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A PRACTICAL APPROACH TO

WATER QUALITY MANAGEMENT PLANNING

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I. INTRODUCTION

Rapid growth in the volume of waste material produced by a burgeoning population and a consumer-oriented economy, coupled with an increased awareness of the importance of environmental quality, has necessitated more efficient methods of dealing with problems of environmental pollution. Paramount among these problems is the pollution of the Earth's water resources.

The existence of the technology necessary to produce potable water supplies and the availability of the capital necessary to build the needed purification facilities have removed most of the health hazards of water pollution in developed nations such as the United States. In this age of ecological awareness, however, public demand goes beyond the basic requirement of pure drinking water. Emphasis is now being placed on the restoration and preservation of the nation's streams to such an extent that they can support a balanced population of aquatic life, provide recreational benefits and be aesthetically pleasing to the human senses. This emphasis is reflected in the objectives of the Federal Water Pollution Control Act Amendments of 1972:

> Sec. 101. (a) The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. In order to achieve this objective, it is hereby declared that, consistent with the provisions of this Act-
>
> (1) it is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985;

> (2) it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983;
> (3) it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited... (FWPCAA 1972, p. 1)

Basic technology already exists to accomplish these goals, and advanced techniques are being developed and tested which will make waste treatment even more efficient. While a broad and immediate application of this technology to all waste sources throughout the United States is obviously desirable, it is currently impossible due to economic factors and to the inavailability of manpower and equipment resources. It is, therefore, necessary to have a model for a plan of action which would optimize our present resources so that the goals for in-stream water quality can be met in the shortest possible time.

Models for analysing the response of water resources systems to waste inputs have been developed and refined within the last few years. While they may be mathematically correct and theoretically sound, most of these models require extensive data on both stream and waste characteristics. Data necessary to drive many of the mathematical models for predicting in-stream quality, given waste inputs, is not now available on a state-wide basis and cannot be obtained except through expensive and time-consuming monitoring operations.

The impetus in water quality management is for action now. The public, through legislation and governmental regulatory agencies, is demanding that action be initiated immediately without waiting for the development of the data base necessary to calibrate and drive sophisticated mathematical and managerial models. In the face of such public pressure, the temptation to "do something, even if it's wrong" must be resisted. If we are to move in a positive direction, there is a great need for a model water quality plan that will provide for the preservation and/or attainment of desirable water quality at the earliest possible date, given the existing restraints of data inadequacies, financial limitations, current treatment practices, and legal, social, and political realities.

The purpose of this paper is to develop such a model water quality plan. The following pages will contain a description of the basin for which the plan will be developed, an evaluation of the historical and present water quality, an analysis of the existing waste discharges, a discussion of possible approaches to waste-load allocations and the selection of a maximum utility approach, a waste load allocation for present dischargers, and recommendations for a data generating system which will allow for improving the model at future planning intervals. This model will be developed for the Middle Arkansas River Planning Basin in Oklahoma but should be applicable to other basins in Oklahoma and other states. The model will utilize only the data which is currently available in the files of the state water quality agencies or which could be obtained quickly by utilizing the existing resources of the state pollution control agencies. The model will, however, contain mechanisms for periodically updating and increasing the level of sophistication of techniques as more and better data becomes available.

In keeping with the practical application philosophy, the model plan will satisfy the requirements for the Federal Water Pollution Control Act Amendments of 1972 and the state statutes concerning water pollution control and will stress implementation capability.

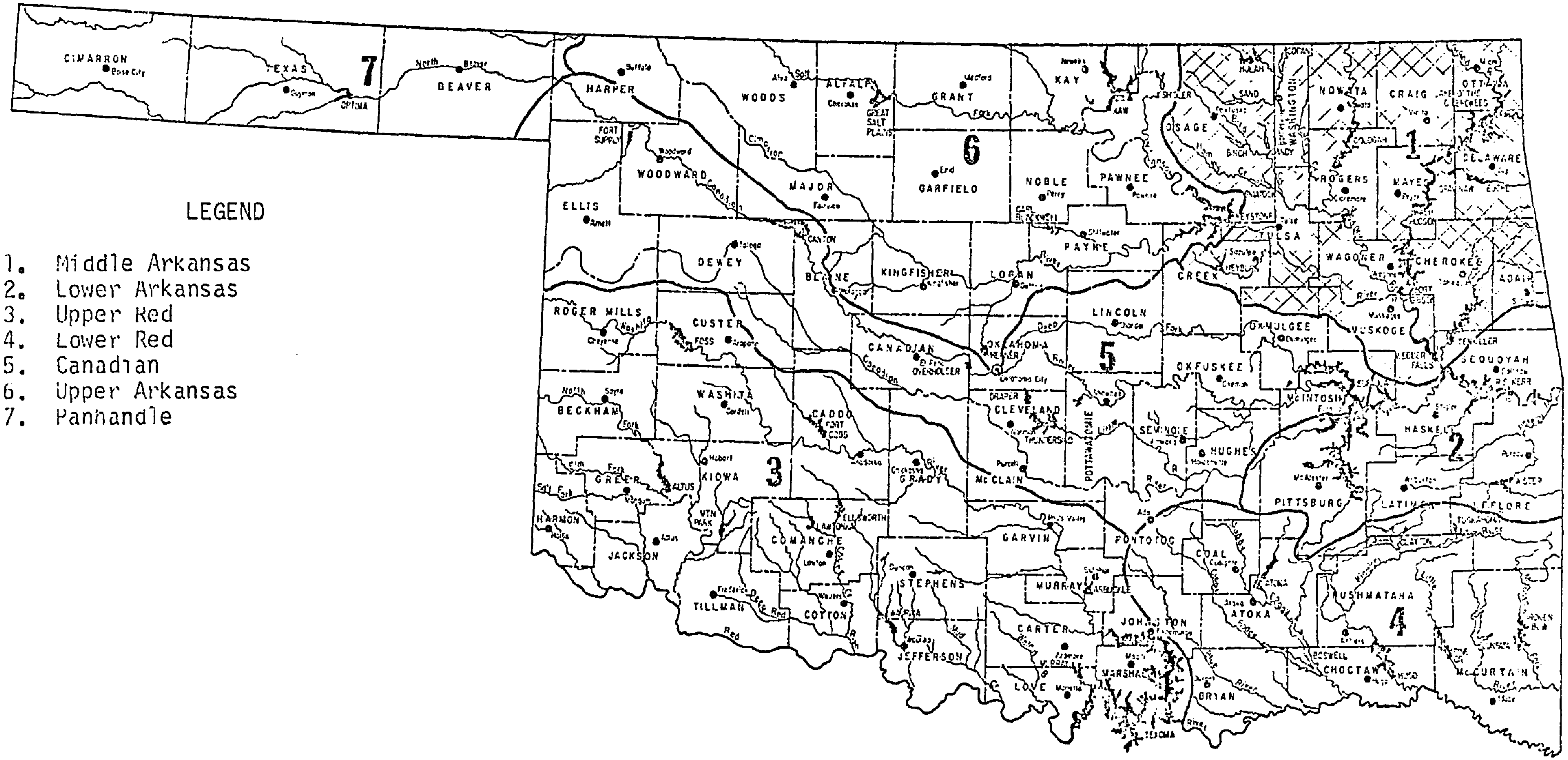
II. BASIN CHARACTERIZATION

Boundaries

The planning basin under consideration consists of all the area in Oklahoma draining into the Arkansas River from approximately three miles below Keystone Dam to a point just above the Arkansas confluence with the Canadian River. The basin is referred to as the "Middle Arkansas" since other planning basins cover portions of the Arkansas River upstream and downstream from the basin boundaries. The boundaries correspond exactly with those of Region IX as established in a study entitled Appraisal of the Water and Related Land Resources of Oklahoma by the Oklahoma Water Resources Board and supported in part by the Water Resources Council. (OWRB 1971)

Political Boundaries

The area encompassed by the Middle Arkansas Basin includes approximately 9,685 square miles in Oklahoma. It is bounded on the north by Kansas and on the east by Missouri and Arkansas. Counties included in the area are Ottawa, Delaware, Craig, Mayes, Nowata, Wagoner, Rogers, and Washington. In addition, virtually all of Tulsa and Muskogee and parts of McIntosh, Cherokee, Sequoyah, Adair, Okmulgee, Creek, and Osage counties are within the planning basin. (OWRB 1971) A map of the basin



