average annual runoff of 4,567,000 acre-feet, a maximum year in 1941 of 9,206,000 acre-feet, and a minimum year in 1925 of 720,000 acre-feet, during the 45 years 1905-6 and 1922-64. Runoff in the Neches River basin through 1964 was not affected greatly by reservoir storage.[11]

In the Neches River basin, as well as the surrounding vicinity, the most severe drought of record is considered to be the 1951-1957 drought. The Bureau of Reclamation has concluded that the worst droughts since 1890 were those of 1909-1913, 1916-1918, 1925, and 1951-1957.[12] Because of the increased number and dependability of recording stations, it is generally accepted that the most accurate estimate of dependable yield by a reservoir operation study is obtained through use of the 1951-1957 drought period.

<u>Floods</u>. The streams in the Neches River basin generally have comparatively small main channels, flat slopes, and wide, timbered flood plains. The usually abundant rainfall produces frequent floods that overflow the flood plain for lengthy periods, rise and fall slowly, have low velocity, and have lower maximum unit discharge rates than streams in Central and West Texas.

The maximum discharge at the gaging station near Rockland, Texas, during the period 1904-64 was 49,800 cubic feet per second recorded on May 6, 1944, from a drainage area of 3,637 square miles. The greatest flood on record at this site was in May 1884 when the maximum stage reached was three feet higher than the maximum stage reached May 6, 1944.[10]

Quality. The water of most streams in the Neches River basin is of good chemical quality, although waste water disposal degrades the quality occasionally. Organic degradation occurs in areas of urban growth and should increase with the expanding population; however, it has not been a serious problem in the past.

The chief cause of reduced quality is the disposal of saline water produced during oil field operations. The weighted-average concentrations of dissolved solids in the streams throughout the basin, except for Striker Creek, are less than 250 parts per million. Day-to-day quality varies considerably with rates of streamflow in the Angelina and upper Neches Rivers. In the Neches River near Alto, records show dissolved-solids concentration ranging from 41 to 568 parts per million, and in the Angelina River near Lufkin the range has been from 36 to 530 parts per million. In the Neches River at Evadale, concentrations have been much lower, ranging from only 14 to 222 parts per million. Attoyac Bayou, a major tributary to the Angelina River, and Village Creek, the principle tributary to the lower Neches River, carry water in which the dissolved-solids content averages less than 100 parts per million.[3]

Reservoirs in the basin, except for Striker Creek Reservoir, store water of excellent mineral and organic quality. Typical concentrations of dissolved solids in the principal reservoirs include: Flat Creek Reservoir, 100 parts per million; Lake Palestine, 150 parts per million; Lake Jacksonville, 60 parts per million; and Lake Tyler, 60 parts per million. Water in Sam Rayburn Reservoir, which began filling in 1965, contained less than 150 parts per million dissolved solids in February 1966. In October 1962, the water of Striker Creek Reservoir contained 171 parts per million chloride and 342 parts per million dissolved solids. In March 1964, concentrations had increased to 272 parts per million chloride and 525 parts per million dissolved solids. This demonstrates the effect of the saline water pollution coming from the oil fields.

Surface water reservoirs. Eight major reserovirs presently exist and one is under construction in the Neches River basin. Storage capacities in these reservoirs range from 16,200 to more than 4,000,000 acre-feet. The existing reservoirs are Flat Creek, Tyler, Palestine (Blackburn Crossing), Striker Creek, Jacksonville, Kurth, Sam Rayburn, and Dam B. Mud Creek Reservoir currently is under construction. Figure 3-1 shows the location of these reservoirs.

Sam Rayburn Reservoir, constructed and operated by the Corps of Engineers, is the largest reservoir in the basin. Its projected dependable yield for the year 2020 is 820,000 acre-feet per year.[10] This multi-purpose reservoir provides flood control, hydroelectric

NECHES RIVER BASIN RESERVOIRS

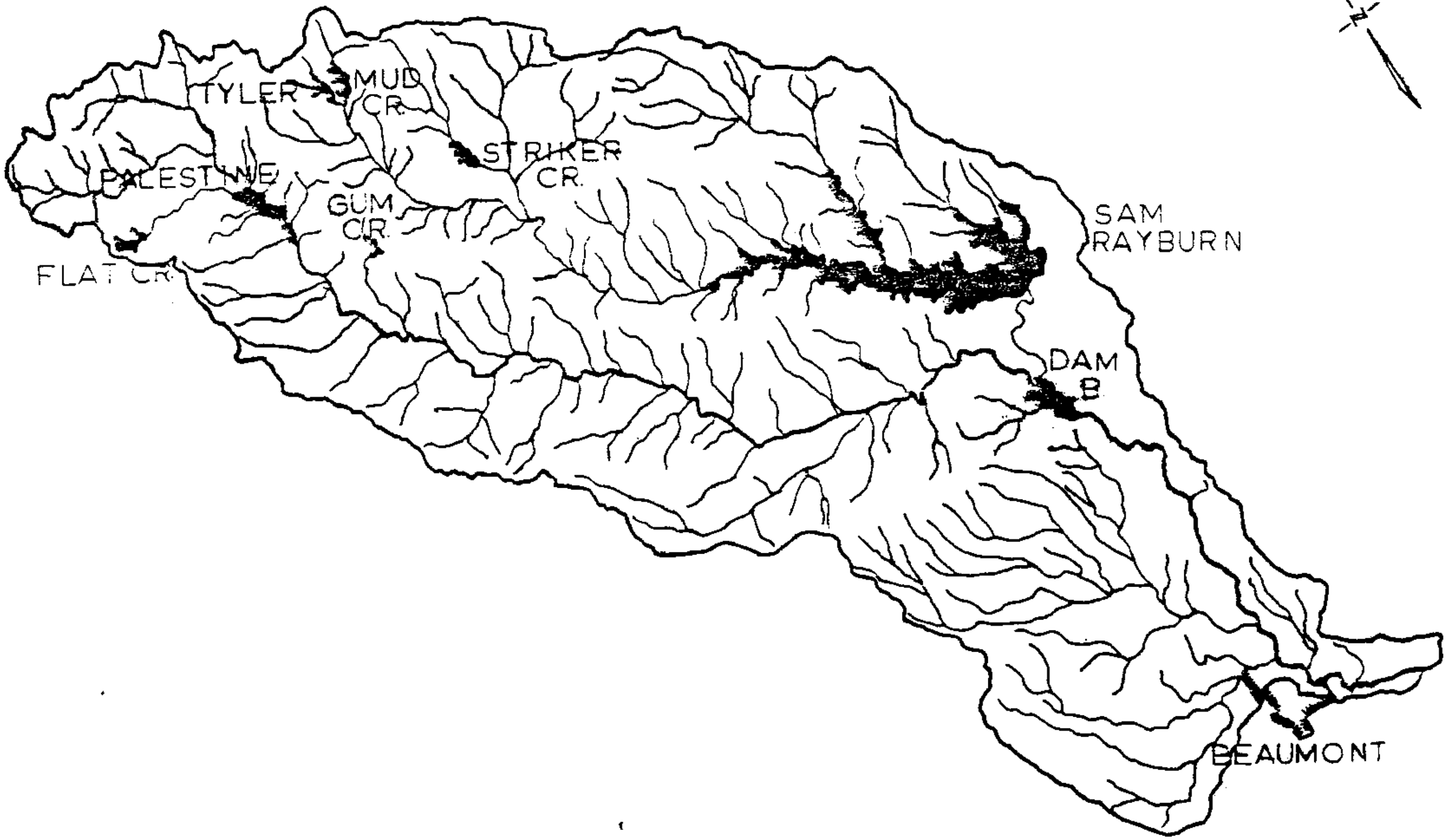


FIGURE 3-1

power generation, conservation storage, and recreation. The Lower Neches Valley Authority has contracted for the conservation storage in the reservoir to provide a firm supply to water users within their service area.

Of the other existing reservoirs in the basin, nearly all are used primarily for municipal and industrial supply by either the Upper Neches River Municipal Water Authority, the Lower Neches Valley Authority, or the neighboring municipalities. The only exception is Kurth Reservoir which was constructed as an off-channel reservoir by the Southland Paper Mills, Inc., and is used only for industrial supply.

Reservoir yield. The yield of all the reservoirs in the basins under consideration was not determined. Blackburn Crossing Reservoir (Lake Palestine) was selected to illustrate the use of the computer programs and to provide a value of reservoir yield for relative comparison.

Currently, the most popular method for yield determination is the reservoir operation study. The gain in reservoir volume from runoff is added on a month-to-month basis to the existing reservoir volume from which losses from evaporation and water demands have been subtracted. The maximum demand that can be sustained, with some conservation storage volume remaining, is the reservoir yield.

Another traditional technique is the Ripple Mass Analysis, which is a graphical procedure based on the principles stated above. There has been much criticism of the reservoir operation procedure and the graphical analysis because there is no attempt to determine the recurrence interval deficiencies in the source of replenishing water.[13, 14] Hydrologists always estimate statistical properties of large hydrologic events when designing reservoirs by determining the recurrence intervals of these events. It is advantageous to apply the same rationale to development of a procedure for a low-flow analysis.

To examine a sample, in this case a period of historic streamflow record, so that properties of the parent population can be estimated, it is desirable for the sample size to be large in comparison to the population. For example, if a thousand years of streamflow recordings were available, an estimate of the low-flow event with a recurrence interval of 100 years could be made with relative confidence. If the period of streamflow record is divided into 50 segments with a duration of 20 years, there is less confidence in the estimate of the event whose recurrence interval is 100 years if only one of these 20 year segments is available. It is easy to see the problems associated with a statistical analysis based on a short period of record.

However, if a traditional approach is used, which considers only the most critical period record as the minimum possible runoff, there is a good chance that this sample will give a value of yield which is too large. There is no way for a water resources planner to know, by examining the record alone, if the period of record contains a very rare event or does not contain an event which should normally occur within that period. There is much more opportunity for exceeding the true yield value because no attempt is made to estimate a critical value.

It would seem favorable to be able to deliver more water than promised rather than to have a slight shortage. This is usually true; however, it is an economic loss to provide more conservation storage than necessary. In addition, it would be profitable to arrange a sale of water for irrigation, power generation, or quality control with the understanding that this water will not be available for a certain contracted percentage of the time. A detailed discussion of this idea is included in Chapter IV.

Computer programs.

Partial duration - independent low flow events program. This program was initially prepared by the Corps of Engineers, Hydrologic Engineering Center, Sacramento, California, to compute data necessary to plot a partial-duration curve. The resulting curve will depict independent low-flow events for specific durations as a function of nonexceedence percentage. Up to 20 durations may be specified per computer run with partial-duration plotting data being determined for each duration. It was necessary to modify the program slightly and an additional program was written to check the results after modification.

Basically, the program accumulates the flow volumes in increasing magnitude for the specified duration and then calculates the plotting positions for the individual events. The following equation was used by Beard [15] to compute the plotting position:

$$P_1 = [1 - (0.5)^{1/N}] \times 100,$$

where P_1 is the plotting position of the rarest event expressed as a percentage and N is the number of years of record.

The plotting position of the least rare event of record is the compliment of P_1. All other plotting positions are determined by linear interpolation between these two values. For partial-duration curves, particularly where there are more events than years, plotting positions larger than 50 percent may be obtained by use of the following equation:

$$P = (2m - 1)/2N,$$

in which m is the order number of the events.

Program input. The basic form for the input data is an eight digit floating point field (F8.0). This form allows 10 items of data per card and is used for all data cards except the flow data cards, which should be punched according to the following Fortran format specification: (2A4, 18, 6F8.0). Two cards per water year are required. A description of the data cards complete with variable names follows.

Data cards. The information below describes the necessary data.

Card 1.

1. M1 is the calendar month of first monthly flow on data cards.
2. MON2 is the starting calendar month of flow record. This can be any calendar month but it is usually the tenth month if data is supplied by water year.
3. IYR1 is the starting calendar year of flow record. For example, if the flow record began in the water year 1940, IYR1 would be 1939.
4. LMON is the last calendar month of flow record.
5. LYR is the last year of flow record. If data are submitted by water year, use the year in which that water year began. In order to insure that all monthly flow data has been read in properly, always check the initial and final data appearing in the data print out table.

6. INUNIT is the units of input flow data, and is determined by the following:

Flow Unit	Supply to INUNIT
Acre-Feet	1
Cubic Feet per Second	2
Inches-Runoff	3.

Card II. DA is the drainage area in square miles.

Card III and III.1. MONDUR (I), where I may vary from one to 20, is the number of months within a desired duration. Two cards are required and a duration of one month is not permitted. These data should be furnished in integer form in an eight column field using right hand orientation.

Flow data cards.

1. ID is the station identification number.
2. IYR is the specific year of record for the monthly data. This may be either the calendar year or the water year.
3. Monthly flow (1) thru (6) on first card, and (7) thru (12) on second card. Both cards contain ID and IYR. It is suggested that the second card should contain the annual flows in columns 65 through 72 so that the second card can be distinguished from the first card.