LEGEND

1. Middle Arkansas
2. Lower Arkansas
3. Upper Red
4. Lower Red
5. Canadian
6. Upper Arkansas
7. Panhandle

*Base map from OWRB

FIGURE 1*

WATER QUALITY MANAGEMENT
PLANNING BASIN

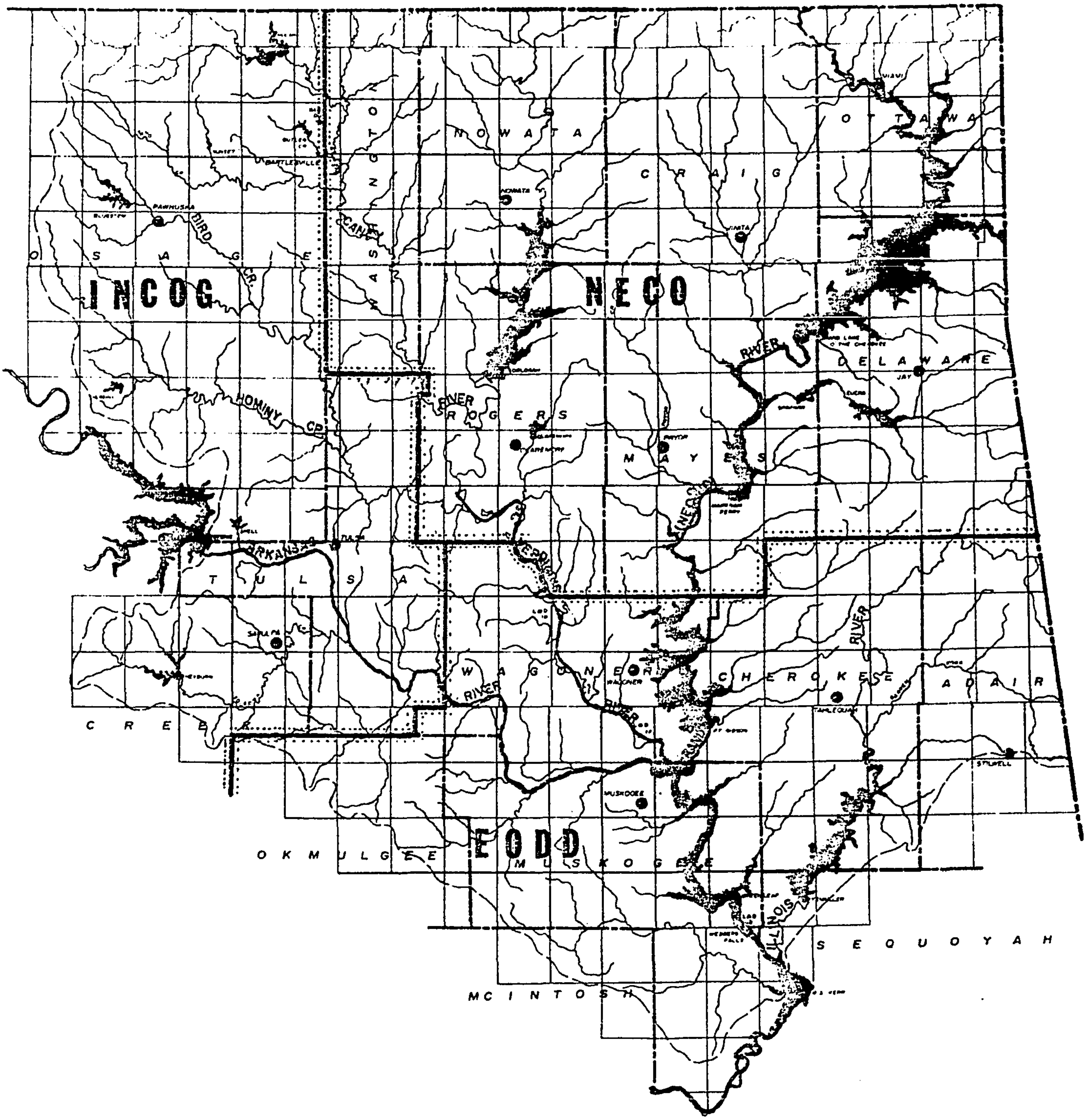


FIGURE 2*

SUB-STATE PLANNING
DISTRICTS

*Base map from OWRB

is included on the following page.

Sub-state planning organizations within the basin include Northeast Counties of Oklahoma Economic Development Association (NECO), Eastern Oklahoma Development District (EODD), and Indian Nations Council of Governments (INCOG). NECO lies totally within the basin while most of EODD and INCOG are within the basin boundaries. Boundaries of these organizations are shown on the map on page 7.

Hydrological Units

In addition to the Arkansas River, the principal hydrological units in the Middle Arkansas Planning Basin are the Illinois, Grand Neosho, Verdigris, and Caney Rivers and Bird and Hominy Creeks. Tributaries to these streams complete the drainage system.

The Illinois River enters the state of Oklahoma from Arkansas. Approximately 900 square miles of area in Oklahoma drains to this stream. The Grand Neosho, Verdigris, and Caney Rivers all enter the state from Kansas. Oklahoma lands within these basins cover approximately 2700, 4300, and 1600 square miles respectively. (OWRB 1971, pp. 65-66) Bird and Hominy Creeks drain the northwestern part of the basin and merge into a single stream before passing through the Tulsa area and into the Verdigris. A map showing these hydrologic units is included on page 8.

Stream Segmentation

The streams in the Middle Arkansas Planning Basin were divided into segments having similar characteristics with respect to hydrology, water quality, and water use designation. The map on page 9 shows the result of this segmentation.

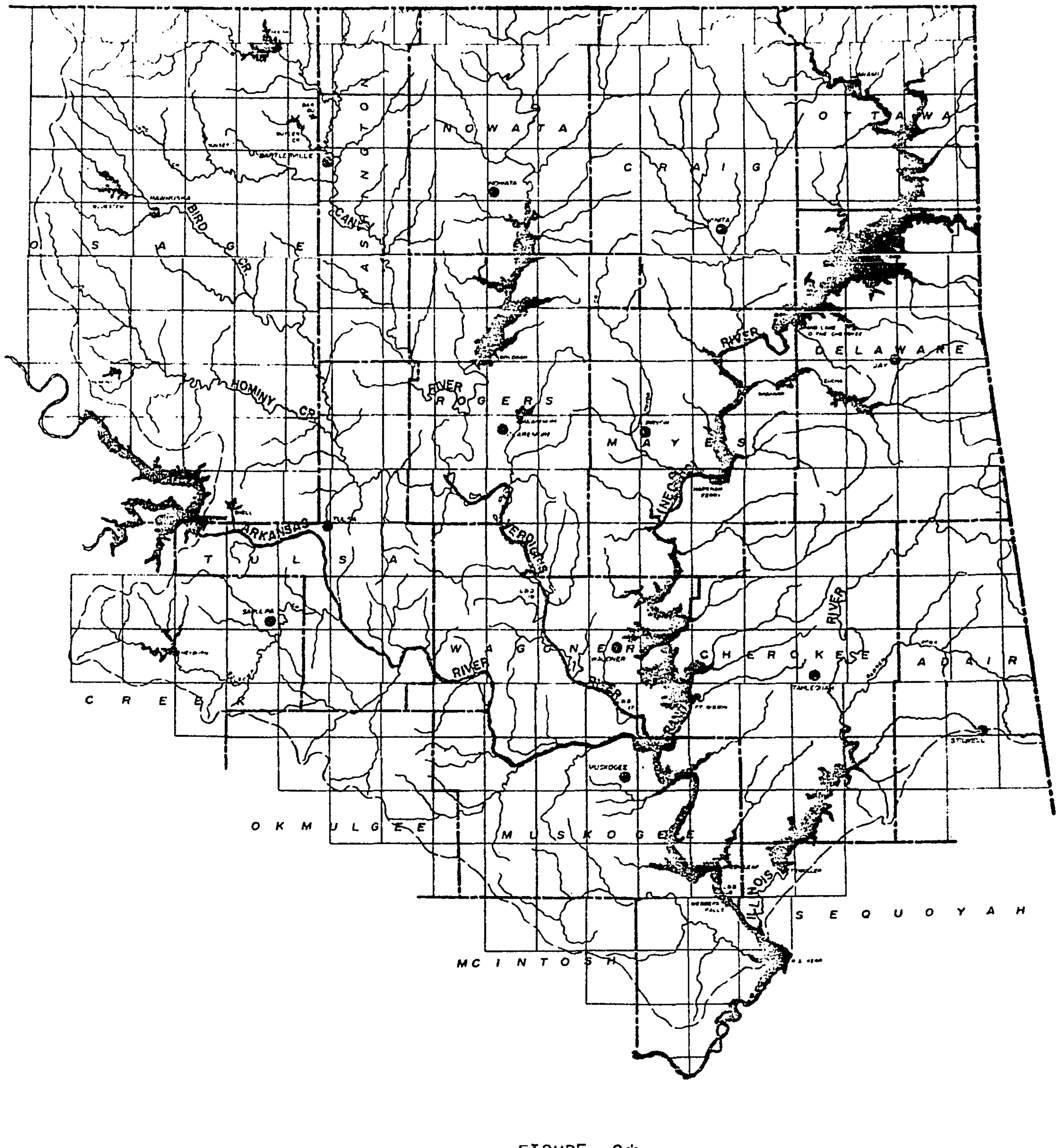


FIGURE 3*

BASIN STREAM SYSTEM

*Base map from OWRB

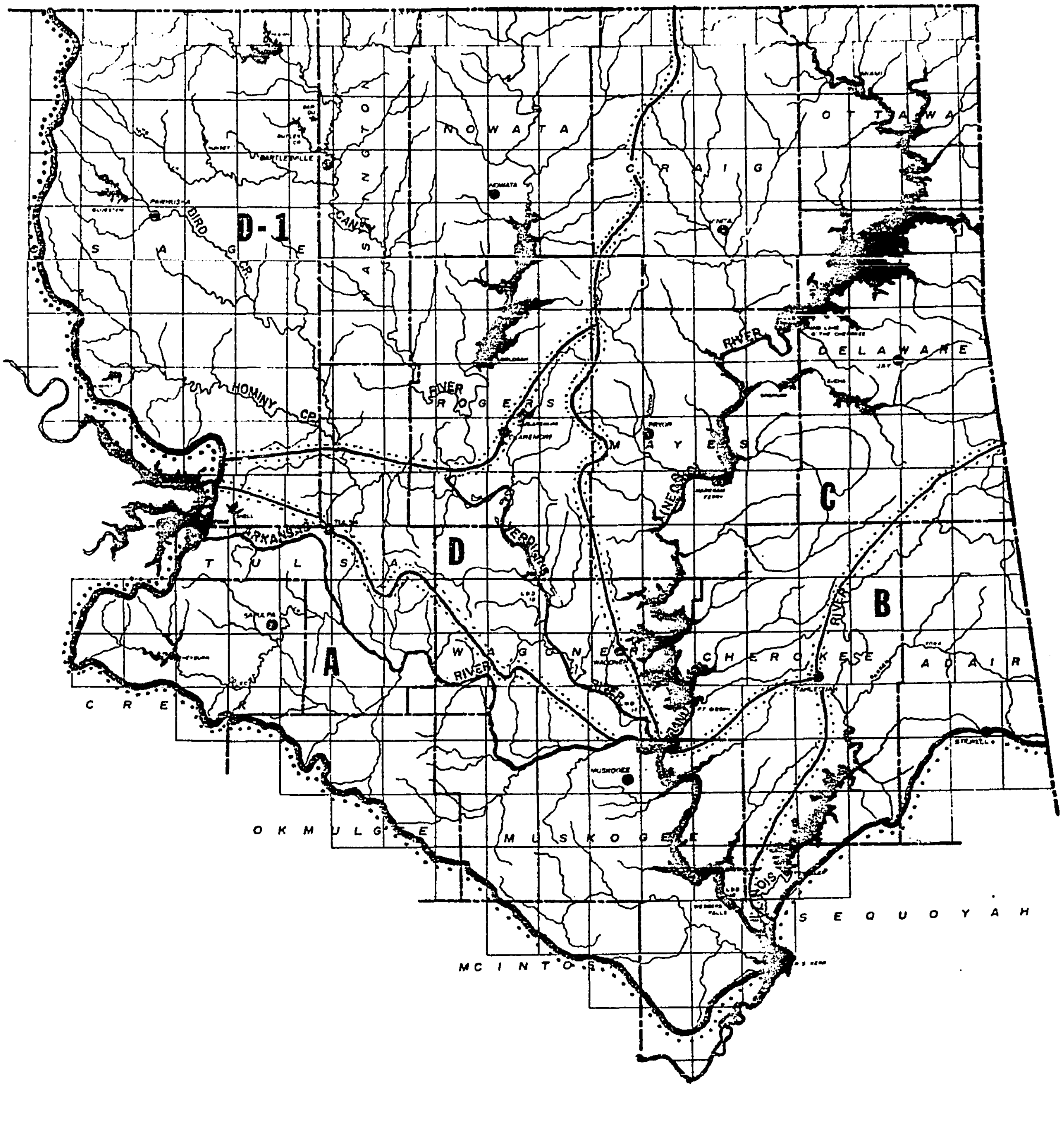


FIGURE 4 *

BASIN SEGMENTATION

*Base map from OWRB

The above segmentation should not be interpreted to mean that all streams within each segment are similar with respect to the previously named characteristics, since in most cases this distinction is made only for the main streams. Similar separation for tributaries would result in a large and unwieldy number of segments. The principal segments encompass the drainage areas of the Illinois River (1-B), the Grand Neosho River (1-C), and the Verdigris River (1-D); the remaining land drainage goes directly into the Arkansas River (1-A).

Segment 1-B

The Illinois River, which drains a somewhat mountainous region, has the swift, turbulent characteristics of mountain streams. Tenkiller Reservoir, located on the lower part of the stream, covers approximately 12,650 acres at conservation pool and has the designated uses of flood control, hydroelectric power generation, water supply, recreation, and fish and wildlife propagation. (OWRB 1971, p. 85) The reservoir is a major recreation center in the state, and development near the shore line is increasing steadily.

Segment 1-C

Segment 1-C encompasses the Grand Neosho and its tributaries in Oklahoma. The Grand Neosho is one of the largest streams in Oklahoma, draining a total area of 12,520 square miles covering portions of Kansas, Missouri, Arkansas, and Oklahoma. (OWRB 1971, p. 65) Since completion of John Reddman Reservoir upstream in Kansas, flow in the Grand Neosho is regulated to some extent throughout Oklahoma. The major part of the stream within Oklahoma is impounded by a series of dams which create three large reservoirs. These reservoirs regulate downstream flow throughout the year. (Eng. Advisory Committee 1961, p. 29)

Flow in the stream is in a general southward direction. The area to the east of the river consists of low mountain ranges while the area to the west rises in gentle prairie slopes. This distinctly different topography results in different flow regimes in the tributary streams draining these areas. Tributaries from the east are generally perennial streams while tributaries from the west are mostly intermittent streams which have no natural flow part of the year.

Segment 1-D

The Verdigris River flows southward into Oklahoma from Kansas and empties into the Arkansas River near Muskogee. Total drainage area of the stream is approximately 8300 square miles, about half of which lies in Oklahoma. (OWRB 1971, p. 65) Tributaries in Oklahoma are Caney River and Bird Creek.

For the purpose of current planning effort, the Verdigris basin is divided into two sub-segments. The upper reaches of the Verdigris and its tributaries, Caney River and Bird Creek, have been separated as a sub-segment, 1-D(1), of the total segment. This area is composed mostly of low rolling hills. Vegetation consists mostly of scrub oak in the eastern two-thirds and native grass sod in the western one-third of the sub-segment. Oil and gas activities are extensive throughout the area (OWRB 1971, p. 65)

The lower Verdigris sub-segment encompasses some of the most highly developed areas in Oklahoma. This sub-segment includes area in and around Tulsa which drains into Bird Creek below the confluence of Hominy

Creek and into the Verdigris River below the confluence of the Caney River. The Kerr-McClellan Navigation System extends about three-fourths of the way up the sub-segment to Catoosa. Extensive development has commenced in this area and is expected to continue rather rapidly.

Segment 1-A

Segment 1-A includes all of the land that drains directly to the Arkansas River (excluding the Verdigris, Grand Neosho, and the Illinois) between the confluence of the Canadian and Arkansas and the dam of Keystone Reservoir. The shape of this basin is roughly rectangular, measuring approximately 80 miles long and 20 miles wide. The area of this segment is approximately 1560 square miles and includes some highly developed areas around Tulsa and Muskogee. The Kerr-McClellan Waterway follows the river from the downstream segment boundary to the Verdigris River at Muskogee. Most of the undeveloped area consists of flat woodlands along the river with sharp, broken hills along the perimeters. (OWRB 1971, p. 65) With the exception of the major streams previously discussed, tributaries are small streams with comparatively insignificant flow.

Natural Characteristics

Meteorological, hydrological and other natural characteristics of the Middle Arkansas Basin are covered in great detail in the Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine, published by the Oklahoma Water Resources Board in 1971. Most of the descriptive material below has been summarized form this source. For a more thorough description, the reader is referred to the above mentioned document.

Both meteorological and hydrological characteristics of a drainage basin are likely to have significant effects on water quality. In the Meteorology section below, an overview of such meteorological characteristics as temperatures, precipitation, wind, and evaporation is followed by an examination of the ways in which these characteristics might affect water quality. The Hydrology section is divided into Surface Water Hydrology and Ground Water Hydrology. The first section moves from a discussion of stream-flow characteristics and surface characteristics into speculation as to the ways in which these characteristics may affect in-stream water quality. The second section describes such characteristics as geology and mineral deposits and concludes with remarks relating these characteristics to water quality.

Meteorology

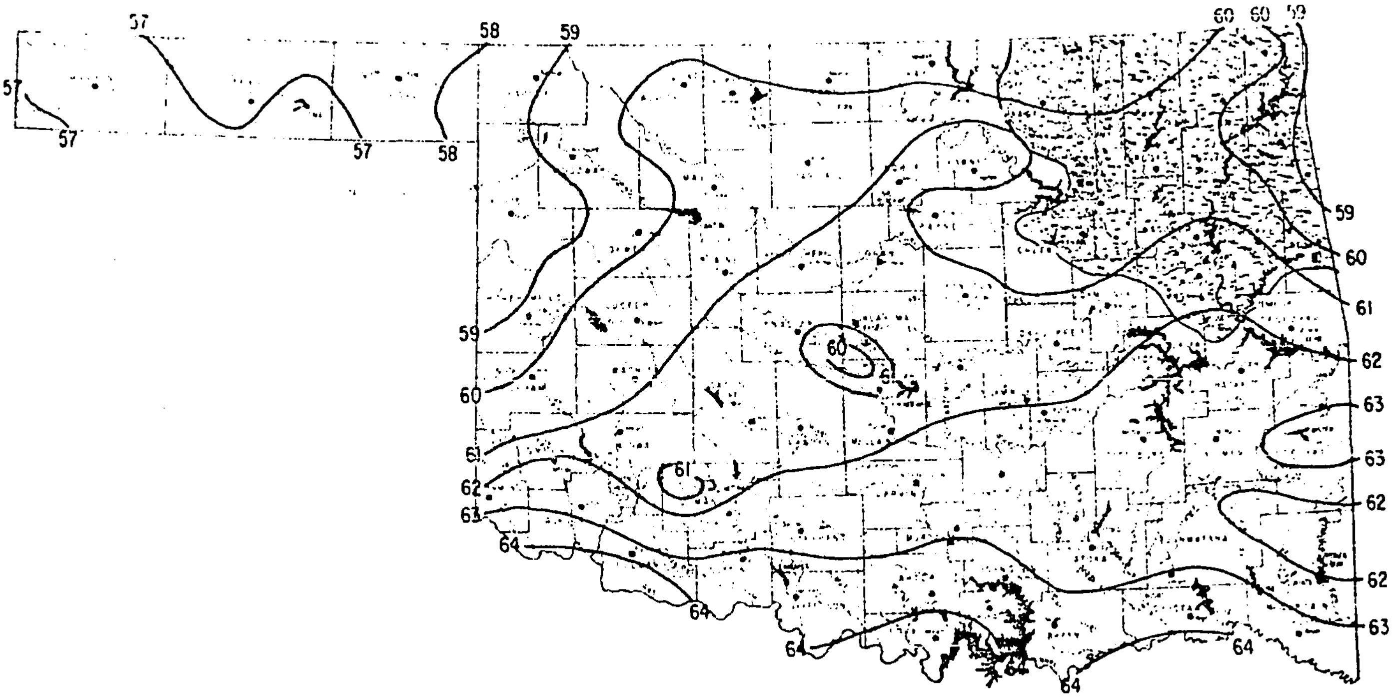
Description

The climate of the Middle Arkansas Basin varies from moist and subhumid in the west to moist and humid in the east. Summers are lòng and not unusually hot. While winters are usually comparatively mild, brief periods of colder temperatures do sometimes occur. Spring and autumn months are mild with warm days and cool nights.

Temperature variations across the basin are slight. Mean annual temperature varies from approximately 59^{o}F in Delaware County in the eastern portion to 61^{o}F in southwestern Osage County in the west. A map of the state of Oklahoma showing its mean annual temperature contours is shown in Figure 5 on the following page. Daily maximum temperatures average around 44^{o}F in January and 92^{o}F in July. Daily minimum temperatures average

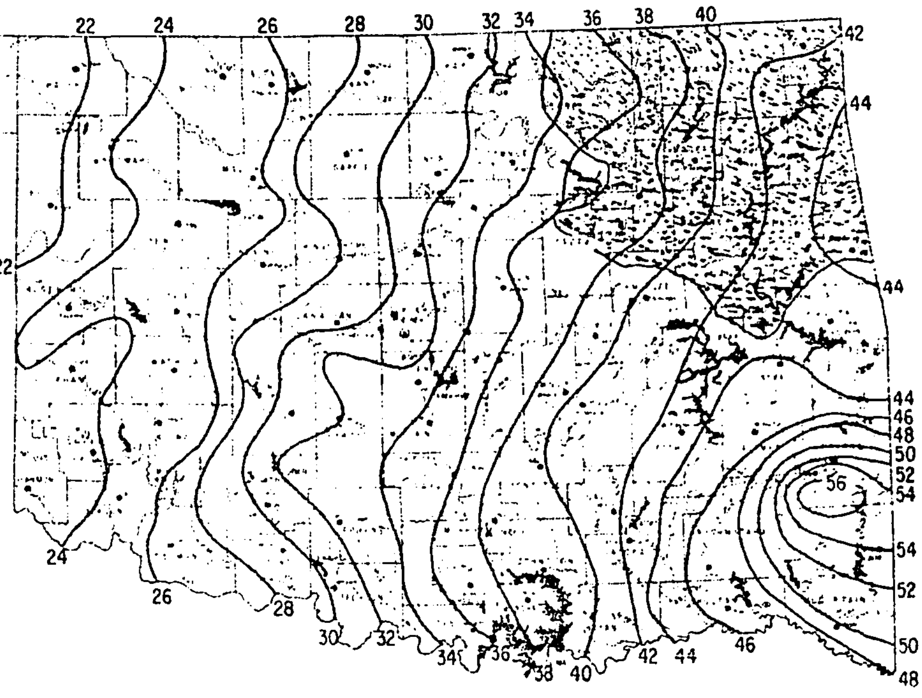
MEAN ANNUAL TE PERATURE
(in °F)
Period 1931-1960

Figure 5



AVERAGE ANNUAL PRECIPITATION
(in inches)
Period 1931-1960

Figure 6



From: Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine, Oklahoma Water Resources Board, 1971.

approximately 26^{O}F in January and 69^{O}F in July

The growing season, that period of time between the average date of the last 32^{O}F temperature in the spring and the first 32^{O}F temperature in the fall, varies from about 190 days in the higher elevations of Delaware and northern Adair Counties to 210 days along the southwestern border of the basin.