Body of the program. A listing of the source pro-program follows.

```
$EXECUTE       IBJOB
$IBJOB JHCOOK
$IBFTC MAIN
C      PARTIAL DURATION - INDEPENDENT EVENTS
C      SELECTION OF LOW FLOW PERIODS FROM PERIOD OF RECORD FLOWS
C      BASED ON NO OVERLAP OF DURATIONS
       DIMENSION MONDUR(20),FLOW( 8000),ACCUM( 8000)
  100  FORMAT (10F8.0)
  110  FORMAT (10I8)
  112  ICYCLE=0
       READ (5,110)M1,MON1,IYR1,LMON,LYR,INUNIT
       READ (5,100) DA
       READ (5,110) (MONDUR (N),N=1,20)
       J=(LYR-IYR1)*2+2
       N=1
       K=6
       DO 120 I=1,J
  115  FORMAT (2A4,I8,6F8.0)
       READ (5,115) ID,ID,IYR,(FLOW(N),N=N,K)
       WRITE(6,1)(FLOW(N),N=N,K)
    1  FORMAT(1H0,30X,6F8.0)
       N=K+1
  120  K=K+6
       NP=K-6
       IF(MON1-M1)122,124,124
  122  I1=12+MON1-M1
       GO TO 125
  124  I1=MON1-M1
  125  IF(LMON-M1)126,127,127
  126  I2=M1-LMON-1
       GO TO 128
  127  I2=LMON-12+M1-1
  128  XNP=NP-I1-I2
       NP=NP-I2
```

```
      YEARS=XNP/12.0
      MONTHS=XNP-(YEARS*12.0)
      IYEARS=YEARS
  130 ICYCLE=ICYCLE+1
      IF(ICYCLE-20)140,140,400
  140 MD=MONDUR(ICYCLE)
      IF(MD)400,400,150
C     COMPUTE BEARDS PLOTTING POSITIONS FOR SMALLEST AND LARGEST EVENTS
  150 XMD=MD
      EFFYRS=(XNP-(XMD-1.))/12.0
      P2=(0.5**(1.0/EFFYRS))*100.0
      P1=100.0-P2
  160 FORMAT (1X,21HYEARS (RECORD) MONTHS,5X,18HDURATION IN MONTHS)
      WRITE (6,160)
  170 FORMAT (I5,10X,I5,15X,I3)
      WRITE (6,170) IYEARS,MONTHS,MD
  172 FORMAT (/1X,15HEFFECTIVE YEARS,11X,21HDRAINAGE AREA (SQ MI))
      WRITE (6,172)
  174 FORMAT (F11.2,16X,F10.2)
      WRITE (6,174) EFFYRS,DA
  180 FORMAT (/3X,6HNUMBER,3X,6HVOLUME,2X,5HDEPTH,6X,4HRATE,2X,6HEXCEED,
     12X,5HRECUR,2X,6HENDING/13X,5HAC-FT,1X,6HINCHES,7X,3HCFS,3X,4HFREQ,
     24X,3HING,4X,4HDATE)
      WRITE (6,180)
C     ACCUMULATE FLOWS FOR GIVEN DURATION
      ACCUM(1)=FLOW(1)
      DO 220 N=2,MD
  220 ACCUM(N)=ACCUM(N-1)+FLOW(N)
      N=MD+1
      DO 230 N=N,NP
      J=N-MD
  230 ACCUM(N)=ACCUM(N-1)-FLOW(J)+FLOW(N)
      T=MD
      IF(INUNIT-2)231,233,235
```

```
C     CONVERT AC-FT TO AVERAGE CFS
  231 DO 232 N=MD,NP
  232 ACCUM(N)=ACCUM(N)*.016598/T
      GO TO 238
C     CONVERT CFS TO AVERAGE CFS
  233 DO 234 N=MD,NP
  234 ACCUM(N)=ACCUM(N)/T
      GO TO 238
C     CONVERT INCHES RUNOFF TO AVERAGE CFS
  235 DO 236 N=MD,NP
  236 ACCUM(N)=ACCUM(N)*DA*.88523/T
  238 NLFP=NP/MD
      IF(NLFP-((NP/12)/2))250,250,240
  240 NLFP=((NP/12)/2) +1
C     DETERMINE FLOW PERIODS IN ASCENDING ORDER AND PRINT
  250 DO 380 I=1,NLFP
      LVP=I1+MD
      VOLUME=ACCUM(LVP)
      J=LVP+1
      DO 270 N=J,NP
      IF(ACCUM(N)-VOLUME)260,270,270
  260 VOLUME=ACCUM(N)
      LVP=N
  270 CONTINUE
      IF(VOLUME-9999999.)275,274,274
  272 FORMAT(29H INDEPENDENT EVENTS EXHAUSTED)
  274 WRITE (6,272)
      GO TO 390
C     ASSIGN LARGE NUMBERS TO ADJACENT ACCUMULATIVE FLOW VOLUMES
  275 N=LVP-MD+1
      J=LVP+MD-1
      IF(J-NP)290,290,280
  280 J=NP
  290 DO 300 N=N,J
  300 ACCUM(N)=9999999.
```

```
C     COMPUTE BEARDS PLOTTING POSITION (FREQUENCY)
      IF(I-1)310,310,320
  310 BPP=P1
      GO TO 330
  320 EVENT=I
      BPP=P2-(((EFFYRS-EVENT)/(EFFYRS-1.))*(P2-P1))
      IF(BPP-50.0)330,330,390
C     COMPUTE DATE OF EVENT
  330 LVP=LVP+M1-1
      IF(LVP-12)340,340,350
  340 IYEAR=IYR1
      MOE=LVP
      GO TO 370
  350 XLVP=LVP
      YEARS=(XLVP/12.0)-.001
      J=YEARS
      IYEAR=J+IYR1
      MOE=LVP-J*12
  370 RATE=VOLUME
      VOL=RATE *60.373*T
      DEPTH=(VOL*.01875)/DA
      RI=100./BPP
  375 FORMAT (I6,F12.0,F7.2,F10.1,F8.2,F7.1,I4,I5)
      WRITE (6,375) I,VOL,DEPTH,RATE,BPP,RI,MOE,IYEAR
  380 CONTINUE
  385 FORMAT(1H0,20X,31HEND OF OUTPUT FOR THIS DURATION )
  390 WRITE (6,385)
      GO TO 130
  400 GO TO 112
      END
```

Program output. In order to demonstrate the output of this program, the streamflow of the Neches River at Rockland, Texas, was used as input data. Continuous streamflow records were available from the U. S. Geological Survey for the period 1905 to 1964; however, the water years 1962 thru 1964 were discarded because impoundment by Lake Palestine altered the natural runoff. Thirteen durations were selected beginning with one year and increasing in six-month increments to a final duration of seven years.

A listing of input data and a sample program output follows.

Input Data

```
$DATA
   10     10   1905      9   1960      2
 3637
   12     18     24     30     36     42     48     54
   60     72     78     84
8 335   1905     47     27    743   1520   3290   5620
8 335   1905   7620  13800   3800   6660   2440    202
8 335   1906    189   1870   2630   6680   3280   2480
8 335   1906   2160   2120   1140   1240    855    402
8 335   1907   1340    327   1150   2960   1340   1800
8 335   1907   1090   9950   5580    470    212    293
8 335   1908    422   7550   8750   4340   9030   5190
8 335   1908   4650  10300   3130    427    272    585
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
8 335   1960    494    974   2280   4458   5022   5149
8 335   1960   1543   1272    886    815    448    219
8 335   1961    538   1466   8756  12310   7206   7131
8 335   1961   5391    992    836   2069    385   1423
CARD COUNT = 23
```

Program Output

EFFECTIVE YEARS 54.08

DRAINAGE AREA (SQ MI) 3637.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR ING	ENDING DATE	
1	702017.	3.62	484.5	1.27	78.5	10	1919
2	280080.	4.02	538.4	3.11	32.2	4	1958
3	1045298.	5.39	721.4	4.95	20.2	3	1912
4	1276466.	6.58	881.0	6.78	14.7	11	1953
5	1756492.	9.06	1212.2	8.62	11.6	5	1941
6	1760175.	9.07	1214.8	10.45	9.6	4	1930
7	1770619.	9.13	1222.0	12.29	8.1	12	1938
8	2384552.	12.29	1645.7	14.12	7.1	4	1915
9	2432368.	12.54	1678.7	15.96	6.3	7	1950
10	2518882.	12.99	1738.4	17.80	5.6	3	1956
11	2529931.	13.04	1746.0	19.63	5.1	3	1927
12	2549914.	13.15	1759.8	21.47	4.7	12	1944
13	2722641.	14.04	1879.0	23.30	4.3	3	1935
14	2793761.	14.40	1928.1	25.14	4.0	9	1961
15	2843266.	14.66	1962.3	26.98	3.7	11	1932
16	3107217.	16.02	2144.5	28.81	3.5	8	1908
17	3423330.	17.65	2362.6	30.65	3.3	2	1923
18	3472293.	17.90	2396.4	32.48	3.1	10	1917
19	6209725.	32.01	4285.7	34.32	2.9	2	1925
20	6656365.	34.32	4593.9	36.15	2.8	4	1948

INDEPENDENT EVENTS EXHAUSTED

END OF OUTPUT FOR THIS DURATION

YEARS (RECORD)MONTHS 56 -0

DURATION IN MONTHS 30

EFFECTIVE YEARS 53.58

DRAINAGE AREA (SQ MI) 3637.00

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR ING	ENDING DATE	
1	935540.	4.82	516.5	1.29	77.8	12	1919
2	1282202.	6.61	707.9	3.14	31.9	1	1912
3	1355374.	6.99	748.3	4.99	20.0	12	1953
4	1409408.	7.27	778.2	6.84	14.6	12	1953

continued

Program Output (Cont.)

NUMBER	VOLUME AC-FT	DEPTH INCHES	RATE CFS	EXCEED FREQ	RECUR ING	ENDING DATE	
5	2201018.	11.35	1215.2	8.70	11.5	12	1938
6	2210437.	11.40	1220.4	10.55	9.5	10	1941
7	2689013.	13.86	1484.7	12.40	8.1	11	1914
8	2693240.	13.88	1487.0	14.26	7.0	12	1930
9	2912092.	15.01	1607.8	16.11	6.2	12	1927
10	2941674.	15.17	1624.2	17.96	5.6	12	1950
11	3074374.	15.85	1697.4	19.81	5.0	11	1935
12	3519142.	18.14	1943.0	21.67	4.6	9	1961
13	3656430.	18.85	2018.8	23.52	4.3	12	1944
14	4385012.	22.61	2421.1	25.37	3.9	11	1908
15	5135388.	26.47	2835.4	27.23	3.7	1	1923
16	5273038.	27.18	2911.4	29.08	3.4	6	1917
17	8008720.	41.29	4421.8	30.93	3.2	11	1947

INDEPENDENT EVENTS EXHAUSTED.

The sample output is for durations of 24 and 30 months. Similar output is available for the other specified durations. As stated previously, the primary purpose of this program is to compute the information needed to plot a relationship between low-flow volume and nonexceedence percentage. Figure 3-2 shows the derived relationship for this particular example.

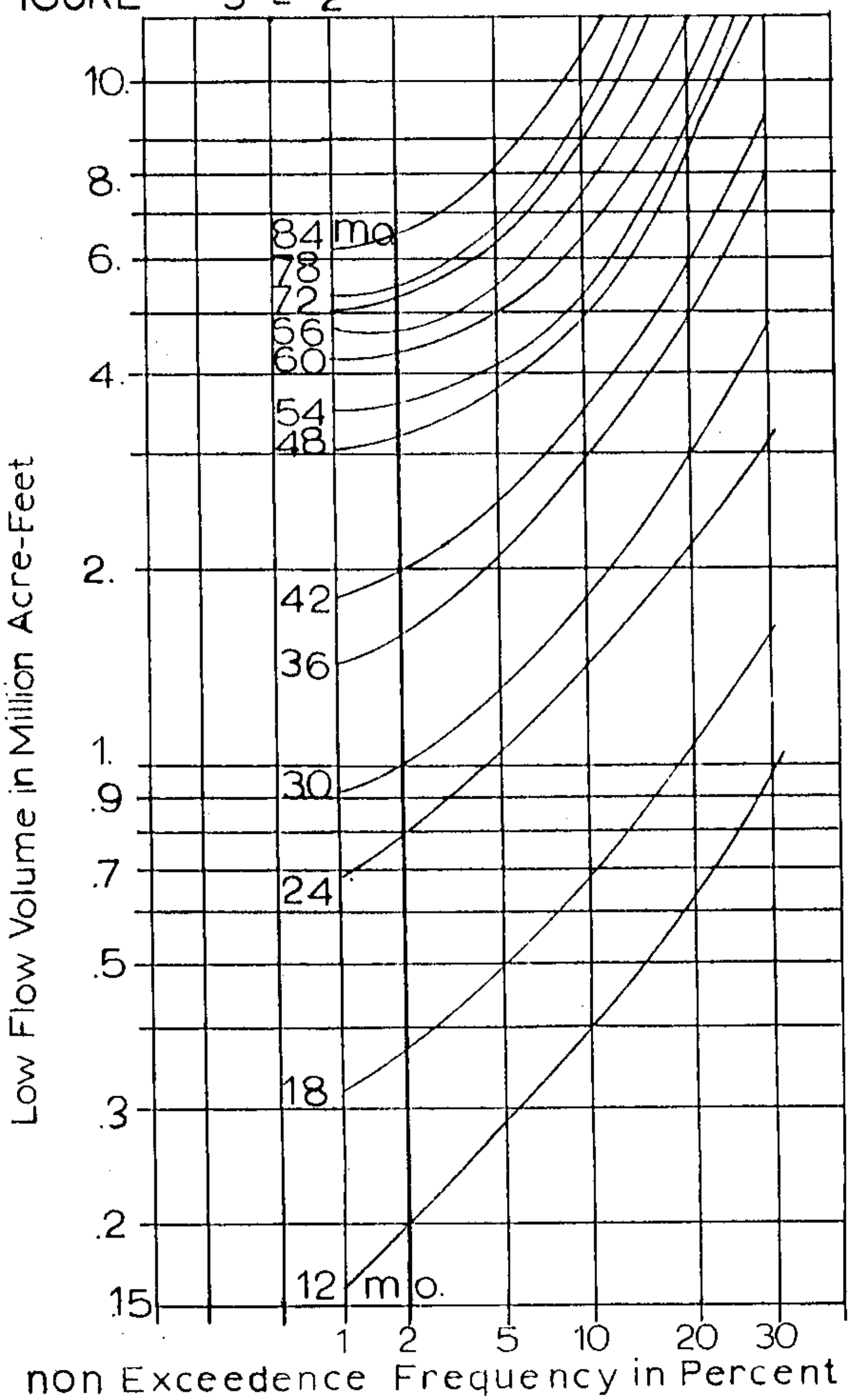
Reservoir yield program. The computer program discussed in the following paragraphs is used to determine reservoir yield. This program requires the relationship obtained from the low-flow series analysis program.

Gooch [14] has proposed a simplified method for determination of surface water reservoir yield which has many advantages over the traditional approach previously discussed. The main features of the proposed method are summarized in the following discussion. The primary factors associated with the severity of drought are: duration of drought, overall runoff during drought period, and net reservoir surface evaporation. The first relationship used in the original procedure was obtained by enveloping the minimum recorded runoff for specific durations. It was observed that the seasonal nature of surface runoff resulted in a more severe yield condition for fractional 12-month periods, i.e., 18 months, 30 months, 42 months, etc. Characteristically, an increased length of historic records produced lower minimum runoff values and shifted the resulting curve downward in relation to the plotted curve of shorter duration.

LOW FLOW EVENTS NECHES RIVER

at Rockland, Texas

FIGURE 3 - 2



The possibility of a low-flow event occurring that is more stringent than indicated by the enveloping curve is recognized. Because this possibility always exists, the determination of the statistical dependability would enhance the resulting answer.

The second relationship used in this procedure was obtained by enveloping the maximum net evaporation vs. duration data, as shown in Figure 3-3. Figure 3-3 was developed from evaporation data for the Blackburn Crossing Reservoir near Palestine Texas. These data were published by the Texas Board of Water Engineers, Bulletin 6006, Monthly Evaporation Rates for Texas - 1940 through 1957.

The use of the design drought concept makes the month-by-month reservoir operation study unnecessary. To determine the yield by means of a single-interval estimate covering the entire critical drought period, the following expression was used:

$$Y = \frac{C}{N} + R - L,$$

where

Y = yield in acre-feet/year,

C = reservoir capacity, in acre-feet,

N = drought duration in years,

R = minimum probable runoff for the corresponding duration in acre-feet/year, and

L = average reservoir loss in acre-feet/year.

Experience has shown that more consistent results are obtained by the following modification:

$$Y = .97 \left[\left(\frac{C}{N} + R \right) - (E \times A) \right],$$

where E is the average rate of net reservoir surface evaporation in feet per year and A is the average of the reservoir areas at the beginning and end of the critical period. This formula was compared with the monthly-increment method for 25 examples. The answers ranged from 10 percent less to four percent more with an overall average of one percent lower.

The Corps of Engineers, Hydrologic Engineering Center, has modified the Gooch method. The main modification is the replacement of the minimum observed runoff vs. duration curve with a relationship of runoff vs. nonexceedence percentage. Figure 3-3 shows this relationship for the streamflow at Blackburn Crossing Reservoir and was developed from the output of the low-flow series computer program. The information furnished by the computer output is minimum runoff vs. the exceedence percentage for each required duration. As suggested by Gooch, this modification gives more meaning to a value of yield.

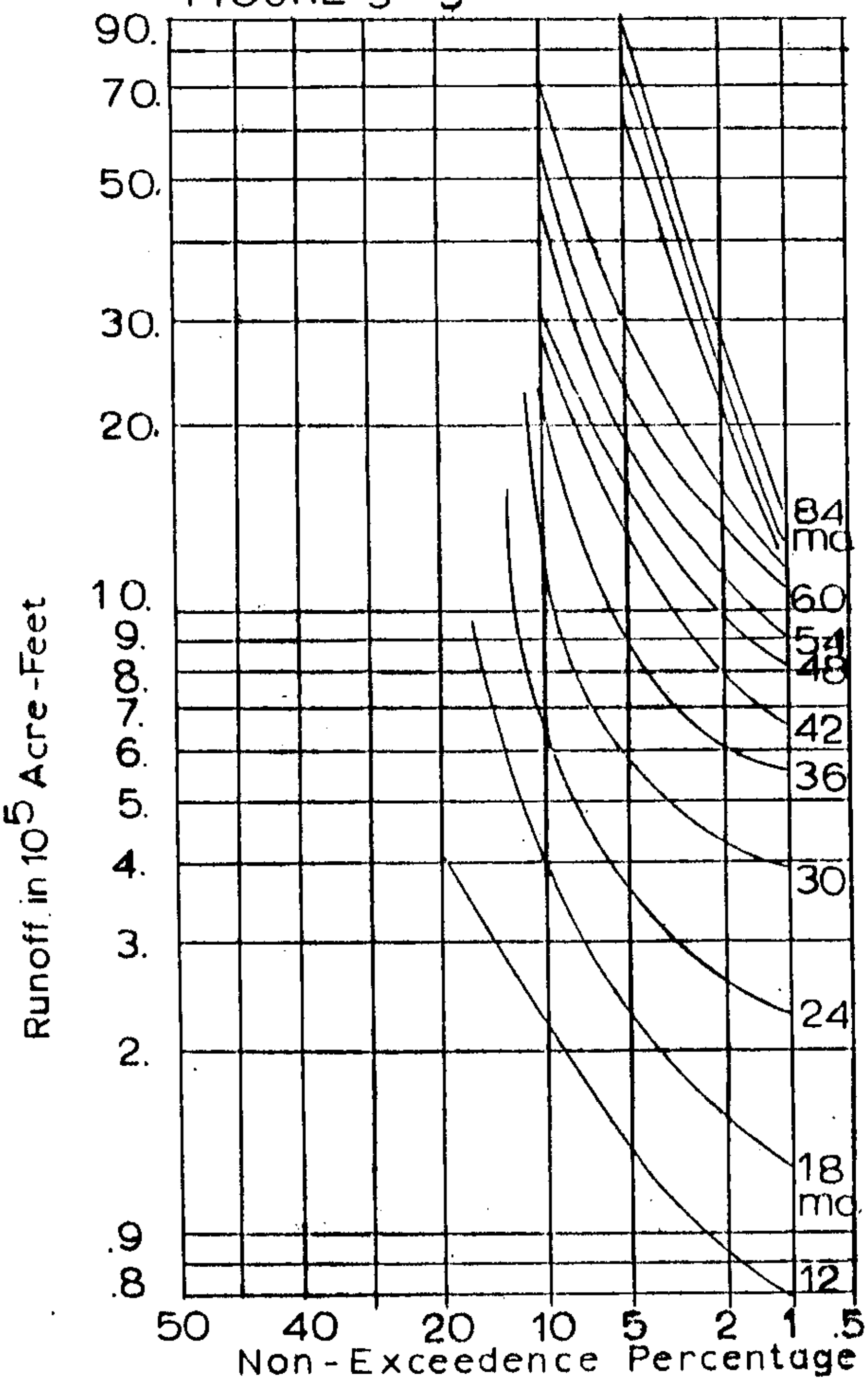
Another suggestion was the use of a best-fit curve for maximum observed net evaporation to replace the enveloping curve (Figure 3-4). However, this suggestion would give an increased yield value and was not used in the following example.

This example is for determination of the yield of Blackburn Crossing Reservoir (Lake Palestine). The reservoir is located on

LOW FLOW EVENTS NECHES RIVER

at Blackburn Crossing, Texas

FIGURE 3 - 3



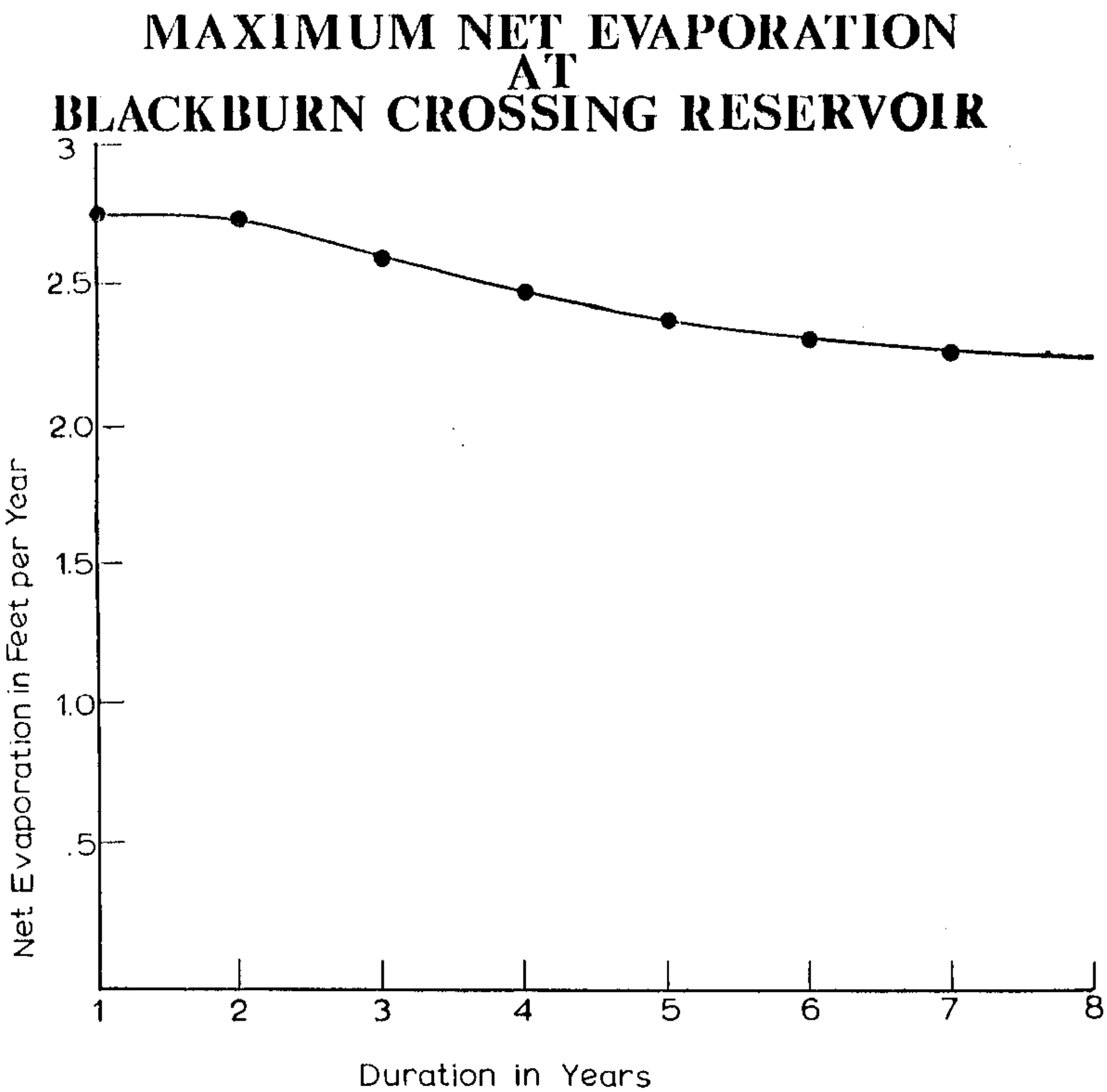

MAXIMUM NET EVAPORATION
AT
BLACKBURN CROSSING RESERVOIR
3
2.5
2.0
1.5
1.0
.5
Net Evaporation in Feet per Year
1
2
3
4
5
6
7
8
Duration in Years

FIGURE 3-4

the main stem of the Neches River in the northern part of the basin. Blackburn Crossing Dam is approximately 10 miles upstream from the Neches, Texas, gaging station, and the flow at the dam site was obtained by adjusting the flow at the Neches gage by the drainage area ratio (847/1156). Twenty-two years of streamflow recordings were available. This is normally an extremely short period of record; however, this period includes the 1951 to 1957 drought which is considered the most severe ever recorded during the 60-year history of stream gaging in that basin. Also, in 1960, the Bureau of Reclamation published the runoff for the streams in the Neches River basin and concluded that the drought of 1951-1957 was the most severe since at least 1880. Because of these findings, the exceedence percentage as normally computed would be much too high and would indicate that the critical drought should recur about every 20 years. In order to avoid this, a period of record of 60 years was used to compute the exceedence percentage in the low-flow program.

<u>Input data</u>. The required input information is shown below. The Blackburn Crossing input is shown in parenthesis.

I. Three title cards

II. Specification Card. (1018)

1. NDUR - number of durations. Ex. (13)
2. NCAP - number of different storages to be used with same data. Ex. (1)
3. NRI - number of frequencies. Ex. (2).

III. Duration Cards, (10F8.0)

DUR - durations in months. (NDUR values). Ex. (12, 18, 24, ..., 84)

IV. Evaporation Cards. (10F8.0)

EVAP - evaporation in feet per year corresponding to the durations (NDUR values). Ex. (2.74, 2.73, 2.72, ..., 2.26).

V. Frequency Cards. (10F8.0)

VRI - exceedence frequencies in percent. (NRI values) Ex. (1, 5)

VI. Runoff Cards. (10F8.0)

RNOFF - runoff in acre-feet. (NDUR cards with NRI values on each card.) Ex. (79000, 134000,/130000, 230000,/..., 1450000, 9000000).

VII. Reservoir Data Card. (10F8.0)

NCAP cards containing:

1. CAPA - capacity at top of conservation pool in acre-feet. Ex. (411,840).
2. AREAA - area of above capacity, in acres. Ex. (25,562).
3. CAPB - capacity at top of sediment pool, in acre-feet. Ex. (18,500).
4. AREAB - area at top of sediment pool, in acres. Ex. (2,590).
5. CONST - Gooch's correction factor. Ex. (.97).

<u>Body of the program.</u> A listing of the source program and input data for the example follows.

```
C     PROGRAM  23-J2-L250  SIMPLIFIED RESERVOIR YIELD
      DIMENSION DUR(20),EVAP(20),RNOFF(20,20),CAP(10),VRI(20),
     1YLD(10,20),YIELD(20)
      WRITE(6,999)
  999 FORMAT(1H1)
  100 DO 115 K=1,3
      READ(5,110)(DUR(I),I=1,20)
      WRITE(6,110)(DUR(I),I=1,20)
  110 FORMAT (20A4)
  115 CONTINUE
      READ(5,120) NDUR,NCAP,NRI
  120 FORMAT (10I8)
      READ(5,136)(DUR(I),I=1,NDUR)
      READ(5,136)(EVAP(I),I=1,NDUR)
      READ(5,136)(VRI(I),I=1,NRI)
      DO 135 I=1,NDUR
      READ(5,136)(RNOFF(I,N),N=1,NRI)
  137 FORMAT(1X,F8.0,5X,8F13.0)
  135 CONTINUE
      DO 340 K=1, NCAP
      READ(5,136) CAPA,AREAA,CAPB,AREAB,CONST
  136 FORMAT (10F8.0)
C            AVERAGE AREA
      AVAR = (AREAA + AREAB) * 0.5
C            NET CAPACITY
      C = CAPA - CAPB
      CAP(K)=C
      WRITE(6,140)CAPA,AREAA,CAPB,AREAB,C,AVAR
  140 FORMAT (/4X,44H CAPACITY AT TOP OF CONSERVATION POOL, AC-FT 4X,F9.
     10/4X,40H AREA AT TOP OF CONSERVATION POOL, ACRES 8X,F8.0/4X,36H CA
     2PACITY OF SEDIMENT RESERVE, AC-FT 12X,F9.0/4X,39H AREA AT TOP OF S
     3EDIMENT RESERVE, ACRES9X,F8.0/4X,37H NET CONSERVATION STORAGE USED
     4, AC-FT,11X,F9.0/4X,38H AVERAGE RESERVOIR SURFACE AREA, ACRES 10X,
     5F8.0)
      N = 1
```

```
150 WRITE(6,160)VRI(N)
160 FORMAT (/4X,27H EXCEEDENCE FREQ IN PERCENT 9X,F8.1 //4X,26H DROUTH
   1   AVG NET       AVG/4X,36H PERIOD     EVAP      RUNOFF    YIELD/5X,
   236H (MOS)    (FT/YR)    (AF/YR)    (AF/YR)/)
    DO 200 I=1,NDUR
    TEMP = DUR(I)/12.
    IF (RNOFF(I,N)) 190,190,170
170 XTEMP = RNOFF(I,N)/TEMP
    YIELD(I) = CONST*(C/TEMP+XTEMP-EVAP(I)*AVAR)
    WRITE(6,139)DUR(I),EVAP(I),XTEMP,YIELD(I)
180 FORMAT (I10,F10.2,2I10)
139 FORMAT(1H0,F8.0,4X,F9.3,1X,F10.0,1X,F10.0)
    GO TO 200
190 YIELD(I) = 0.
200 CONTINUE
    II=1
    Y=YIELD(1)
    DO 220  I=2,NDUR
    IF(YIELD(I))220,220,205
205 IF(Y)210,210,206
206 IF (YIELD(I)-Y)210,210,220
210 Y=YIELD(I)
    II=I
220 CONTINUE
    IF (II-1)280,280,230
230 IF(II-NDUR)240,280,280
240 AA=DUR(II-1)
    BB=YIELD(II-1)
    CC=DUR(II)
    DD=YIELD(II)
    EE=DUR(II+1)
    FF=YIELD(II+1)
    DET=(CC-EE)/AA+(AA-CC)/EE+(EE-AA)/CC
    G1=((BB-FF)*CC+(DD-BB)*EE+(FF-DD)*AA)/DET
    G2=((DD-FF)/AA+(BB-DD)/EE+(FF-BB)/CC)/DET
```

```
      G3=BB-G1/AA-G2*AA
      X=SQRT (G1/G2)
      Y=G1/X+G2*X+G3
      YLD(K,N)=Y
      GO TO 290
  280 Y=YIELD(II)
      X=DUR(II)
  290 WRITE(6,300)X,Y
  300 FORMAT(14H MINIMUM YIELD/ F10.2,20X,F10.0)
  310 N = N+1
      IF (N-NRI)150,150,340
  340 CONTINUE
      WRITE(6,320)(VRI(I),I=1,NRI)
  320 FORMAT (//42H SUMMARY TABLE - MINIMUM YIELD IN AC-FT/YR/10X,39H --
     1-EXCEEDENCE FREQUENCY IN PERCENT ---/8H STORAGE, 6X,8F13.1)
      DO 350 I=1,NCAP
  350 WRITE(6,137)CAP(I),(YLD(I,N),N=1,NRI)
      GO TO 100
      END
$DATA
      JOHN H COOK
        BLACKBURN  CROSSING
     STAGE  THREE  DEVELOPMENT
      13        1       2
      12       18      24      30      36      42      48      54      60      66
      72       78      84
    2.74     2.73    2.72    2.65    2.58    2.52    2.46    2.41    2.36    2.33
    2.30     2.27    2.26
       1        5
   79000   134000
  130000   230000
  225000   360000
  390000   600000
  550000   900000
```