Average yearly precipitation in the basin varies from about 34 inches in western Osage County to 44 inches in Adair, eastern Cherokee, and southern Delaware County. A map of the State of Oklahoma showing the mean annual rainfall countours in inches is shown in Figure 6 on page 14. A maximum precipitation occurs in late spring and early summer mainly in the form of frequent thunderstorms. The highest precipitation occurs in May with 14 percent of the year's total followed closely by June with 13 percent. A secondary precipitation maximum occurs in September and October (11 percent and 9 percent of the year's total, respectively).

The precipitation levels are higher in the spring and summer seasons due to locally heavy showers. The precipitation is more general and widespread in the fall and winter months. During the average year a measurable precipitation of 0.01 inches or more is observed on 90 to 95 days. On about 10 of these days, rainfall is at least one inch.

Mean annual snowfall in the basin is from eight to ten inches and is fairly well distributed over the three winter months; December, January and February.

Although periods of relatively heavy snowfall do occur, the frequency of occurence is not very great. During an average year there are only four days with snowfall totalling one inch or more, and daily snowfall of four inches or more is observed only once every two years. Probably more troublesome than the snowfall are the occasional ice storms, observed on an average of five days each year, causing considerable damage to trees and utility lines and making travel difficult.

The process of evaporation, which is enhanced by dry, hot and windy weather conditions, inevitably extracts significant quantities of water from lakes and reservoirs. Evaporation plays an important role in water quantity and, subsequently, water quality.

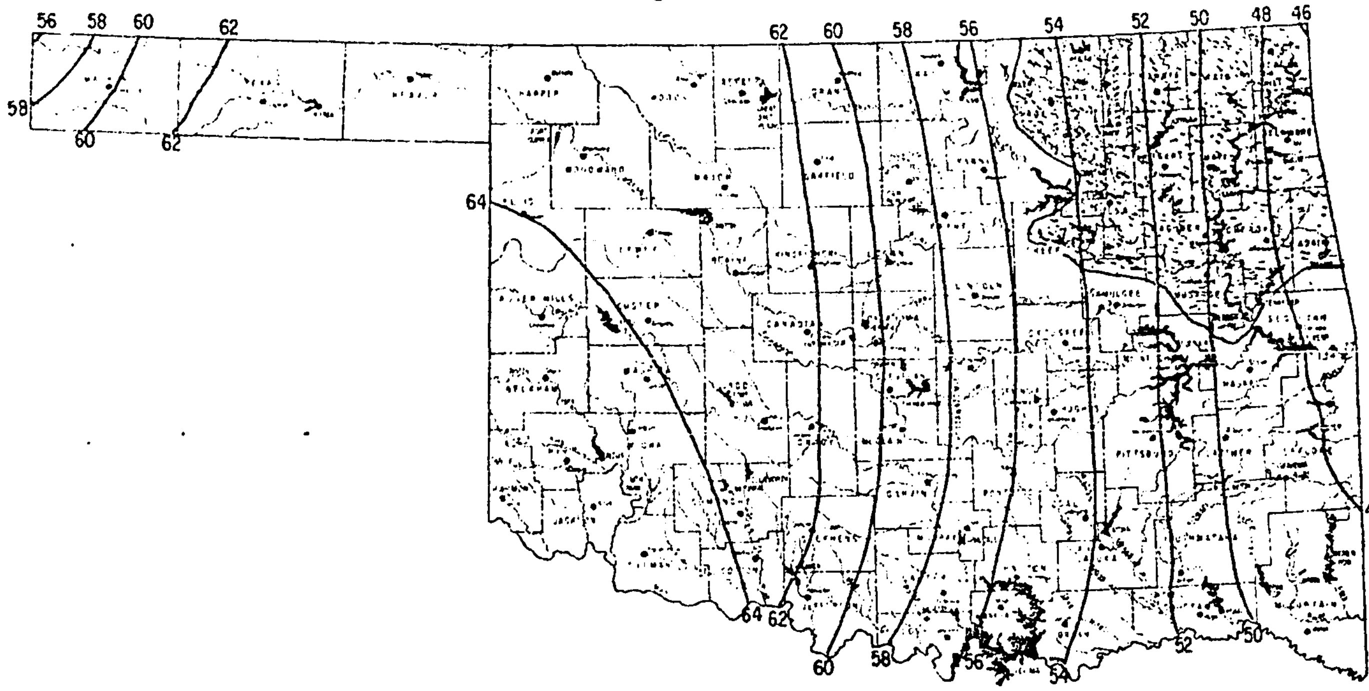
Because of the difficulty in measuring evaporation from lakes, United States Weather Bureau Class A pans are located near reservoirs and lakes of interest. If both ban and reservoir are subject to the same climatological conditions, the water evaporation from the reservoir is approximately 70 percent of the Class A pan evaporation. Figure 7 on page 17 shows the average annual lake evaporation in Oklahoma.

Two climatological properties which have pronounced effects on the rate of evaporation of the surface water are the relative humidity of the air and the magnitude of the surface winds. The mean relative humidity in the basin averages approximately 60 percent during the winter months and 55 percent during the summer months.

Throughout the basin prevailing winds in January and February are northerly, but in all other months winds are generally from a southerly direction. Average yearly wind speeds are 10 to 12 miles per hour across the basin and range from 13 miles per hour in March and April to 9 miles per hour during July, August, and September. Winds of 30 to 40 miles per hour are not uncommon during the spring months when storm centers move eastward across Oklahoma and Kansas. Strong, gusty winds also occur during thunderstorms and during winter months. (Oklahoma Water Resources Board 1971, pp. 41-44)

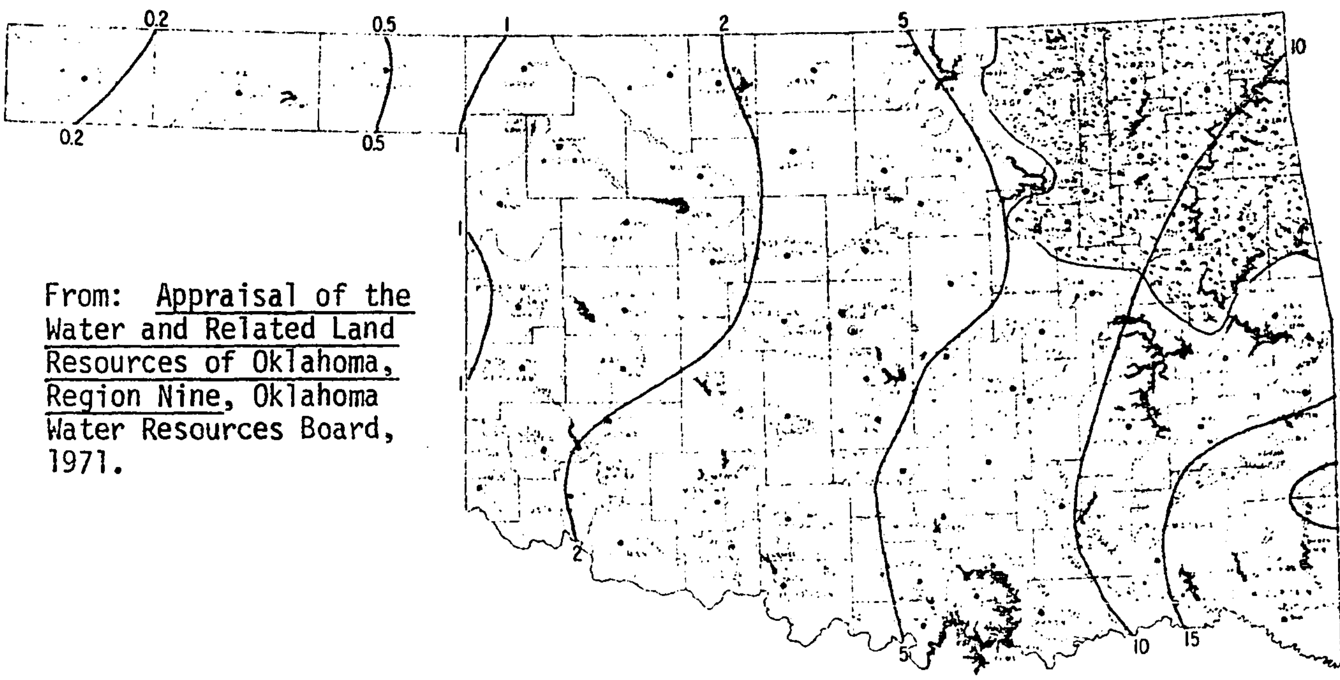
AVERAGE ANNUAL LAKE EVAPORATION
(in inches)
Period 1946-1955

Figure 7



AVERAGE ANNUAL RUNOFF
(in inches)
Period 1931-1960

Figure 8



From: <u>Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine</u>, Oklahoma Water Resources Board, 1971.

Effects on Water Quality

Meteorological conditions determine to a lage extent the quantity of water available for stream flow and infiltration, thus directly affecting both surface water and ground water. Climate conditions influence both the total volume and rate of delivery of precipitation. These in turn affect both quantity and quality of stream flow. Precipitation data is, therefore, an essential part of a water quality study.