650000	1320000			
810000	1600000			
900000	1900000			
1050000	2250000			
1180000	3000000			
1200000	6400000			
1300000	7500000			
1450000	9000000			
411840	25562	18500	2590	.97

Program output. A sample of the program output is attached for an exceedence frequency of five percent. At the end of this output is a summary table showing the minimum yield values for all the specified frequencies.

EXCEEDENCE FREQ IN PERCENT 5.0

DROUTH PERIOD (MOS)	AVG NET EVAP (FT/YR)	AVG RUNOFF (AF/YR)	YIELD (AF/YR)
12.	2.740	134000.	474109.
18.	2.730	153333.	365819.
24.	2.720	180000.	328232.
30.	2.650	240000.	349234.
36.	2.580	300000.	382953.
42.	2.520	377143.	440433.
48.	2.460	400000.	449797.
54.	2.410	422222.	461437.
60.	2.360	450000.	480585.
66.	2.330	545455.	566649.
72.	2.300	1066667.	1066853.
78.	2.270	1153846.	1146935.
84.	2.260	1285714.	1270791.

MINIMUM YIELD

24.11 328223.

SUMMARY TABLE - MINIMUM YIELD IN AC-FT/YR

	---EXCEEDENCE FREQUENCY IN PERCENT---	
STORAGE	1.0	5.0
393340	221686.	328223.

The results of the reservoir yield analysis show that, on the average, once in 100 years there will be less than 221,686 acre-feet per year available from the stage-three development of Blackburn Crossing. Also, note that if a user would not be seriously damaged by periodic shortages, there is a much greater amount of water available on a five percent nonexceedence frequency.

Red River Basin

General description. The Red River, which is one of the principle tributaries of the Mississippi River, drains approximately 93,000 square miles, extending from eastern New Mexico across northern Texas, southern Oklahoma, southern Arkansas, and northern Louisiana. The Texas portion of the basin is bounded on the north by the Canadian River basin and on the south from west to east by the Brazos, Trinity, and Sulphur River basins.

The headwater stream in the Red River basin, Tierra Blanca Creek, rises in the high plains of eastern New Mexico (40 miles west of the New Mexico-Texas boundary) at an elevation (mean sea level datum) of about 4,800 feet. It flows easterly across the Texas High Plains and becomes the Prairie Dog Town Fork Red River in eastern Randall County, Texas. This stream then flows easterly to become the Red River and form the Texas-Oklahoma boundary at the southeast corner of the Texas Panhandle. The streambed elevation at this point is about 1,550 feet. The stream continues easterly as the Red River and as the Texas-Oklahoma and Texas-Arkansas boundaries. At the northeast corner of Texas, the elevation of the streambed of the Red River is about 250 feet. The Texas portion of the basin has a length of 610 miles, a maximum width of 200 miles, and a total drainage area of approximately 31,000 square miles. This area includes the Texas portion of the basin drained by tributaries rising in Texas which flow into other states before entering the main stem. That portion of the basin lying above the Caprock Escarpment, nearly 5,000 square miles, is a part of the High Plains Area and contributed virtually no runoff to the Red River. The Sulphur River and Cypress Creek basins in Texas, which become part of the Red River drainage in Arkansas and Louisiana, usually are considered as separate basins. Based on this delineation, the Texas portion of the Red River contains 24,463 square miles, or 9.3 percent of the area of Texas. Of this total area 5,272 square miles are considered noncontributing to the Red River or its tributaries.[16] The western portion of the contributing area is characterized by the rough eroded areas of the western prairies that gradually change downstream to brushy rolling terrain. The eastern portion of the basin is a low hilly terrain.

The Red River, upstream from the point where it leaves Texas at the northeast corner of the State, has many major tributaries from both Texas and Oklahoma. The Washita River, Sweetwater Creek, and the North and Salt Forks of the Red River rise in the eastern half of the Texas Panhandle and flow into Oklahoma before joining the Red River from the north. The major all-Texas tributaries to the Red River are the Pease, Wichita, and Little Wichita Rivers. The Texas drainage to the Red River between Little Wichita River and the northeast corner of the state is narrow and is drained by numerous small streams.

The Red River and its upstream tributaries rise in the Great Plains geographical province, entering the Central Lowland province near the eastern edge of the Texas Panhandle. The river enters the Coastal Plain province at the western boundary of Grayson County, Texas.[16]

Rainfall and evaporation. The average annual rainfall for the entire Red River basin in Texas is 33 inches, and the average annual net lake-surface evaporation loss is 35 inches. The variability of rainfall and evaporation is extreme since the basin extends from New Mexico to Louisiana. The extremes range from 17 to 49 inches for rainfall (west to east), and from eight to 62 inches for net evaporation (east to west). Rainfall and evaporation can best be considered by dividing the basin into western and eastern sectors, using Lake Texoma as a dividing point. In the area west of Lake Texoma, the average annual rainfall is 22 inches, and the average annual net lake-surface evaporation loss is 58 inches. The rainfall increases from 17 inches at the western edge to 28 inches at the eastern edge while the evaporation loss decreases from 62 inches at the western edge to 43 inches at the eastern edge.

In the eastern portion, the average annual rainfall is 36 inches, and the average annual net lake-surface evaporation loss is 32 inches. The rainfall increases from 23 inches at the western edge to 49 inches at the eastern edge while the evaporation loss decreases from 56 inches at the western edge to eight inches at the eastern edge.[3, 16]

Ground water. Approximately 120,000 acre-feet of ground water is available as a perennial yield from major and minor aquifers in the Red River basin in Texas. In addition, about 60 million acre-feet of water is stored within the basin in the Ogallala Formation. Major aquifers in the basin are the Ogallala, the Alluvium (Seymour Formation), and the Trinity Group. Minor aquifers in the basin are the Woodbine and the Blaine, which extend through Collingsworth, Childress, Hardeman, Cottle, and King Counties. Less important water-bearing formations can supply small quantities of water for domestic and livestock uses and, in some areas, furnish sufficient supplies for limited municipal, industrial, and irrigation usage.[3, 5, 16]

Ogallala aquifer. The Ogallala Formation is located on the High Plains in the upper end of the basin. Yields from the large-capacity wells in this formation average about 550 gallons per minute with some reaching 1,100.

Recharge to the Ogallala is insignificant compared to the present pumpage, which is principally for irrigation. An estimated 47 million of the 60 million acre-feet of water stored in the Ogallala in the basin is economically recoverable.

The aquifer yields water that is suitable for irrigation and usually acceptable for municipal and industrial water.

Alluvium (Seymour Formation) aquifer. Yields of large-capacity wells average about 300 gallons per minute, with some attaining 1,300. Recharge to the Alluvium is by direct infiltration of precipitation. Based on one inch of annual recharge, or approximately five percent of the rainfall, the perennial yield of the aquifer is about 63,000 acre-feet per year.

In general, from a quality standpoint, the water is suitable for most purposes, but is primarily used for irrigation.

Blaine aquifer. The Blaine aquifer is found in Collingsworth, Childress, Hardeman, Cottle, and King Counties. Yields of large-capacity wells average about 400 gallons per minute, with some reaching 1,500.

Approximately 40,000 acre-feet of water is available annually from the Blaine aquifer.

Water from the Blaine aquifer is used almost entirely for irrigation, as it is generally too highly mineralized for industrial and municipal supplies. Dissolved solids generally range from 2,000 to 5,000 parts per million and sulphate content from 1,000 to 2,000 parts per million. The water is very hard and in some areas contains excessive amounts of fluoride (greater than eight parts per million).

Trinity group aquifer. The Trinity Group aquifer extends from eastern Montague County to Red River County. Yields of large-capacity wells in the Trinity Group aquifer average about 325 gallons per minute, and some reach 700.

Approximately 3,700 acre-feet of water is available annually from the Trinity Group aquifer in the basin.

In general, the water contains less than 1,000 parts per million dissolved solids, and is suitable for municipal, irrigation, and most industrial uses.

Woodbine aquifer. The Woodbine aquifer extends from western Grayson County to western Lamar County. Yields from the large-capacity wells average about 175 gallons per minute, with some reaching 700.

Approximately 14,000 acre-feet of water is available annually from the Woodbine aquifer in the Red River basin. Generally the water is suitable for municipal, irrigation, and many industrial uses.[3, 16]

Surface water.

Runoff. Although the Red River basin drainage begins 40 miles west of the New Mexico-Texas line, the contributing area and runoff are small until the various branches of the stream leave the eastern edge of the Caprock about 150 miles downstream from the originating point.

The average annual runoff per square mile in that part of the Red River basin in Texas increases more or less uniformly west to east, from about 50 acre-feet at the 100th meridian to more than 800 acre-feet at the northeast corner of the state. This unit runoff varies widely from year to year.

The average annual runoff for the 26-year period, 1939-64, at the Red River gaging station near Terral, Oklahoma, (U.S. Highway 81 crossing) was 1,762,000 acre-feet. The maximum year was 5,154,000 acre-feet in 1941, and the minimum year was 378,800 acre-feet in 1953. The contributing drainage area at the Terral station is 22,787 square miles. The flow at this station is affected by conservation storage of eight major reservoirs in Texas with total storage of 666,000 acre-feet and by four reservoirs in Oklahoma with total storage of 309,000 acre-feet.

The average annual runoff for the 28-year period, 1937-64, which is near the northeast corner of Texas, was 8,818,000 acre-feet. The maximum year was 21,370,000 acre-feet in 1957, and the minimum year was 2,591,000 acre-feet in 1956. The contributing drainage at the Index station is 42,094 square miles. Flow at this station is affected by storage in Lake Texoma on the Red River near Denison, Texas, where the contributing drainage area is 33,783 square miles, the conservation storage is 1,684,100 acre-feet, the flood-control storage is 2,694,000 acre-feet, and the total storage is 5,392,900 acre-feet. In addition to Lake Texoma, the flow at Index is affected by conservation in other major reservoirs on tributaries to the Red River.[5, 11, 16]

Floods. Large floods occur infrequently in the upper branches and tributaries of the Red River due to the light annual rainfall; however, extreme floods that produce comparatively high unit discharge rates have been observed. The floods are generally characterized by rapid rise and fall and high velocity.

Proceeding from west to east in the Red River basin both the physiography and climate change, which in turn affects the characteristics of floods. In northeast Texas, the streams tributary to the Red River have wide, timbered flood plains which sustain the more numerous floods longer, and produce smaller unit maximum discharges.

The maximum discharge at the gaging station on the Red River near Terral, Oklahoma, contributing drainage area 22,787 square miles, recorded during the 26-year period, 1939-64, was 197,000 cubic feet per second. This occurred on June 8, 1941. The maximum discharge at the gaging station at Index, Arkansas, contributing drainage area 42,094 square miles, during the 28-year period 1937-64 was 297,000 cubic feet per second. This flood was recorded on February 23, 1938. Since October 1943, runoff and flood flows at the Index station have been affected by storage in Lake Texoma. The maximum discharge at the Index station since the completion of Lake Texoma was 154,000 cubic feet per second, observed on June 8, 1957.[11, 16]

Water quality. The chemical quality of the water in streams varies considerably throughout the Red River basin in Texas. The major problem in regard to water quality is the high mineral pollution load. The concentration of dissolved solids has averaged as much as 35,700 parts per million in Childress County and 5,550 parts per million in Wichita County.

In the eastern, high-rainfall section, tributaries carry water containing less than 100 parts per million dissolved solids, while in the western section many streams are so saline that the water is unsuitable for most uses.

Several streams with headwaters at the edge of the High Plains carry water of good quality. These include Prairie Dog Town Fork Red River above Palo Duro Canyon State Park; Salt Fork Red River near Clarendon; Washita River; and Tule, Lelia Lake, Elm, McClellan, Sweetwater, and Quitaque Creeks.

At low flow, waters of the lower portion of Prairie Dog Town Fork Red River, Pease River, and Wichita River are extremely saline, frequently exceeding 25,000 parts per million dissolved solids, 3,000 parts per million sulfate, and 10,000 parts per million chloride. These high concentrations of sulfates and chlorides are emitted largely from natural salt springs and seeps. The average concentrations in the water of the Wichita River, as mixed by impoundment in Lake Kemp, have been about 3,000 parts per million dissolved solids, 650 parts per million sulfate, and 1,100 parts per million chloride.

Both the Corps of Engineers and the U. S. Public Health Service have intensively studied the water quality problems of the Red River basin. A two part publication, prepared by the Corps of Engineers, Survey Report on Arkansas-Red River Basins Water Quality Control Study, has resulted in the formulation of plans for improving the salt problem and for development of specific control facilities. This report recommends alleviation measures for the following locations: Elm Fork of the Red River, North Fork of the Wichita River, South Fork of the Wichita River, North and Middle Pease Rivers, Middle Fork of the Wichita River, Jonah Creek of Prairie Dog Town Fork of the Red River, and Little Red River of Prairie Dog Town Fork of the Red River.

The ground water in this basin also suffers mineral degradation, primarily due to manmade pollutants. The reinjection of oil field brines and water flooding operations have polluted local portions of the Ogallala aquifer. The use of unlined surface pits for storage of brine has resulted in the pollution of both surface and ground water. The Red River Authority and the Railroad Commission of Texas are cooperating to eliminate this practice. The Texas Water Development Board reports that 95 percent of salt water produced in the oil field operations is reinjected; however, some water quality degradation resulted because of improperly plugged holes.

The major source of mineral pollution is in the upper reaches of the Red River tributaries. Water quality in the main stem improves downstream. At Gainsville the concentration of dissolved solids in 1963 ranged from 292 to 5,580 parts per million, with a weighted average of 1,590 parts per million.[17]

Lake Texoma, on the main stem, receives the better quality water of the Washita River. The resulting dilution has reduced the average concentrations of dissolved solids, sulfate, and chloride in water discharged from Lake Texoma during the 10-year period 1955-64 to 994 parts per million, 233 parts per million, and 331 parts per million, respectively.

It is of great interest to the feasibility of this proposal to determine the effects of the salt control measures, as described by the Corps of Engineers. The analysis made from data gathered by the U. S. Public Health Service indicates that if only manmade chlorides were controlled, Lake Texoma would be of good quality only 37 percent of the time. If only natural sources are controlled, Lake Texoma water would be good 97 percent of the time. Control of both manmade and natural chlorides to the maximum degree would yield water meeting Public Health Service Standards 100 percent of the time.[17]

Figure 3-5 shows the anticipated improvements associated with the corresponding control projects and an explanation of the curves is as follows:

A - with existing flow and chlorides

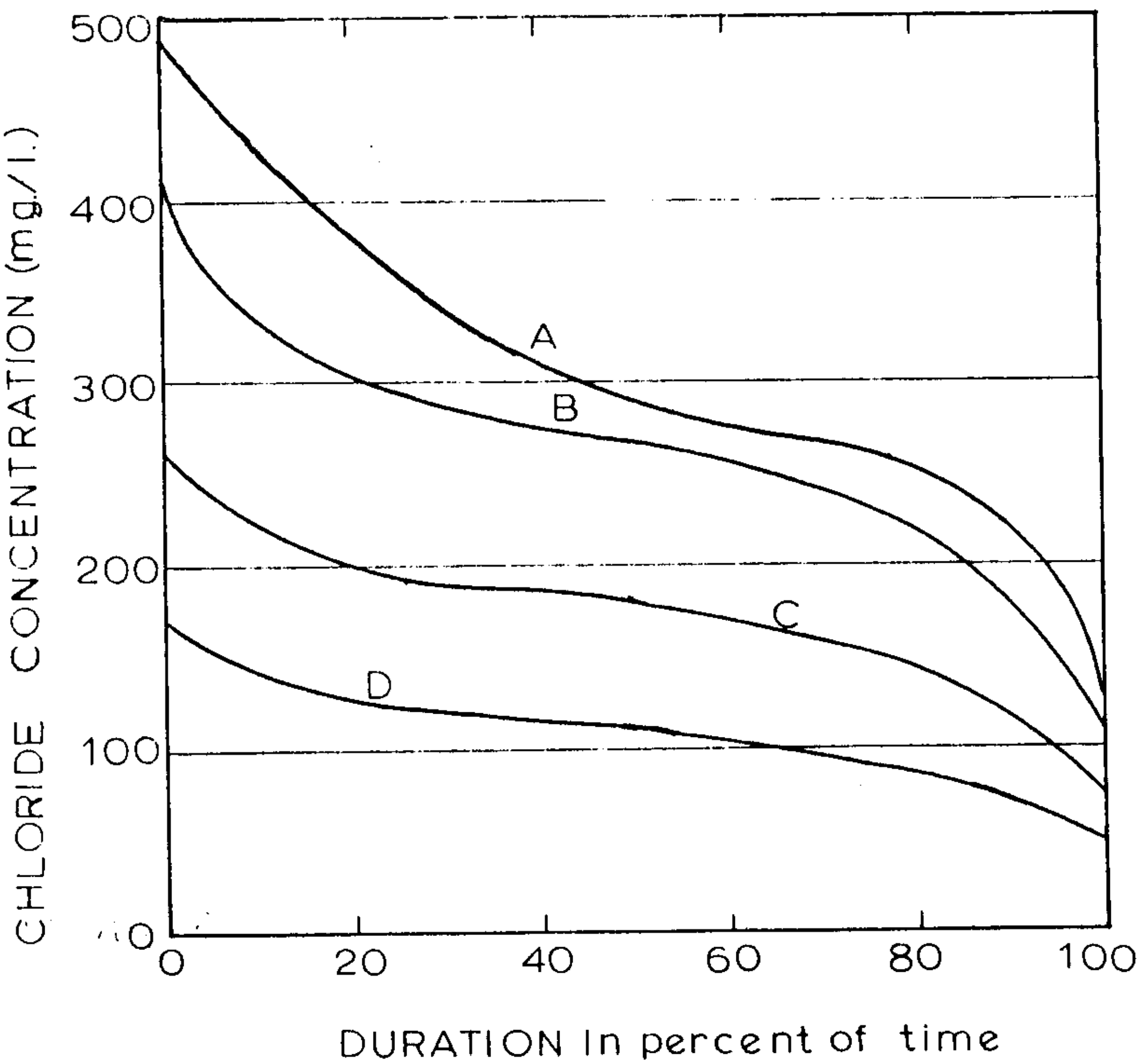
B - with maximum control of manmade chlorides

C - with maximum control of natural chlorides

D - with maximum control of manmade chlorides and natural chlorides.

TEXOMA CHLORIDE DURATION

FIGURE 3 - 5



In personal conversation, Mr. John J. Vandertulip, Chief Engineer for the Texas Water Development Board, indicated that these projected control values are reasonable after an initial period of stabilization.[18] This stabilization phase is necessary to allow above-normal flows to flush out all existing salt deposits in the flood plain. With improved water quality, a bountiful new supply of water is available for beneficial consumptive use.

Below Lake Texoma, waters of all tributaries to the Red River are very low in dissolved constituents, thus improving Red River water quality. At Arthur City, Oklahoma, the average concentration of dissolved solids is about 800 parts per million, and at Index, Arkansas, it is about 600 parts per million, with 125 parts per million sulfate and 170 parts per million chloride.

Organic quality is generally satisfactory throughout the Red River basin in Texas.

Surface water reservoirs. There are 14 major existing reservoirs located in the Red River Basin in Texas and an additional four reservoirs under construction (see Figure 3-6); the reservoirs are listed at the end of this paragraph. The only reservoir in the Red River Basin of primary interest to this study is Lake Texoma.

Corresponding to Figure 3-6, the reservoirs are numbered and named as follows:

(1) Buffalo

(2) Bivins

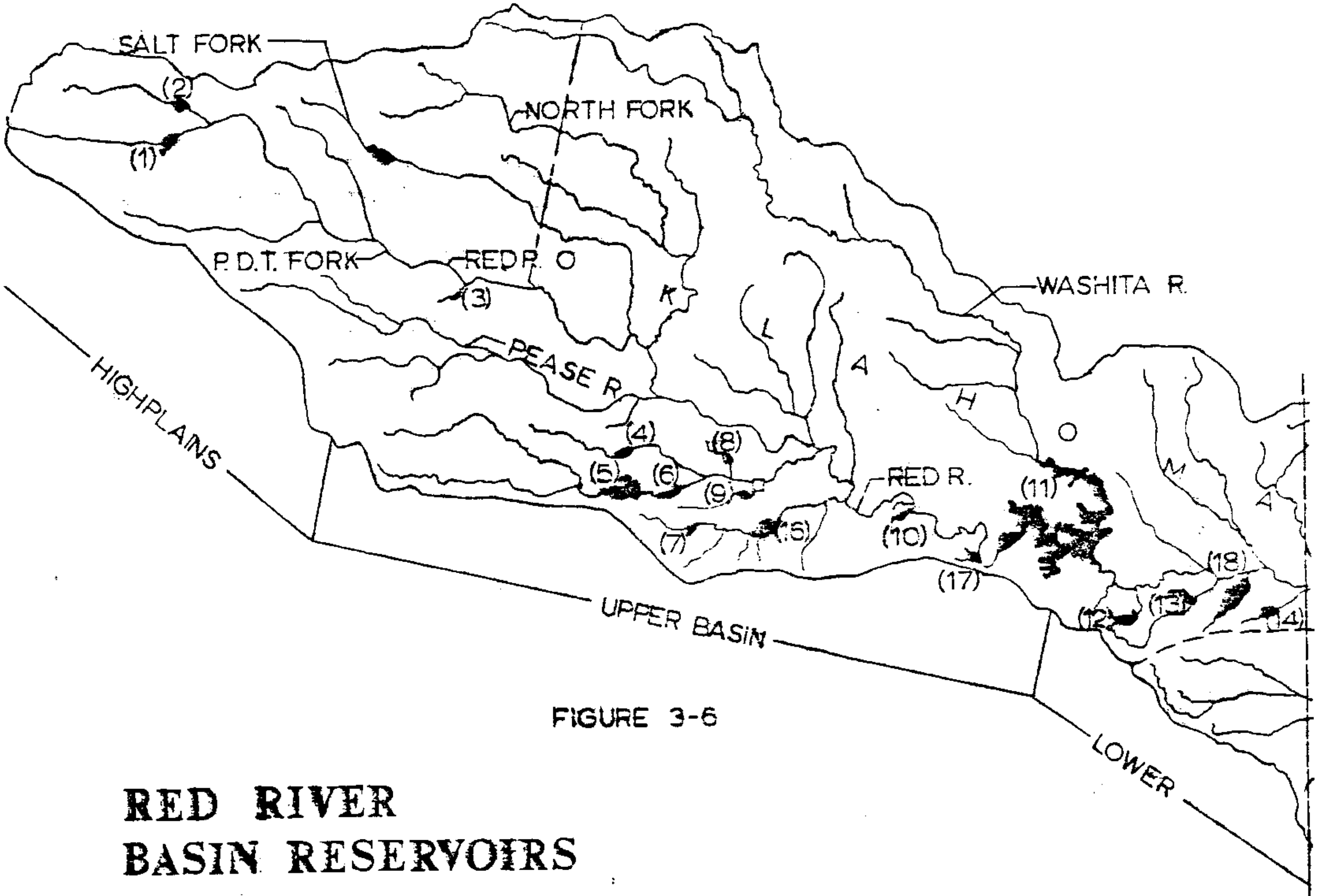


FIGURE 3-6

RED RIVER BASIN RESERVOIRS

(3) Baylor Creek

(4) Santa Rosa

(5) Kemp

(6) Diversion

(7) Kickapoo

(8) Buffalo Creek

(9) Wichita

(10) Farmers Creek

(11) Texoma

(12) Brushy Creek

(13) Coffee Mill

(14) Crook

(15) Greenbelt

(16) Arrowhead

(17) Fish Creek

(18) Pat Mayse.

Denison Dam, creating Lake Texoma, is constructed five miles north of Denison, Texas, on the main stem of the Red River. This reservoir is the largest in the basin having a yield which is approximately 15 times that of Lake Kemp, the second largest reservoir.[16] The water of the Washita River flows into Texoma, increasing the quality by dilution. At present, the water of this large reservoir is used primarily for hydroelectric power generation and recreation because poor chemical quality usually makes it unacceptable as a municipal or industrial supply.

Reservoir yield. To determine the amount of water that is available for diversion from Lake Texoma, a reservoir yield study was made. The procedure used was the same as that for Blackburn Crossing Reservoir, i.e., (a) development of minimum runoff relationship from the low-flow series program and (b) computation of reservoir yield by the Gooch method.

In order to obtain monthly inflow data to Lake Texoma for input data to the low-flow series program, the following simulation was made. The gaging station near Colbert, Oklahoma, located on the main stem of the Red River, has been operating continuously since 1924. Prior to the construction of Lake Texoma (1941), this gage recorded the inflow that would have entered the reservoir. Therefore, the flow at this station can be used as input data once it has been adjusted according to the known future reductions in drainage area. The reduction factor used was 28,234/33,869, or .83362, and was based on the fact that this contributing drainage area has, because of reservoir construction, decreased to 28,234 square miles from the area of 33,869 square miles that contributed during the period 1924 through 1940.

Beginning with January 1941, the flow at the Colbert, Oklahoma, station cannot be used because of the impoundment of water by Denison Dam. There are two streamflow gages located on the main tributaries (Washita and Red Rivers) which reflect the historical inflow into Lake Texoma. Both the gage near Durwood, Oklahoma, on the Washita and the gage near Gainesville, Texas, on the Red River have been recording since 1941. The combined drainage area of these two gages is 32,048 square miles; however, the total drainage area above Denison Dam is 33,783 square miles. Therefore, in order to account for the increased flow that will result from the additional drainage area, the following procedure was adopted. The drainage area between the Paul's Valley, Oklahoma, gage and the downstream Durwood, Oklahoma, gage of the Washita River closely approximates the unaccounted contributing area. The assumption was made that the runoff from an equal area of this hydrologically similar watershed would be the same as from the ungaged area. The monthly flow at Paul's Valley was subtracted from the monthly flow at Durwood, and this value was multiplied by the drainage area ratio of 0.926. The inflow resulting from the ungaged area should be closely approximated by this method.

The recorded flow of the Washita River near Durwood, Oklahoma, was considered to be representative of the future inflow since no major reservoirs were constructed or known to be planned.