Meteorolgical factors such as temperature, relative humidity, and wind velocity and direction help to determine the frequency and intensity of precipitation, both important factors in water quality. The yearly maximums noted earlier for the spring and autumn months for the Middle Arkansas Basin are a result of the warm, humid air masses from the south being brought into contact with the cooler, dryer masses from the northern plains. The driving force is the southerly winds which are predominant at these times of the year. The result is a rainfall of high intensity and short duration. At other times of the year when the air masses are nearer the same temperature, or when lower wind forces allow slower mixing, the resulting precipitation is at a slower rate and over a longer time period.

The intensity of precipitation has an effect on the amount of pollutants flushed off the land surfaces. Generally, the heavier, more intense storms tend to transport a larger amount of suspended pollutants into the streams than slower rainfall of longer duration. The intense storms also yield a larger percent of their total volume to surface runoff while the less intense storms allow greater time for infiltration; thus, an area which receives most of its rainfall in the form of localized thundershowers is likely to have a less sustained stream flow than areas which recieve their precipitation in the form of slow, general rainstorms.

Stream flow from the smaller watersheds in the Middle Arkansas Basin reflect the thunderstorm activity which characterizes the precipitation during the spring and early summer months. Most of the smaller streams lose their flow entirely during the late summer-early fall, while others suffer a significant reduction in flow. This flow reduction severely restricts the assimilative capacity of these streams and limits the allowable discharge load.

Temperature, relative humidity, and winds also affect the rate of evaporation from streams, ponds, reservoirs, and surface soils. The contours in Figure 7 presented earlier indicate that evaporation in the Middle Arkansas Basin is significant. The problems associated with reduction in flow were just discussed. On the positive side, a larger evaporation potential permits the use, in some instances, of total retention ponds in which waste water is evaporated rather than being discharged. This method of treatment is currently being used by several of the smaller communities and some industries in the basin.

In addition to the above effects, temperature also influences the dissolved oxygen content of surface waters and the rate of aquatic biological activity. The concentration of DO at saturation is inversely proportional to the temperature, while biological activity is approximately doubled for every ten-degree (centigrade) rise in temperature. If suitable substrate is available in the streams, the increased demand for oxygen at higher ambient temperature, coupled with the lower saturation level can cause significant DO problems. Unfortunately, the highest temperatures occur in the basin during low flow conditions. This places a greater stress on stream assimilative capacity.

Surface winds also play additional roles in water quality. Wave action created by winds helps keep particles in suspension, particularly in shallow impoundments. This is both an asset and a liability to water quality. The increased turbidity, while aesthetically displeasing, does limit algal growth. The constant mixing also prevents sludge blankets or organics from being deposited and increases the rate of reoxygenation.

Hydrology

Hydrology, the science that deals with the properties, distribution and behavior of water in nature, includes the study of surface water and groundwater. Surface water hydrology describes the flow of creeks and rivers, storage in ponds, lakes, reservoirs, and the physical features and topography which affects these waters. Groundwater hydrology is concerned with the occurrence, movement, and availability of the subsurface water contained in both shallow and deep aquifers.

Surface Water Hydrology

The surface water hydrology portion of this paper includes discussions of stream-flow, surface, and water resources development characteristics of the Middle Arkansas Basin, along with an assessment of their effects on in-stream water quality.

Stream-Flow Characteristics. The following paragraphs contain general information on total basin runoff and on stream-flow characteristics of each of the six river basins comprising the total drainage area of the Middle Arkansas Basin.

Figure 8 on page 17 shows the basin's average annual runoff contours in inches during the period 1931-1960. During an average year when the precipitation is about 38 inches, the drainage area of the basin (9685 square miles) generates a total runoff of approximately nine inches, corresponding to 4,649,000 acre-feet of water. Of this amount only a relatively small percentage of the total (6%) is being utilized according to the water use records of 1968. These records show that in the 17-county area that comprises a somewhat larger drainage area than the area included in the basin, a total of 266,000 acre-feet of water was utilized. (OWRB 1971, p. 65)

Main Stem Arkansas River. The portion of the Arkansas River Basin included in the basin consists of that area between the confluence of the Arkansas with the Canadian River upriver to the Keystone Dam. The actual river length of the Arkansas in the basin is 116.1 miles, due to its meandering path. The total drainage area for the Arkansas River system above its confluence with the Canadian River is 99,127 miles. This area includes a considerable portion of the states of Oklahoma, Kansas, and Colorado.

Since September of 1964, the flow in the Arkansas River has been regulated by the Keystone Reservoir Dam, located near Sand Springs, and to a somewhat lesser degree by the navigational facilities which were completed in 1971 below the confluence with the Verdigris River. (OWRB 1971, p. 65) Figures 9 and 10 on pages 22 and 23 show the duration curve of daily discharge for two points on the Arkansas River.

Grand Noesho River. Above its confluence with Spring River, the Grand Neosho River is usually referred to as the Neosho River; below this point to its termination in the Arkansas River near Muskogee it is called Grand River. The Neosho rises in Morris County, Kansas, and flows generally

ARKANSAS RIVER at TULSA

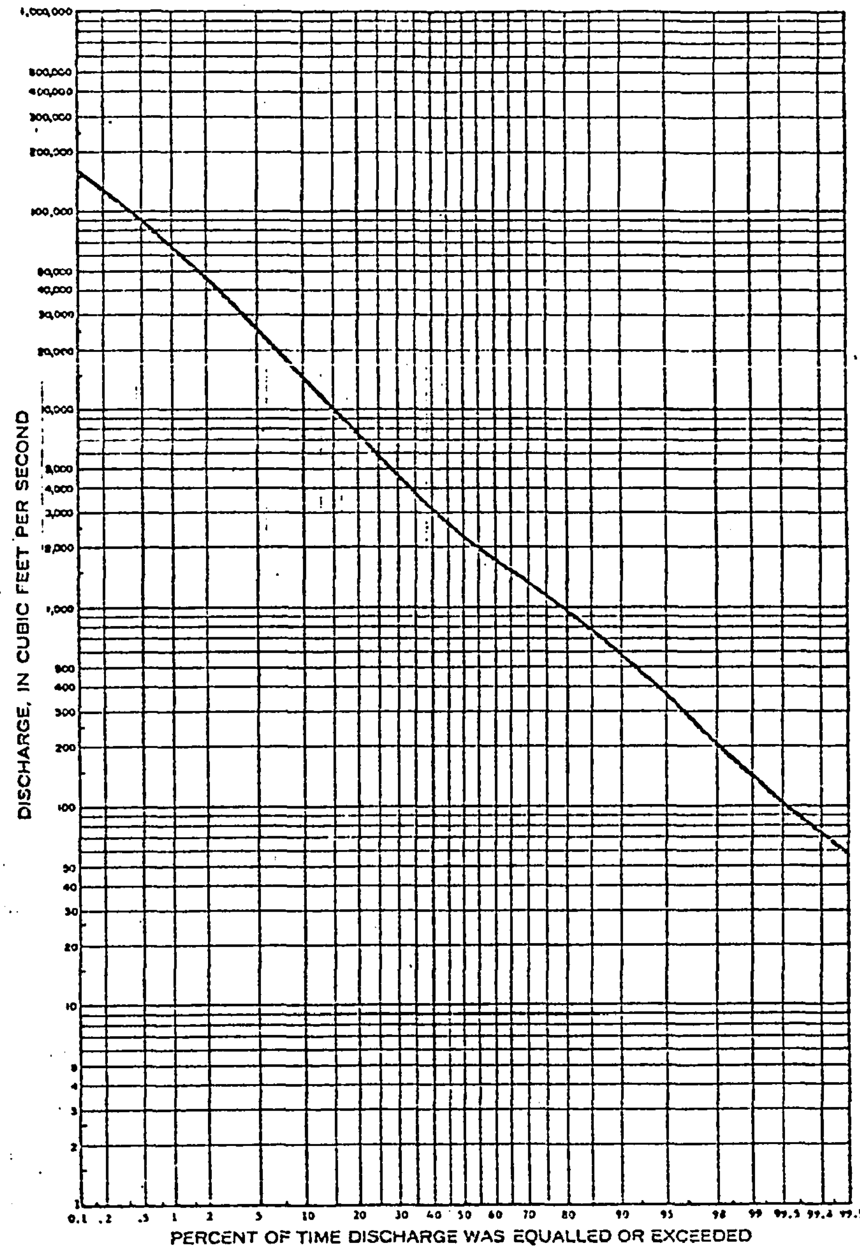


FIGURE 9
DURATION CURVE of DAILY DISCHARGE

From: Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine, Oklahoma Water Resources Board, 1971.