The recorded flow of the Red River near Gainesville was modified to reflect the control of the existing reservoirs which had not been constructed during the period of historical flow. The flow was modified by the ratio of the present drainage of 19,297 square miles to the area which contributed to the historical flow. The area which contributed runoff varied over the period with the construction of new reservoirs. Lake Kemp began impoundment of water October 1, 1922, and no flow has been permitted to pass over the spillway. Therefore, the drainage area above Lake Kemp did not contribute to the historical flow near Gainesville. From January 1941 until November 1943, the contributing area was 22,747 square miles, and a drainage area ratio of 0.848 was used. Lake Altus began impoundment in December 1943, and the contributing area was reduced to 22,472 square miles with a drainage area ratio of 0.859. In February of 1946, the area was reduced to 22,197 by the construction of Lake Kickapoo; the resulting drainage area ratio was 0.869. This correction factor was used until August 1960, which ended the simulated period. A listing of the simulation program follows.

```
$EXECUTE       IBJOB
$IBJOB JHCOOK
$IBFTC MAIN
      DIMENSION FLOW(2000),QGAIN(40,20),QDUR(40,20),QPV(40,20),
     1QTEXO(40,20)
      READ(5,999) ID
      DO 90 K=1,17
  999 FORMAT(4X,A4)
      READ(5,3)   IYR,(FLOW(I),I=1,6),   IYR,(FLOW(I),I=7,12)
    3 FORMAT(8X,I8,6F8.0/8X,I8,6F8.0)
      DO 80 I=1,12
   80 FLOW(I)=28234./33869.*FLOW(I)
   90 WRITE(6,2) ID,IYR,(FLOW(I),I=1,6),ID,IYR,(FLOW(I),I=7,12)
      DO 6 K=1,20
    6 READ(5,1)(QGAIN(K,I),I=1,12)
    1 FORMAT(16X,6F8.0/16X,6F8.0)
      DO 7 K=1,20
    7 READ(5,1)(QDUR(K,I),I=1,12)
      DO 8 K=1,20
    8 READ(5,1)(QPV(K,I),I=1,12)
      IYR=1940
      DO69 K=1,3
      DO 9 I=1,12
    9 QTEXO(K,I)=QDUR(K,I)+QGAIN(K,I)*.848+(QDUR(K,I)-QPV(K,I))*.926
      IYR=IYR+1
   69 WRITE(6,2)ID,IYR,(QTEXO(K,I),I=1,6),ID,IYR,(QTEXO(K,I),I=7,12)
      DO 10 I=1,2
   10 QTEXO(4,I)=QDUR(4,I)+QGAIN(4,I)*.848+(QDUR(4,I)-QPV(4,I))*.926
      DO 11 I=3,12
   11 QTEXO(4,I)=QDUR(4,I)+QGAIN(4,I)*.859+(QDUR(4,I)-QPV(4,I))*.926
      IYR=IYR+1
      WRITE(6,2)ID,IYR,(QTEXO(4,I),I=1,6),ID,IYR,(QTEXO(4,I),I=7,12)
      DO 12 I=1,12
   12 QTEXO(5,I)=QDUR(5,I)+QGAIN(5,I)*.859+(QDUR(5,I)-QPV(5,I))*.926
```

```
      IYR=IYR+1
      WRITE(6,2)ID,IYR,(QTEXO(5,I),I=1,6),ID,IYR,(QTEXO(5,I),I=7,12)
      DO 13 I=1,5
   13 QTEXO(6,I)=QDUR(6,I)+QGAIN(6,I)*.859+(QDUR(6,I)-QPV(6,I))*.926
      DO 14 I=6,12
   14 QTEXO(6,I)=QDUR(6,I)+QGAIN(6,I)*.869+(QDUR(6,I)-QPV(6,I))*.926
      IYR=IYR+1
      WRITE(6,2)ID,IYR,(QTEXO(6,I),I=1,6),ID,IYR,(QTEXO(6,I),I=7,12)
      DO 16 K=7,20
      IYR=IYR+1
      DO 15 I=1,12
   15 QTEXO(K,I)=QDUR(K,I)+QGAIN(K,I)*.869+(QDUR(K,I)-QPV(K,I))*.926
   16 WRITE(6,2)ID,IYR,(QTEXO(K,I),I=1,6),ID,IYR,(QTEXO(K,I),I=7,12)
    2 FORMAT(1H0,4X,A4,I8,6F8.0/1H0,4X,A4,I8,6F8.0)
      STOP
      END
$DATA
    TEXO
```

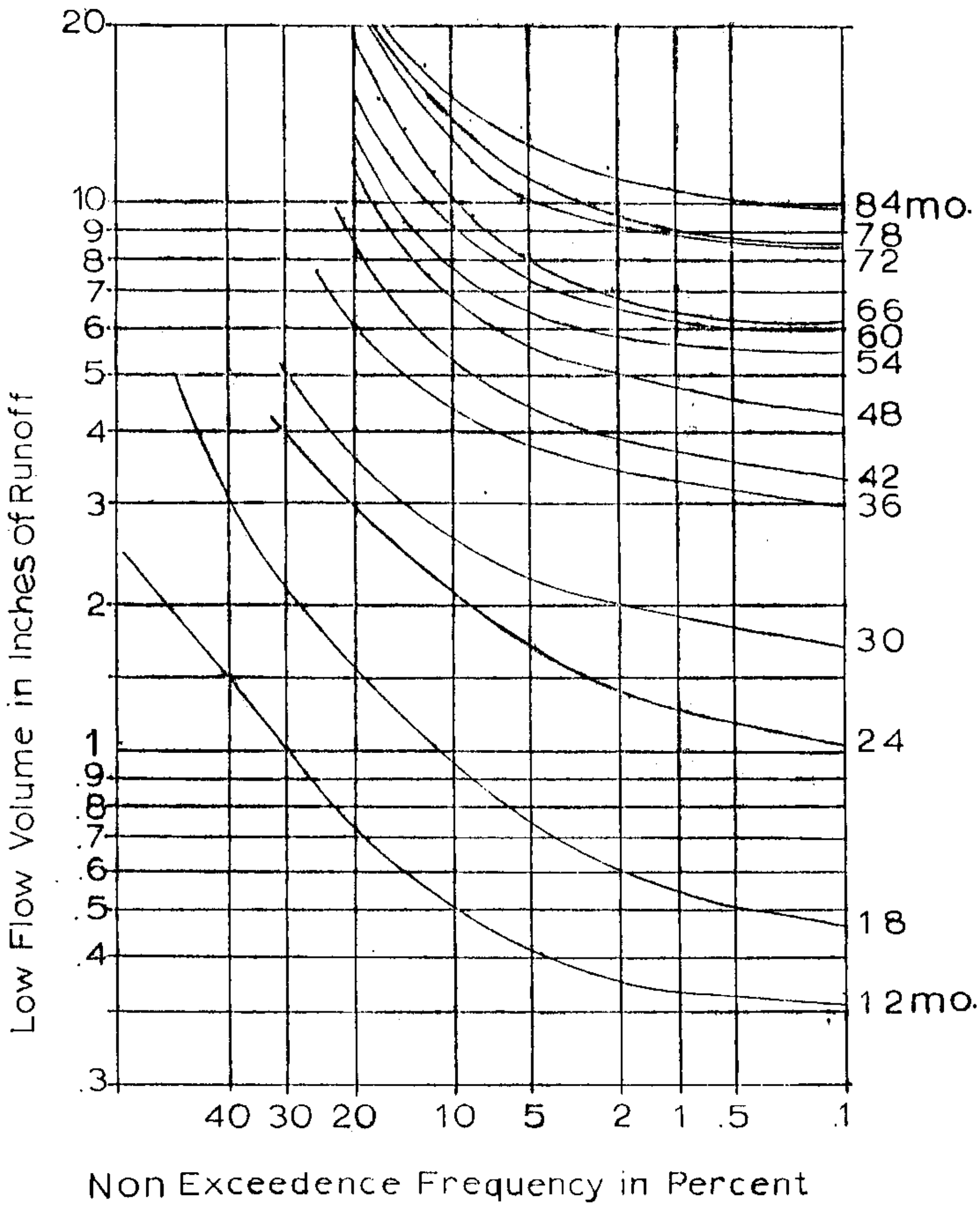
Program Output

TEXO	1924	29093.	12338.	8236.	2351.	1434.	4135.
TEXO	1924	7994.	5193.	2226.	1400.	1117.	925.
TEXO	1925	917.	614.	569.	618.	621.	484.
TEXO	1925	4243.	6394.	1017.	479.	3326.	14005.
TEXO	1926	5135.	2359.	633.	1317.	850.	1617.
TEXO	1926	6002.	4918.	2826.	6144.	7528.	4185.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
TEXO	1957	1136.	1101.	1280.	296.	1157.	1565.
TEXO	1957	12103.	72986.	29368.	2820.	1205.	3481.
TEXO	1958	2099.	5964.	1146.	2971.	1630.	3083.
TEXO	1958	3780.	8866.	3231.	2696.	1477.	448.
TEXO	1959	387.	321.	393.	409.	422.	363.
TEXO	1959	1391.	5947.	6201.	4405.	1561.	3464.
TEXO	1960	12759.	2694.	5675.	5500.	5118.	3183.
TEXO	1960	1910.	7213.	5456.	3538.	1222.	1084.

The output from the monthly flow simulation program was used as input for the low-flow series program. The results of this analysis were used to develop Figure 3-7, a minimum runoff vs. nonexceedence percentage curve for Lake Texoma. Using this relationship and the required information concerning evaporation (Figure 3-8), conservation storage, and net surface area the reservoir yield computations were made for nonexceedence percentages of 0.1, 2.0, 5.0, 10.0, and 20.0.

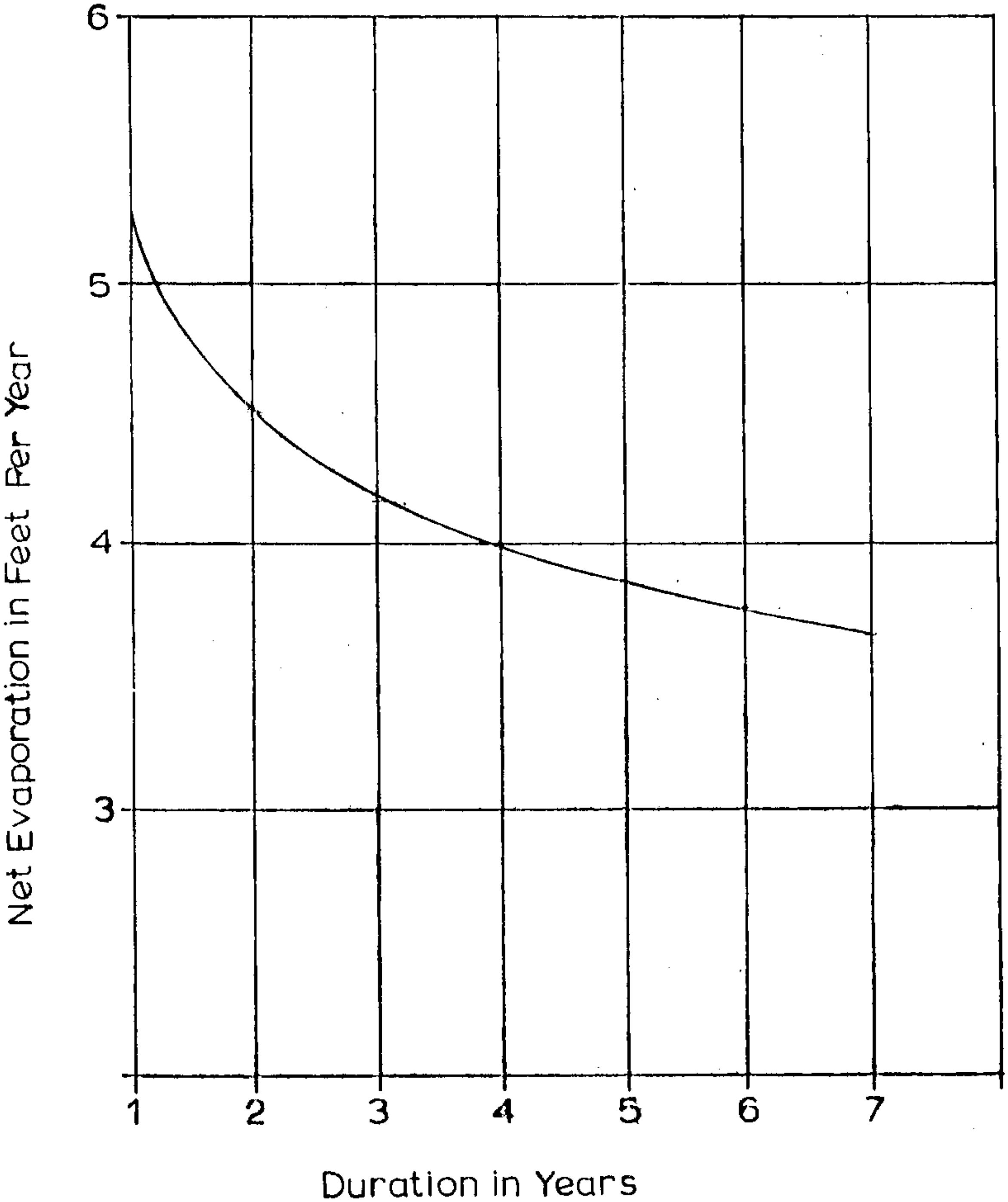
LOW FLOW EVENTS RED RIVER AT LAKE TEXOMA

FIGURE 3-7



MAXIMUM NET EVAPORATION AT LAKE TEXOMA

FIGURE 3 - 8



JOHN H. COOK

YIELD OF LAKE TEXOMA

USING SYNTHETIC STREAMFLOW

CAPACITY AT TOP OF CONSERVATION POOL, AC-FT	5530300.
AREA AT TOP OF CONSERVATION POOL, ACRES	121700.
CAPACITY OF SEDIMENT RESERVE, AC-FT	2836300.
AREA AT TOP OF SEDIMENT RESERVE, ACRES	92700.
NET CONSERVATION STORAGE USED, AC-FT	2694000.
AVERAGE RESERVOIR SURFACE AREA, ACRES	107200.

EXCEEDENCE FREQ IN PERCENT 0.1

DROUTH PERIOD (MOS)	AVG NET EVAP (FT/YR)	AVG RUNOFF (AF/YR)	YIELD (AF/YR)
12.	5.260	634000.	2681204.
18.	4.800	568000.	1793957.
24.	4.480	890000.	1704042.
30.	4.280	1044000.	1612900.
36.	4.150	1509000.	1903256.
42.	4.060	1465714.	1746191.
48.	4.000	1576750.	1766806.
54.	3.920	1827556.	1945818.
66.	3.820	1701091.	1727963.
78.	3.700	1996462.	1953855.
84.	3.640	2112571.	2044004.

MINIMUM YIELD

27.97 1588776.

continued.

EXCEEDENCE FREQ IN PERCENT 2.0

DROUTH PERIOD (MOS)	AVE NET EVAP (FT/YR)	AVG RUNOFF (AF/YR)	YIELD (AF/YR)
12.	5.260	649000.	2695754.
18.	4.800	724320.	1945587.
24.	4.480	1094000.	1901922.
30.	4.280	1219200.	1782844.
36.	4.150	1760667.	2147373.
42.	4.060	1681429.	1955434.
48.	4.000	1886250.	2067021.
54.	3.920	1881222.	1997875.
66.	3.820	1893091.	1914203.
78.	3.700	2205462.	2156585.
84.	3.640	2263500.	2190405.

MINIMUM YIELD

28.01 1753450.

EXCEEDENCE FREQ IN PERCENT 5.0

DROUTH PERIOD (MOS)	AVG NET EVAP (FT/YR)	AVG RUNOFF (AF/YR)	YIELD (AF/YR)
12.	5.260	769590.	2812726.
18.	4.800	855100.	2072444.
24.	4.480	1282650.	2084912.
30.	4.280	1358100.	1917577.
36.	4.150	1911333.	2293520.

continued.