ARKANSAS RIVER at MUSKOGEE

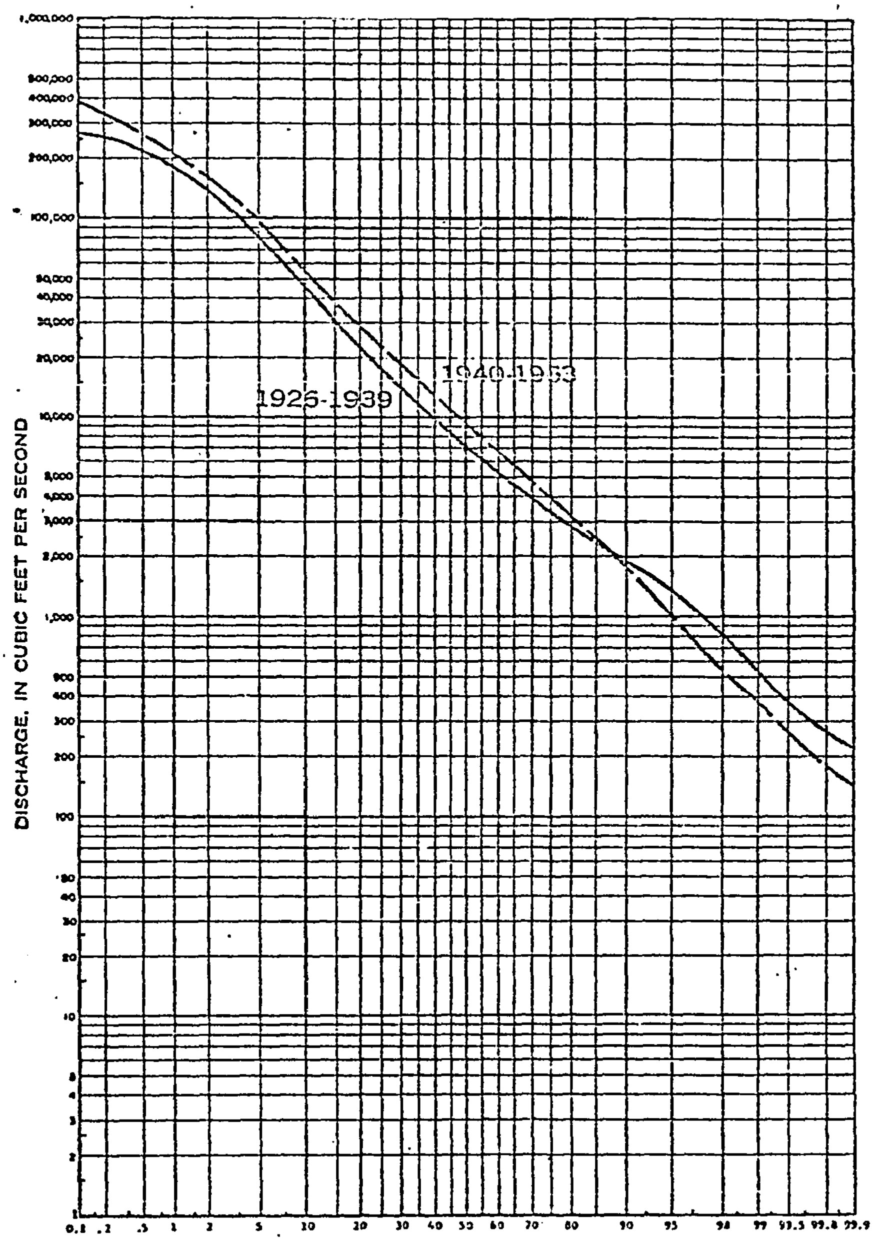


FIGURE 10

DURATION CURVE of DAILY DISCHARGE

From: Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine, Oklahoma Water Resources Board, 1971.

south to southeastward, joined by its major tributaries, Labette Creek, Spring River, Spavinaw Creek, and Pryor Creek before its confluence with the Arkansas. The stream basin of the Neosho River is quite irregular comprising a drainage area of 12,520 square miles in Oklahoma and the neighboring states of Kansas, Missouri, and Arkansas. The most important feature of this area is the chain of reservoirs providing hydroelectric power and recreation facilities for this reach of the river in Oklahoma. (OWRB 1971, p.65) Figure 11 on page 25 shows the duration curve of daily discharge for the stream gaging station located below the Fort Gibson Reservoir on the Grand Neosho.

Verdigris River. Rising in the southeast corner of Chase County, Kansas, and running in a general southerly direction, the Verdigris River is joined by its main tributaries of Willow Creek, Fall River, Elk River, Caney River, and Bird Creek before its confluence with the Arkansas River near Muskogee. Within Oklahoma are 4290 of the 8303 square miles included in the Verdigris drainage area.

Stream-flow characteristics will probably be somewhat affected by the navigational facilities completed in 1971 on the Verdigris River below Catoosa, although these facilities do not include provision for flood control. (OWRB 1971, p. 65) Figure 12 on page 26 shows the Surface Water Records and Duration Curve of Daily Discharge for the gaging station located on the Verdigris River at Lenapah.

Caney River. The Caney River enters Oklahoma in the northern portion of Osage County and flows in a southeasterly direction through Hula Reservoir and then turns to a southerly—southeasterly direction through Washington and Rogers Counties to its confluence with the Verdigris River

GRAND-NEOSHO RIVER at FT. GIBSON

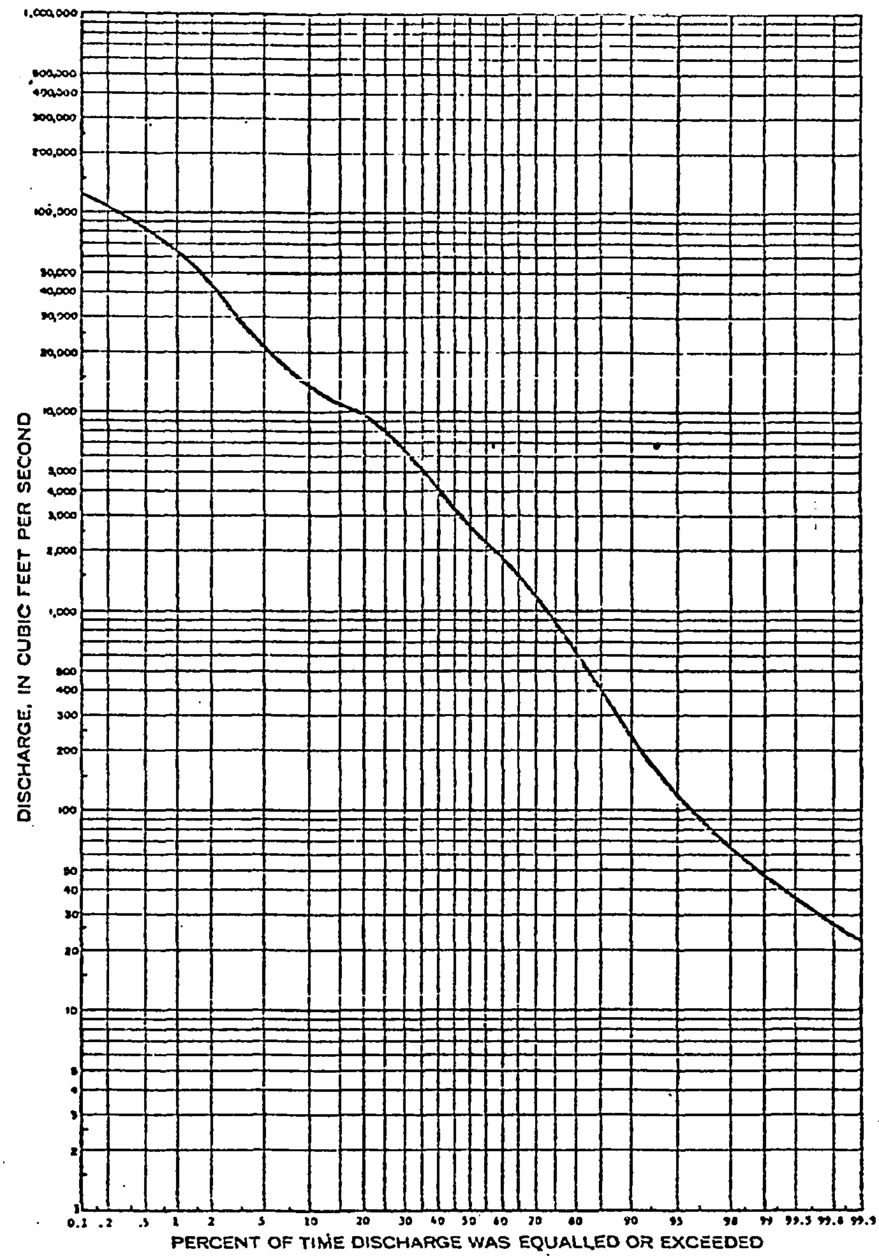


FIGURE 11

DURATION CURVE of DAILY DISCHARGE

From: <u>Appraisal of the Water and Related Land Resources of Oklahoma</u>, Region Nine, Oklahoma Water Resources Board, 1971.

VERDIGRIS RIVER at LENAPAH

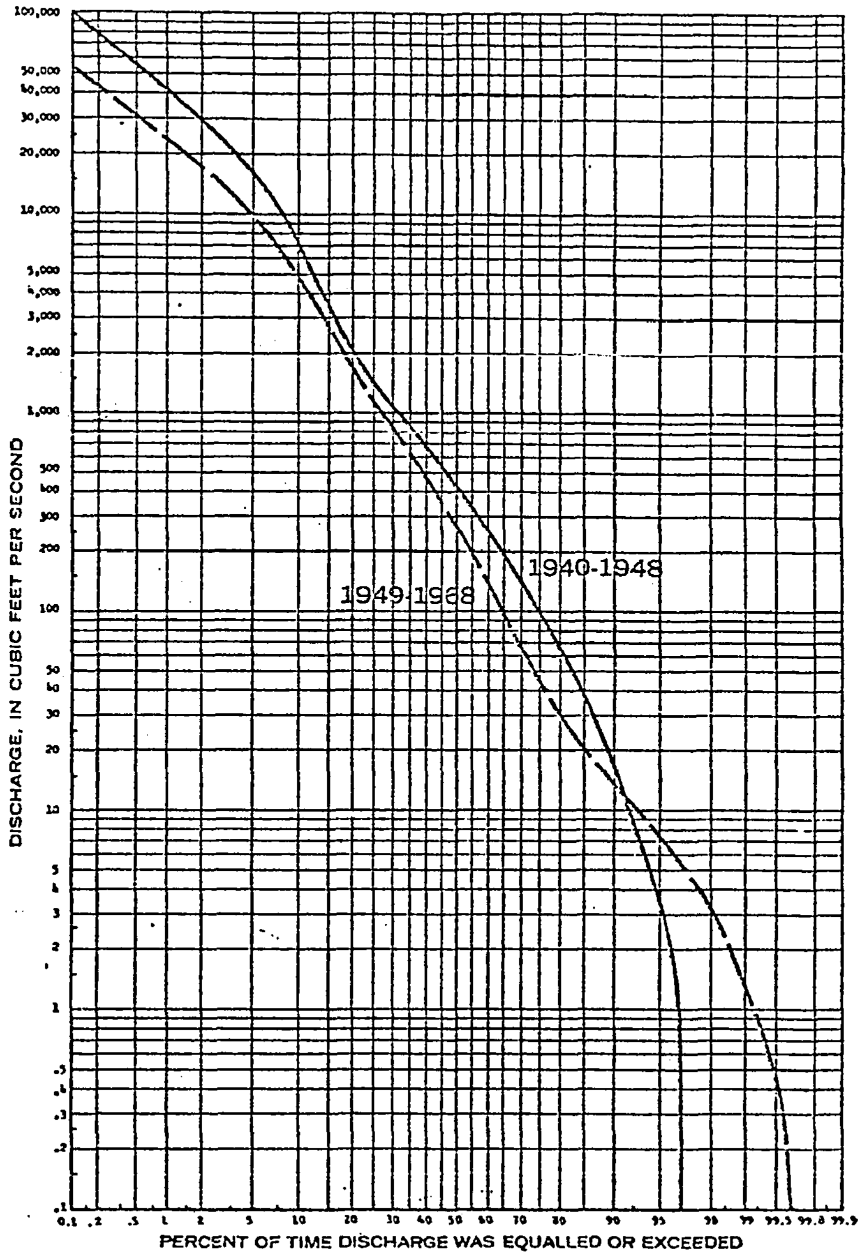


FIGURE 12

DURATION CURVE of DAILY DISCHARGE

From: Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine, Oklahoma Water Resources Board, 197 northwest of Claremore. One-thousand, sixteen square miles of the Caney River's 2111 square mile drainage area are in Oklahoma. The Caney River rises in the western part of Elk County, Kansas, at an elevation of about 1660 feet above mean sea level and terminates at an elevation of 550 feet at its confluence with the Verdigris. The average annual discharge at the U.S.G.S. gaging station located near Ramona, Oklahoma is 623,000 acre-feet for the 27-year period ending in 1969. (OWRB 1971, pp. 65-66)