42.	4.060	1897029.	2164566.
48.	4.000	2150325.	2323174.
54.	3.920	2146133.	2254839.
66.	3.820	2194909.	2206967.
78.	3.700	2553692.	2494368.
84.	3.640	2694643.	2608613.
MINIMUM YIELD			
28.33			1894818.

EXCEEDENCE FREQ IN PERCENT

DROUTH PERIOD (MOS)	AVG NET EVAP (FT/YR)	AVG RUNOFF (AF/YR)	YIELD (AF/YR)
12.	5.260	920490.	2959099.
18.	4.800	1096533.	2306643.
24.	4.480	1584450	2377658.
30.	4.280	1569360.	2122500.
36.	4.150	2213200.	2586330.
42.	4.060	2285057.	2540953.
48.	4.000	2565300.	2725700.
54.	3.920	2598800.	2693925.
66.	3.820	2798545.	2792494.
78.	3.700	3250154.	3169936.
84.	3.640	3276686.	3173195.
MAXIMUM YIELD 28.58			2101081.

continued

EXCEEDENCE FREQ IN PERCENT

DROUTH PERIOD (MOS)	AVG NET EVAP (FT/YR)	AVG RUNOFF (AF/YR)	YIELD (AF/YR)
12.	5.260	1282650.	3310395.
18.	4.800	1599533.	2794544.
24.	4.480	2225775.	2999743.
30.	4.280	2172960.	2707992.
36.	4.150	3018000.	3366986.
42.	4.060	3664714.	3879221.
48.	4.000	4451550.	4555362.
54.	3.920	4359333.	4401643.
66.	3.820	5212909.	5134426.
78.	8.700	5107385.	4971450.
84.	3.640	5173714.	5013312.
MINIMUM YIELD			
28.32			2667858.

SUMMARY TABLE - MINIMUM YIELD IN AC-FT/YR
---EXCEEDENCE FREQUENCY IN PERCENT---

STORAGE	0.1	2.0	5.0	10.0	20.0
	1588776.	1753450.	1894818.	2101081.	2667858.

CHAPTER IV

THE PROPOSED PHYSICAL PLAN

Transformation of a proposed physical system into a plan of reality requires studies and evaluations of a nonengineering nature which have considerable bearing on engineering decisions. It is beyond the scope of this study to consider all the problems and factors of this nature which might arise. As might be expected, many of the questions involved with the interbasin transfer of a water resource have not been resolved by the courts or legislature.[4]

Legal Aspects of the Diversion

The paramount problem associated with this plan is that of the legal right to the diversion of water. It will be most important to provide convincing assurance to the water surplus basin that such transfers will not deprive it of supplies needed to satisfy in-basin water requirements. In this connection, Texas law provides: "It shall be unlawful . . . to take or divert any . . . water of the ordinary flow, under flow, or storm flow, of any streams . . . or watershed, to the prejudice of any person or property situated within the watershed from which such water is proposed to be taken or diverted."[19]

The flow of the waters of the state, as described above, belong to the state subject to the rights granted by the current administration or previous governments to individuals or corporations. Ownership of public streams and lands was retained by the state when the Republic of Texas was annexed in 1845. The problems arising in other states in regard to Federal ownership of public waters do not arise in Texas; however, the Federal Government maintains superior jurisdiction in regard to navigation.

The water rights and laws of Texas have changed with development of the laws from Spanish rule to statehood. Texas adopted many of the old customs and laws of the Spanish Civil Law System as a natural consequence of Spanish and later Mexican sovereignty. Water rights of lands granted by the ruling government before 1840 are evaluated under the Spanish Civil Law as modified by the Congress of the Republic of Texas in 1837. Between January 20, 1840, and March 19, 1889, the common law of England governed the character of rights pertaining to land granted by the Republic of Texas and later by the state. Since 1889, the Texas Legislature has enacted many laws relating to Texas rivers and streams and the use of their public waters.

The result of this turbulent legal history is a dual system of surface water laws commonly called the "riparian system" and the "appropriative system." The right to domestic use of the surface waters of a stream adjacent to a landowner's property is known as "riparian right." The right to beneficially use the unappropriated waters of a stream by a nonriparian landholder is known as "appropriative right," and is granted by permit from the government. Riparian rights traditionally have been classified as real property and treated similarly to easements or other interest in land. The courts have ruled that an individual cannot be deprived of these rights, even by the legislature, except upon just compensation.[20]

During the Spanish and Mexican rule, allocation of the water was determined by government representatives. Most of the grants made were for riparian lands; however, some rights were granted to nonriparian lands. Texas courts have upheld that grants of land riparian to a water course made after the adoption of the English Common Law and prior to the adoption of the appropriative system include the right to make use of the waters of the stream for natural wants, industrial use, mining, and for irrigation. Irrigation rights incident to early land grants enjoy no priority over subsequent grants, but all riparian lands share proportionately in the "normal flow" of the stream. The ordinary normal flow of a river is defined in the following manner: "The line of highest ordinary flow is the line of flow which the stream reaches and maintains for a sufficient length of time to become characteristic when its waters are in their ordinary, normal, and usual conditions, not influenced by recent rainfalls or surface runoff."[20]

The Water Law of 1889 instituted the system of prior appropriation by declaring that ". . . all of the unappropriated water of every river or natural stream within the arid portions of the state where irrigation was required, was the property of the state."[21] This law also provided that the first in time was the first in right for these appropriated waters.

In 1913, the appropriated rights doctrine was extended over the entire state, and the State Board of Water Engineers was created to administer appropriations.[22] Since 1889, however, most of the new statutes have incorporated language which has preserved the riparian right of a landowner and these rights have consistantly been defended and upheld by the courts.

Under the 1913 statute, a record of all existing appropriations was to be filed with the State Board of Water Engineers, and these declarations came to be known as "certified filings." All appropriations subsequent to 1913 were to be made by applying to the Board for "permits" to appropriate water. The name of the Board of Water Engineers was changed in 1962 to the Texas Water Commission. It was renamed on September 1, 1965, the Texas Water Rights Commission.[3]

After riparian and appropriative rights have been satisfied in the Red River basin and a compact settled, the unappropriated water may legally be used for interbasin transfer. However, permit must be obtained from the Corps of Engineers for use of conservation storage in the reservoir.

There are three general ways in which conservation storage space can be acquired in Corps of Engineers reservoirs. First, when the reservoir is approved by Congress, provision can be made for use of storage and for the method and amount of payment. Also, if a permit is obtained during preconstruction planning, the reservoir size can be modified to include the storage space, on the condition that the increased cost will be contributed by the permit holder. The third method is as follows: the Secretary of the Army is authorized by the Flood Control Act of 1944 to enter into contract with other interests for the use of conservation storage for municipal and industrial purposes.which has been declared surplus to the needs of the Federal Government. Payment for the storage is usually in annual installments over a period not to exceed 50 years.[4] The latter procedure would be used for acquiring conservation storage in Lake Texoma.

Preliminary indications from the Texas Water Development Board are that the final draft of the Red River Compact will allow the state of Texas to divert approximately 220,000 acre-feet per year from Lake Texoma for interbasin transfer. There has been no further public release of information concerning compact details as of this writing (February 1967).

Advantages of the diversion. The operation of a four-river basin system, as an integral unit, has a number of advantages. For example, suppose that drought conditions have depleted two of the receiving basins, while thundershowers have produced enough runoff to satisfy the demand in the third receiving basin. The diverted flow can be apportioned between the two basins as the demands dictate.

In the discussion of the results of the reservoir yield program, it was mentioned that the possibility of the sale of water corresponding to certain predetermined risks could lead to increased utilization of our water resources. Consider the case of the owners of a single major reservoir in the Neches River basin. Assume that the economic benefits from hydroelectric power generation, recreation, flood control storage, and other aspects remain constant except the revenue from the sale of water from conservation storage. It should be noted that this over-simplified case would rarely, if ever, exist. The owners of this reservoir can perform the reservoir yield analysis and determine the amount of water available with the corresponding statistical dependabilities. Contracts can now be negotiated with water users at various rates which decrease with decreasing dependabilities. An example of the advantage this proposal offers is that a municipality can determine what amount of water is necessary to sustain life and vital industry and can purchase this quantity with high dependability at a corresponding high price. The remaining normal demand can be negotiated at one or more new rates corresponding to the recurrence period at which the municipality is willing to undergo the discomfort of water rationing. The industrial manufacturer or the agricultural producer can evaluate his need for water quantities, with respect to the dependability of supply.

It would seem logical that economists could maximize the use of water and the revenue received from its sale. It would also be beneficial for the economic analysis to relate all the other factors such as recreation and power generation which are affected by the quantity of water remaining in the reservoir. The opportunities for maximum resource utilization are greatly increased when a series of reservoirs can receive benefit. Consider the case of the Neches River with two downstream reservoirs, Rockland and Dam B, which can benefit directly from diversion into Lake Palestine.

The following equations represent the relationship between the quantity of water diverted from Lake Texoma and the amount available at each of the three downstream reservoirs:

Q_o = quantity diverted from Lake Texoma,

$Q_1 = Q_o\ (1\text{-Loss}_1)$ = quantity available in first reservoir,

$Q_2 = (Q_1 + \text{Return}_1)(1\text{-Loss}_2) =$

$[Q_o\ (1\text{-Loss}_1) + \text{Return}_2](1 - \text{Loss}_2) =$

quantity available in the second reservoir, and

$Q_3 = Q_2\ (1\text{-Loss}_3) = [(Q_o\ (1\text{-Loss}_3) + \text{Return}_1)(1\text{-Loss}_2) +$

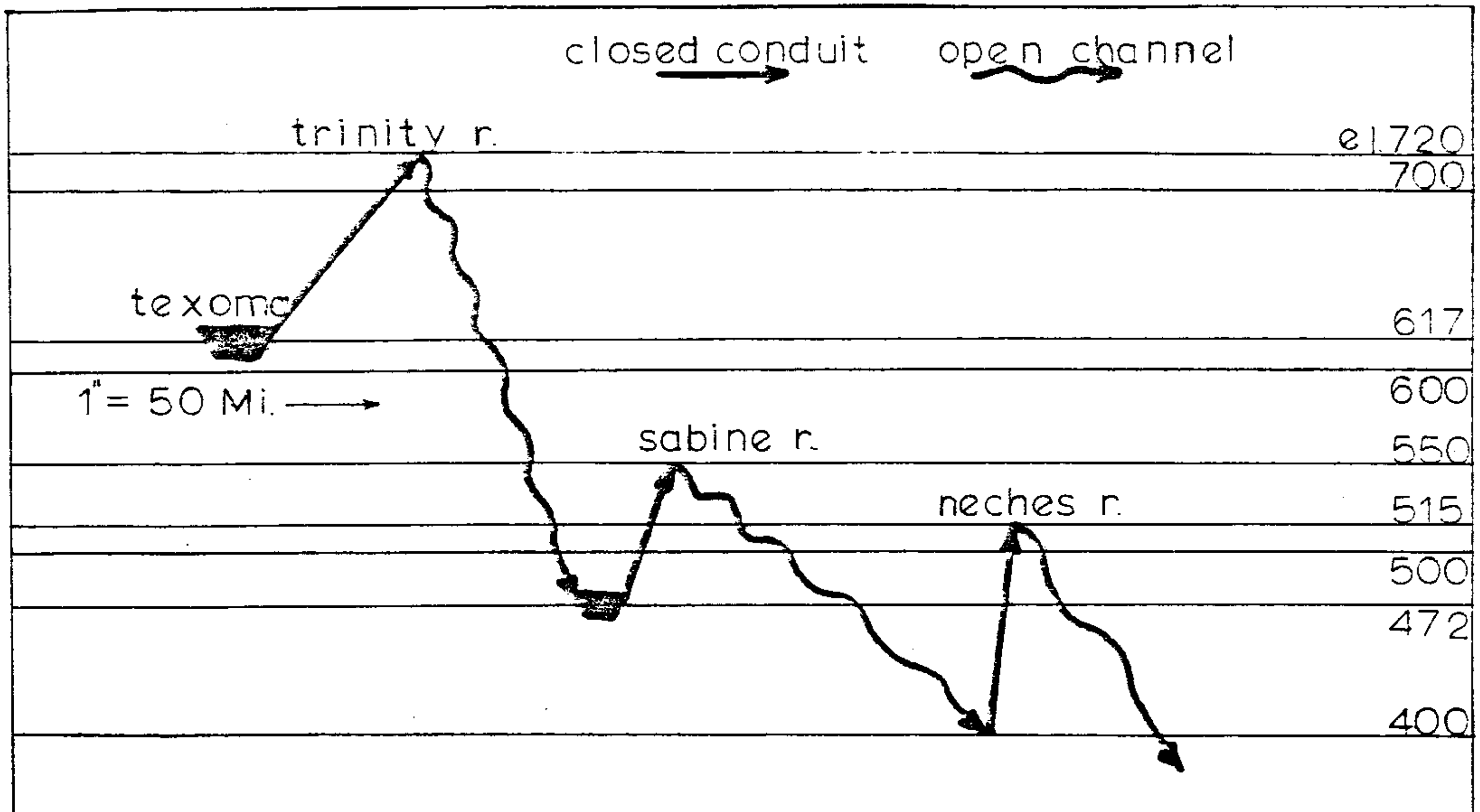
$\text{Return}_2)](1\text{-Loss}_3)$ = quantity available in third reservoir.

The losses term (to be expressed in percent) which appears in the expression accounts for transportation losses and consumptive use, should be accounted for by subtraction from the return-flow quantity. Once this relationship is expanded to include all the reservoirs in the three-river system and adjusted to relate water quantity to economic worth as a function of all water uses such as water supply, flood control, quality control, hydroelectric power potential, and recreation, it has become so lengthy and voluminous as to require a solution by high speed electronic computers.

Mathematical analysis and further research could show that the minimum yield from an integral system was greater than the sum of the minimum yields of the component reservoirs because the probability of the most stringent drought possible occurring in all basins simultaneously should be small.

Distribution system. A detailed engineering study was not conducted for the layout of the diversion facilities; however, this plan should closely follow the results of an extensive study. Figure 4-1 shows a schematic drawing of the system. The length of closed conduit necessary for the pumping facilities should be accurate within several miles. The required pumping elevations are listed with relative confidence; however, there is a greater opportunity for variance with this estimate. The estimated elevations should be correct within 50 feet. The values given should be greater than the required lift but accurate determination of these values would be included in a complete engineering study.

Figure 4-2 shows a plan view of the proposed distribution facilities. The allocated flow of 220,000 acre-feet per year will be taken from Lake Texoma at elevation 617 and pumped for a distance of approximately 26 miles to the divide between the Red and Trinity River basins at elevation 720. This will require a maximum lift of 103 feet. The water will then be discharged into the east prong of Sister Grove Creek and will flow by gravity through the natural channel into Lake Lavon. In order to divert the water from Lake Lavon

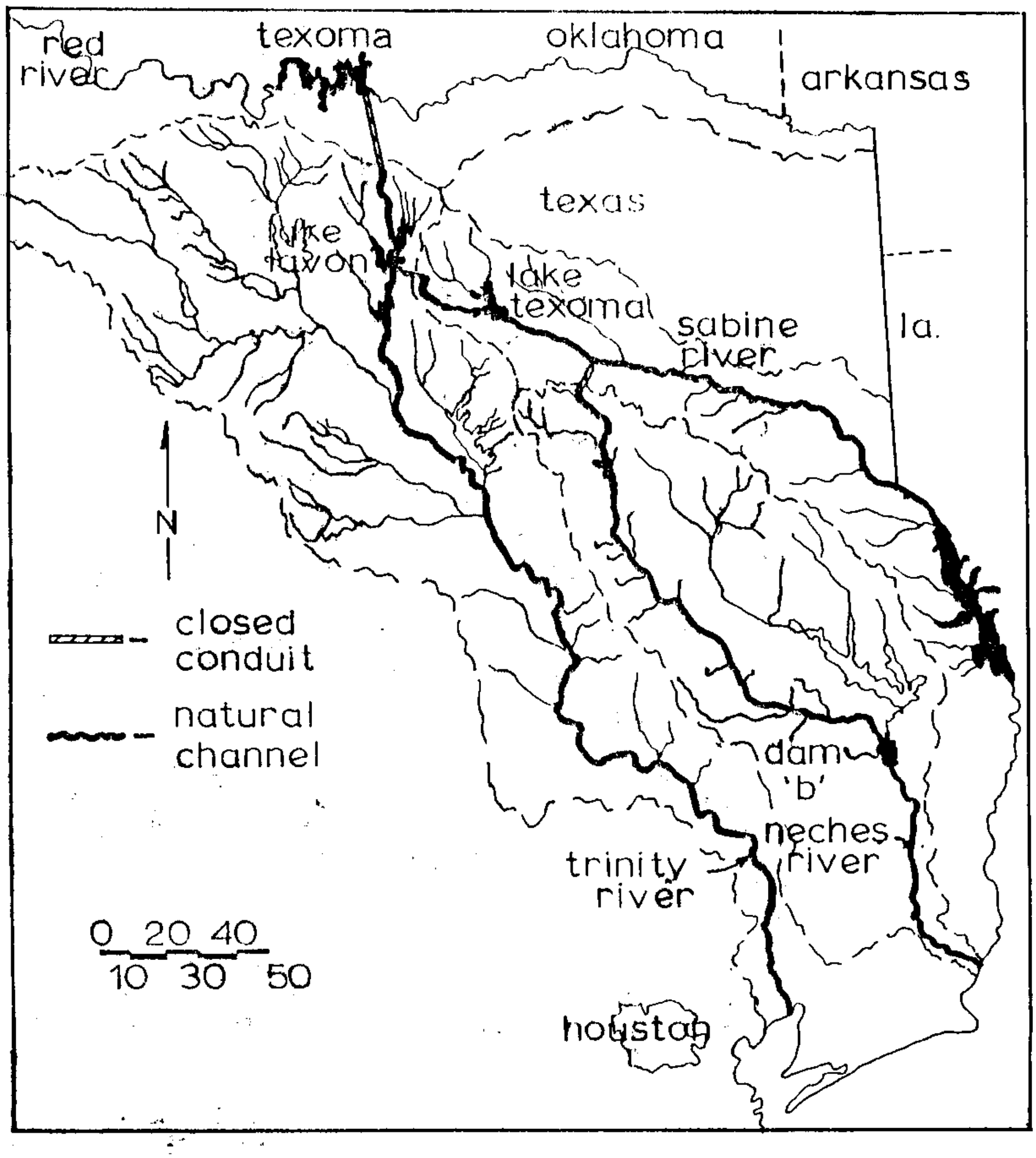


DIVERSION SCHEMATIC

FIGURE 4-1

PROPOSED DISTRIBUTION SYSTEM

FIGURE 4-2



into the Sabine River basin, six miles of closed conduit must be provided. The water will be taken from Lake Lavon at elevation 472 and pumped over the divide between the Trinity and Sabine River basins and discharged at approximately elevation 550. The released water will flow downstream through the natural channel of the south fork of Bois d'Arc Creek into Lake Tawakoni on the main stem of the Sabine River. It will be pumped from a point on the Sabine River, elevation 400, four miles south of Mineola, Texas, into the drainage area of the Neches River and discharged into Caney Creek at elevation 515. This will conclude the distribution of Red River water from Lake Texoma into the Trinity, Neches, and Sabine River basins. The diameter of the conduit should remain constant at 84 inches to allow flexibility of distribution. This diameter is the minimum which will accommodate the flow without excessive pumping costs. This diameter is only an approximate value and a detailed design study should be conducted.

Water uses. Some of the possible uses for the diverted water are discussed in the following paragraphs. Traditionally, the demand for water has been obtained by estimating the municipal and industrial requirements as a function of projected growth and adding the agricultural requirements based on crop production. This procedure has been used by the Bureau of Business Research, University of Texas, to furnish the Water Development Board with water requirements for the year 2020. Using this method, it is anticipated that the Sabine River basin should have an excess of surface water, the Neches River basin should be able to fulfill expected demands, and the Trinity River basin should experience a water shortage by 2020. In view of this information, it seems rather questionable that funds should be expended to construct facilities for conveyance of diverted water into the two eastern basins. However, there are a number of factors which are very difficult to accurately estimate and there are some quantities for which there has been no procedure devised for estimation. The water resources administration of the Sabine and Neches River basins should be certain that an adequate supply is present before disregarding the available Lake Texoma water. These remarks should not be misinterpreted as a rejection of the Water Development Board's quantities, although it is well to note that criticism has been voiced by the river basin authorities concerning projected demands. It would also seem appropriate to emphasize that this proposal makes no attempt to maximize the water resources of the entire state and therefore is not comparable to the State Water Plan. This study has shown that there are definite advantages to the interbasin transfer scheme which outweigh the disadvantages.

Actually, there are relatively few considerations which would tend to discourage the construction of the diversion facilities. The cost of the proposal would be relatively small when compared to the expense of reservoir construction, and the operating expense incurred through pumping costs could be regained by hydroelectric power generation in the lower basins. Additional considerations of this plan will be discussed in detail in the following paragraphs.

There has been no procedure developed for evaluating the change in economic activity that results from increasing the base flow of a river. While increasing the dependable supply of water from a reservoir is a familiar result of enlarging the reservoir, there has been little work done on the effect of "splitting" a larger river and transposing the diverted flow upon the normal flow of another river. The streamflow in the upper reaches of the recipient basin will be increased to several times that which occurred previously. Much more investigation is required before the resulting effects such as stabilizing population density, increased recreation, and increased quality can be evaluated.

Hydroelectric power is produced in all of the basins. The power market demand is not known; however, the power produced can be used to pump the diverted water through the distribution system and hopefully return the capital cost of the pumping facilities. through the sale of power.

The maintenance of a dependable supply of municipal and industrial water is essential to the growth and development of any trade area. This is the reason that the basins which would receive water through this proposal have objected to the predictions of the Water Development Board. The Trinity River Authority, one of the critics of the State Plan, has issued 48.5 million dollars in bonds for the construction of Lake Livingston. A 74 million dollar expenditure by the city of Houston, Texas, is planned for the development of a water distribution system to supply the industrial growth along the Houston Ship Channel. These suppliers cannot accept the chance that their source of replenishment would be less than that required for optimum development. The diversion scheme could be justified on this basis alone.

Another consideration in the lower Trinity basin is quality control for the Galveston Bay-Houston Ship Channel. The present unsatisfactory conditions can be lessened by inplant treatment; however, a minimum fresh water inflow is required even with maximum biological water treatment to insure proper biological conditions for commercial fish reproduction.[23] While at present there is no statute or body of knowledge dictating how much inflow is required, it seems certain that some judgement will be made and a water demand for estuarine quality control will arise. While the legal right of the estuary to this water is a subject of much legal controversy, the demand for this water is no less evident. Johnson [23] states that if a sufficient quantity of water in excess of the riparian demands is not present for estuarine balance, the quantity needed should be acquired by voluntary purchase or condemnation. Consideration was not given to satisfaction of this demand by interbasin transfer. Once the requirement has been determined, the diversion of water from Lake Texoma may well be the solution to the problem for an estuary in the Neches, Trinity, or Sabine River basin.

Furthermore, it should be recognized that this proposal could easily be incorporated into a plan for maximization of the water resources of the entire state. For example, it would lend a greater quantity of water to the interbasin transfer plan which H. P. Burleigh [1] proposed. By combining the Lake Texoma flow with the excess from the three recipient basins in this proposal and the Sulphur-Cyprus River basin, it would be possible to collect practically all of the excess unappropriated water of the state of Texas. To achieve this would mean construction of the additional diversion facilities from the Sulphur-Cyprus basin and channel across the lower Sabine, Neches, and Trinity basins. Once this collection system has been constructed the water can be used either for supply to the lower Rio Grande Valley or for use in a possible Colorado River pump back for distribution in western Texas.[28]

Regardless of the water uses, this study has shown that the Red River can be easily diverted to form an integrated system with the Neches, Trinity, and Sabine Rivers. Any plan for maximization of the water resources of this area or the state would seem less than complete without this proposal or some modification thereof.

CHAPTER V

SUMMARY AND CONCLUSIONS

Objectives

In order to conclude with a clear understanding of the study results, it is necessary to restate the objective and limitations involved herein. The primary objective, as indicated by the title, was determination of the feasibility of diverting surface water from Lake Texoma in the Red River basin into the Trinity, Neches, and Sabine River basins.

There are a number of secondary objectives associated with this study and the author's participation in Water Resources Institute Project 5003, Development of Optimization - System Analysis Techniques of Texas Water Resources.

This study is, in effect, an initial project objective enabling the project staff to review, adapt, and develop water resources planning techniques. The Neches River basin, selected as the project study area, was examined in detail. The rudimentary optimization ideas in Chapter IV have evolved as the result of project influence. This research has offered an opportunity to examine the effects of diverted flow on the Neches River basin.

Limitations. All of the objectives of this research have been limited. For example, the proposal itself was not a complete engineering investigation. Any attempt to consider in detail the complex political, legal, and economic aspects required for construction of the proposed engineering facilities is well beyond the capabilities of any single individual. In addition, sufficient information is not readily available concerning the requirements of surrounding states for the apparent excess of Red River basin water to be used in the diversion scheme. The effect of this proposal upon the lower Red River basin has not been considered. Finally, this study is limited in that it only considers four of the 12 major river basins of the state. No attempt has been made to compete with the recently released Texas Water Plan or to maximize the water resources of the entire state.

Conclusions

The interbasin transfer scheme, as proposed in this study, offers an attractive source of water to the three recipient basins with the cost of construction well within reason when compared to the cost of reservoir construction. However, with the limited information available, it appears unlikely that the legal right to divert this water can be obtained unless it is coordinated with a state water plan.

This plan, as proposed, is not suitable for the entire state because enough of the land area of the state is not involved, and areas of critical deficiency are excluded. It should be noted that this proposal and a plan for diversion from the Sulphur and Cyprus basins could become the inflow network of a system to collect all of the surface water runoff in the state of Texas. This idea is well suited to additional research and study.

REFERENCES

1. Webb, W. P., More Water for Texas, The University of Texas, Austin, Texas (1954).

2. Golze, A. R., "Progress in Implementing the California Water Plan," Proceedings of the Tenth Annual Conference on Water for Texas, Texas A&M University (1965).

3. A Summary of the Preliminary Plan for Proposed Water Resources Development in Texas, Texas Water Development Board, Austin, Texas (1966).

4. Water Development and Potentialities of Texas, U. S. Senate Document 111, Eighty-Fifth Congress, Second Session, Government Printing Office (1958).

5. Master Plan for Water Resource Development in the Texas Portion of the Red River Basin, Freese, Nichols and Endress Consulting Engineers, Fort Worth, Texas (1966).

6. "Economic Potential of the Texas Gulf Basins," Water for the Future, Vol. II, Bureau of Business Research, The University of Texas (1954).

7. A Summary of the Preliminary Plan for Proposed Water Resources Development in the Trinity River Basin, Texas Water Development Board, Austin, Texas (1966).

8. A Summary of the Preliminary Plan for Proposed Water Resources Development in the Sabine River Basin, Texas Water Development Board, Austin, Texas (1966).

9. Master Plan for Water Resource Development in the Neches River Basin, Freese, Nichols and Endress Consulting Engineers, Fort Worth, Texas (1960).

10. A Summary of the Preliminary Plan for Proposed Water Resources Development in the Neches River Basin, Texas Water Development Board, Austin, Texas (1966).

11. Surface Water Supply of the United States, Part 7 and 8, Geological Survey, U. S. Department of the Interior, Washington, D. C. (1960).

12. Runoff - Neches River Basin, Bureau of Reclamation, Department of the Interior, Austin Development Office, Austin, Texas (1960).

13. Stall, J. B., "Reservoir Mass Analysis by a Low-Flow Series," Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 88, No. SA5, pp. 21-40 (September, 1962).

14. Gooch, R. S., "Design Drought Criteria for Evaluation of Surface Water Resources," Annual Conference of the Hydraulics Division, American Society of Civil Engineers, Tucson, Arizona (1965).

15. Beard, L. R., Statistical Methods in Hydrology, U. S. Army Corps of Engineers, Sacramento, California (1962).

16. A Summary of the Preliminary Plan for Proposed Water Resources Development in the Red River Basin, Texas Water Development Board, Austin, Texas (1966).

17. Survey Report on Arkansas - Red River Basins Water Quality Control Study, Part I and II, U. S. Army Corps of Engineers, Tulsa, Oklahoma (April, 1965).

18. Personnel Communication with J. J. Vandertulip, Chief Engineer, Texas Water Development Board (July 25, 1966).

19. Gammel, H. P. N., The Laws of Texas, 1922-1897, Vol. 10, The Gammel Book Company, Austin, Texas, p. 21 (1898).

20. Thompson, J. T., Public Administration of Water Resources in Texas, Institute of Public Affairs, Austin,Texas (1960).

21. General Laws of the State of Texas, Twenty-first Legislature, Chapter 88, p. 100 (1889).

22. General Laws of the State of Texas, Regular Session, Thirty-third Legislature, Chapter 171, p. 358 (1913).

23. Johnson, C. W., "Legal Problems in Water Management," Proceedings of the Eleventh Annual Conference on Water for Texas, Texas A&M University (1966).

24. Moore, J. G., "Recent Developments in the Texas Water Plan," Proceedings of the Eleventh Annual Conference on Water for Texas, Texas A&M University (1966).