Illinois River. Originating in northwestern Arkansas at an elevation of about 1600 feet, the Illinois River flows in a southwesterly direction, entering Oklahoma near Siloam Springs, Arkansas. It flows in a generally south-southwesterly direction through Tenkiller Reservoir to its confluence with the Arkansas River near Gore at an elevation of 550 feet. Joined in its course along the Oklahoma reach by its major tributaries, Ballard Creek, Flint Creek, Barren Fork, and Caney Creek, the Illinois River drains an area of about 1660 square miles in its total basin, about 900 square miles of which are in Oklahoma. (OWRB 1971, p. 66) The topography of the basin is in general rough and broken with the streambed strewn with boulders along a gravelly bottom characteristic of many mountain streams. Stream flow at the U.S.G.S. gaging station below Tenkiller Reservoir has recorded a yearly average of 1,058,000 acre-feet for a 31-year average ending in 1969. Figure 13 shows the Surface Water Records and Duration Curve of Daily Discharge for the stream gaging station located near Tahlequah.

Bird Creek. Rising at an elevation of 1100 feet a short distance northwest of Personia in Osage County, Bird Creek flows generally southeastward to eastward across Tulsa County. Joined along its course by Middle and Lower Bird Creeks (the source of Bluestem Lake), Birch, Candy, Hominy, and

ILLINOIS RIVER at TAHLEQUAH

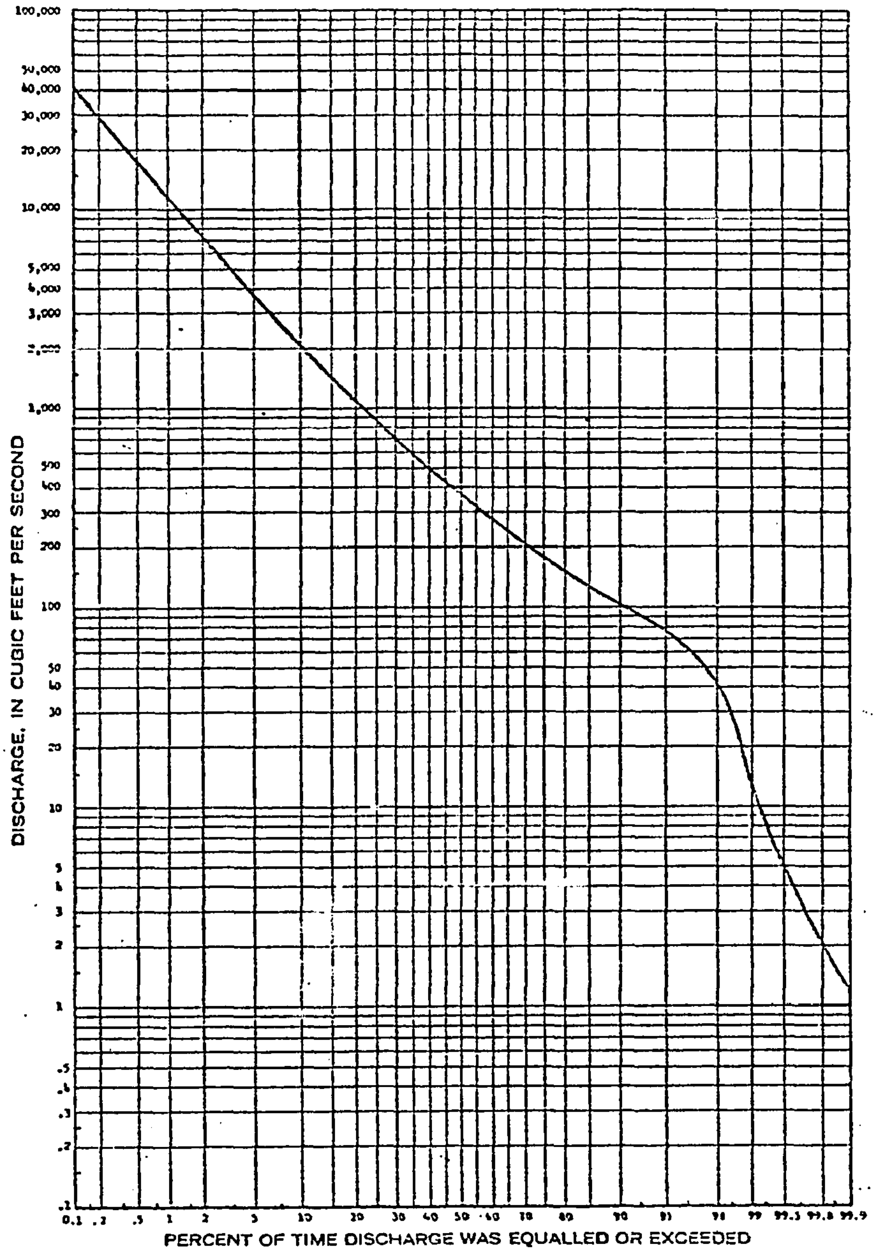


FIGURE 13

DURATION CURVE of DAILY DISCHARGE

From: Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine, Oklahoma Water Resources Board, 1971.

Delaware Creeks, it moves to its confluence with the Verdigris River just north of Catoosa in Rogers County. At this point the elevation is about 530 feet. The entire 1147 square mile drainage area of Bird Creek is in Oklahoma.

Bird Creek's continuous stream gaging station located near Sperry has recorded an average annual flow of 318,100 acre-feet for the 31 year period extending to 1969. (OWRB 1971, p. 66) Figure 14 on page 30 shows the Surface Water Records and Duration Curve of Daily Discharge for the continuous stream gaging station located near Avant.

Surface Characteristics. The surface characteristics of the land area comprising the Middle Arkansas Basin will be discussed under three sub-headings; topography, vegetation cover, and surface soils, and surface water development.

Topography. The Ozark Mountains, generally east of the Grand Neosho River, and the Prairie Homocline, west of the Grand Neosho River, are the two physiographic features found in the basin.

The Park Mountians exhibit deeply dissected karst topography, with fault divides separated by deep, V-shaped valleys. Bugger Mountain, Adair County, boasts the region's highest elevation, 1750 feet mean sea level (msl). The Region's lowest evelvation, about 430 feet msl, is at the confluence of the Arkansas and Canadian Rivers. Local relief is as high as 500 feet, but average relief is about 250 feet. The land surface slopes westward and southward from the Arkansas and Missouri borders, and the topography is mature, with 60 percent slopes, 30 percent uplands, and 10 percent bottomlands. The drainage is dendritic, with streams flowing westward and southwestward into the Grand Neosho and Arkansas Rivers. Flood plains of one to four miles for the main rivers and about one-

BIRD CREEK at AVANT

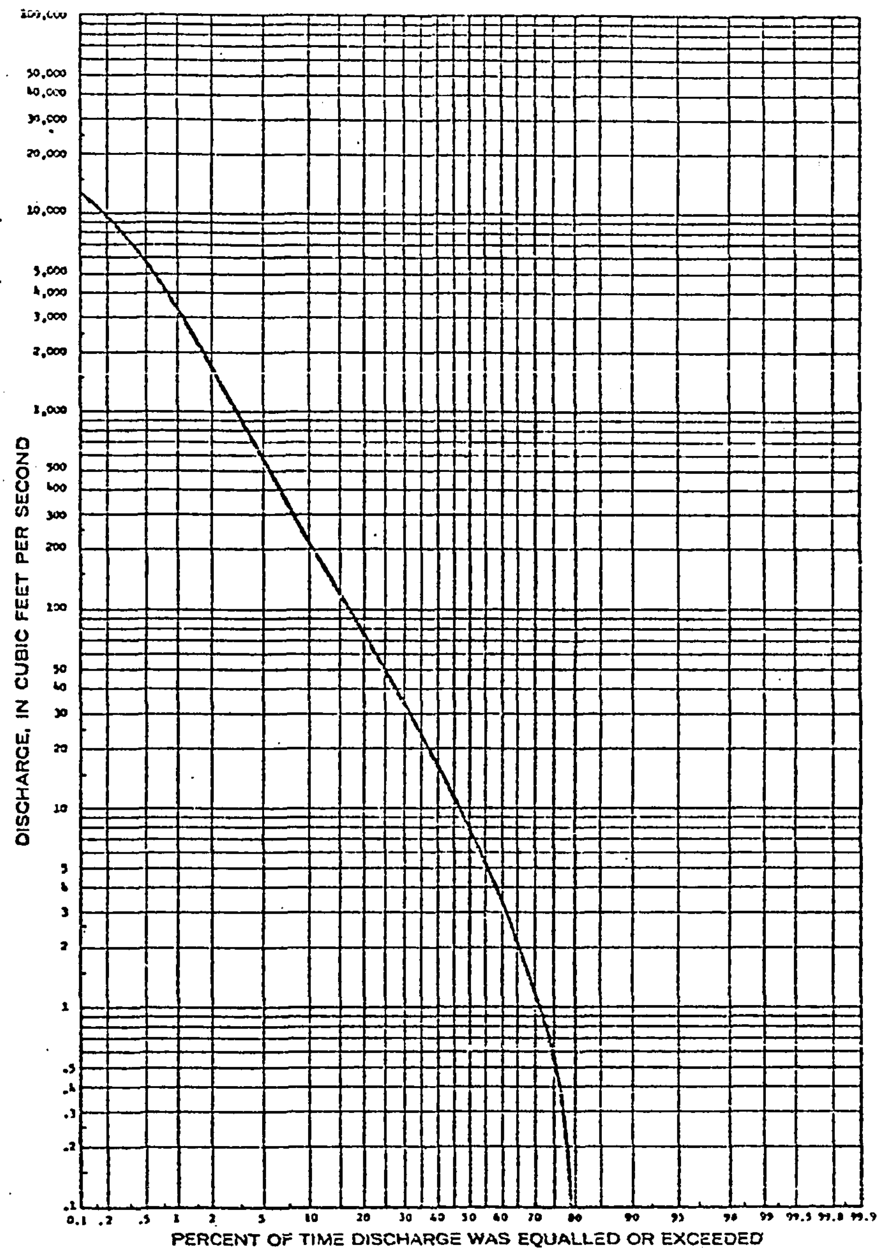


FIGURE 14

DURATION CURVE of DAILY DISCHARGE

From: Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine, Oklahoma Water Resources Board, 1971.

quarter mile for smaller streams are found in the basin. The average gradient for larger rivers is two to four feet per mile and for smaller streams is ten to twenty-five feet per mile. For larger streams entering the Grand Neosho River the stream density is about one stream every two to three miles. (OWRB 1971, pp. 22-23)

The Prairie Plains Homocline slopes eastward from a maximum elevation of 1340 feet msl in northern Osage County to about 500 msl on the Arkansas River with an average elevation of about 750 feet msl. Local relief may be as much as 300 feet. The area is characterized by gently rolling hills with eastward facing escarpments capped by resistant limestone and sandstone with intervening valleys excavated in shales. It exhibits a native topography with 70 percent uplands, 20 percent slopes, and 10 percent bottomlands. The drainage is dendritic, modified trellace, following the escarpments locally with stream flow southward and southeastward. Gradients of three to five feet per mile are found on larger streams, while the smaller tributaries have gradients of ten to twenty-five feet per mile. About one large stream enters the main rivers every three miles. One to five-mile flood plains exist on the major rivers, while smaller streams have flood plains of about one-quarter mile. (OWRB 1971, p. 23)

Vegetation and Soils. Names of soils which dominate and typify the landscape make up a soil association, although other important soils usually occur in each association. The soils in the Middle Arkansas Basin have been divided into ten naturally occurring associations and grouped into three different soil resource areas: Cherokee Prairie, Ozark Highlands, and Cross Timbers. Each soil resource area is defined by its geology, vegetation, and topography.

Soils in the Ozarks are developed from cherty limestone of the Mississippian Age. All other upland soils in the basin are developed from sandstones, siltstones, and shales of Pennsylvanian Age. Soils developed in alluviums deposited by streams which drain a particular upland area are influenced primarily by tall grasses. These grassland soils of the Cherokee Prairie comprise the typical and dominant soil association found in the basin. Cherokee Prairie soils are bordered on the east by soils of the Ozarks which are influenced mostly by blackjack oak, post oak, and hickory. To the west of this area occurs soils of the Cross Timbers; there, mixtures of soils are developed either from grasses or woodlands. (OWRB 1971, p. 35)

Surface Water Resource Development. The existing surface water resources developed in the basin include nine reservoirs, more than 100 smaller lakes, and approximately 30,000 flood retention and stock ponds less than ten acres in surface area. Five more lakes, in addition to these already constructed in the basin, have been authorized for construction by congressional action; another five sites have been considered potential locations for dams. (OWRB 1971, p. 83)

Table 1 on page 33 shows the drainage area, the flood control area, the conservation and the maximum storage area, the conservation pool area, the yield and purpose for the nine major reservoirs. Table 2 on page 34 shows similar information on the five authorized reservoirs.

Several cities and towns in the basin have developed their own projects for use as present or potential water supplies for other beneficial purposes. Table 3 on page 35 shows a list of the 24 city lakes within the basin and gives the surface area and conservation storage of each facility.

Several local organizations have developed watershed programs within

From: <u>Appraisal of the Water and Related Land Resources of Oklahoma</u>, Region Nine, Oklahoma Water Resources Board, 1971.

TABLE 1

DEVELOPED SURFACE WATER RESOURCES

SITE NAME	STREAM	DRAINAGE AREA (sq mi)	FLOOD CONTROL (ac-ft)	CONSERVATION AND SEDIMENT STORAGE (ac-ft)	MAXIMUM STORAGE (ac-ft)	CONSERVATION POOL AREA (acres)	YIELD (mgd)	PURPOSE**
Hulah	Caney	732	257,900	34,700	292,600	3,600	16.9	FC-WS-R-FW-WQC
Heyburn	Polecat	123	49,100	8,200	57,300	980	1.7	FC-WS-R-FW-WQC
Oologah*	Verdigris	4,339	965,500	553,400	1,519,000	29,500	154.0	FC-WS-R-FW-N
Webbers Falls	Arkansas	97,033	-	-	165,200	10,900	-	N-P-R-FW
Fort Gibson	Grand	12,492	919,200	-	1,284,400	19,900	-	FC-P-R-FW
Lake Hudson	Grand	11,533	244,200	-	444,500	10,900	-	FC-P-R-FW
Lake O the Cherokees	Grand	10,298	525,000	-	2,197,700	46,500	-	FC-P-R-FW
Tenkiller Ferry	Illinois	1,610	589,000	294,100	1,230,000	12,650	12.0	FC-P-WS-R-FW
Greenleaf	Big Greenleaf	81	3,600	13,500	17,100	900	-	FC-R
TOTALS		138,241	3,553,600	903,900	7,207,100	135,830	184.6	

*Statistics given for ultimate develoment
** FC-Flood Control, WS-Water Supply, R-Recreation, FW-Fish and Wildlife, P-Power, N-Navigation, WQC-Water Quality Contro

TABLE 2

AUTHORIZED SURFACE WATER DEVELOPMENT

SITE NAME	STREAM	DRAINAGE AREA (sq mi)	FLOOD CONTROL (ac-ft)	CONSERVATION AND SEDIMENT STORAGE (ac-ft)	MAXIMUM STORAGE (ac-ft)	CONSERVATION POOL AREA (acres)	YIELD (mgd)	PURPOSE**
Birch	Birch	66	39,000	19,200	58,200	1,137	6.0	FC-WS-R-FW-WQC
Candy	Candy	43	30,700	41,000	72,400	2,120	8.0	FC-WS-R-FW-WQC
Copan	Little Caney	505	184,300	46,000	230,300	4,350	19.0	FC-WS-R-FW-WQC
Sand	Sand	137	51,700	39,300	91,000	1,940	13.0	FC-WS-R-FW-WQC
Skiatook	Hominy	354	182,300	331,200	513,500	10,540	76.0	FC-WS-R-FW-WQC
		1,105	488,000	476,600	965,400	20,587	122.0	

*Statistics given for ultimate development
**FC-Flood Control, WS-Water Supply, R-Recreation, FW-Fish and Wildlife, P-Power(hydroelectric), N-navigation, and WQC-Water Quality Control

From: Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine, Oklahoma Water Resources Board, 1971.

TABLE 3

MUNICIPAL LAKES

LAKE NAME	CITY SUPPLIED	AREA (acres)	CONSERVATIVE STORAGE (acre-feet)
Frances	Siloam Springs, Ark.	570	2,000
Sahoma	Sapulpa	485	4,850
Eucha	Tulsa	2,880	79,567
Ramona	Ramona	14	70
Spavinaw	Tulsa	1,638	30,590
Hudson	Bartlesville	335	5,300
Pawhuska	Pawhuska	95	2,850
Waxhoma	Barnsdall	140	2,000
Hominy	Hominy	200	5,000
Bluestem	Pawhuska	800	17,000
Claremore	Claremore	431	2,586
Yahola	Tulsa	425	7,000
Mounds	Mounds	16	120
Sapulpa	Sapulpa	96	800
Low Water Dam	Sapulpa	12	40
Pretty Water	Sapulpa	30	150
Warner	Warner	18	144
Chelsea No. 1	Chelsea	14	210
Chelsea No. 2	Chelsea	25	100
Boynton	Boynton	17	85
Haskell	Haskell	17	170
Nowata	Nowata	65	200
Hominy City	Hominy	18	270
Ochelata	Ochelata	15	75
TOTAL		8,356	161,177

From: Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine, Oklahoma Water Resources Board, 1971 the basin since the passage of the Watershed Protection and Flood Prevention Act of 1954. Public Law 566, commonly referred to as the small watersheds program, emphasises the importance of local leadership in initiating plans and applying needed measures for protection of watershed drainage areas and reduction of flooding on productive bottomlands. The Soil Conservation Service of the United States Department of Agriculture gives technical and financial assistance for the planning and installation of works of improvement. Floodwater retarding structures may, at the request of local sponsors, be planned to include additional storage for municipal water supplies, agricultural water management, and recreational fish and wildlife water supplies.

The Double Creek watershed, located within the Middle Arkansas Basin in Washington and Osage Counties, is one of the nation's first completed pilot watershed projects. The Double Creek project contains over 30,000 acres of drainage area and has six floodwater retarding structures. Other watershed developments in the basin include the small hydrological units being planned and installed in the Cherokee Hills project authorized under the Food and Agriculture Act of 1962. This project includes Delaware, Mayes, Sequoyah, and Ottawa Counties. (OWRB 1971, p. 79)

The McClellan-Kerr Navigation Project, opened to traffic in 1970, is certainly a major surface water resource development within the basin. In Oklahoma, this navigation system on the Arkansas River extends up to the Port of Muskogee where the navigation route turns upstream on the Verdigris River for the last 50 miles before reaching the head of navigation at Tulsa's Port of Catoosa. The waterway has a minimum navigation depth of nine feet, with a minimum width of 250 feet provided on the Arkansas River. Constructed 150 feet wide, the Verdigris River Channel was designed for future widening to 250 feet. The 110-foot-wide by 600-foot-long locks can accommodate up to eight 35 by 195 feet barges in each lockage. The three locks and dams located within the basin are Webbers Falls Lock and Dam on the Arkansas River and Chouteau and Newt Graham Locks and Dams on the Verdigris. Also within the basin is a turning basin at the waterways terminus near Catoosa. (OWRB 1971, pp. 90-91)

Effects on Water Quality

The effects of hydrological characteristics on surface water quality can be significant. Runoff carries with it waste loads that are largely dependent upon the land use of the area, a phenomenon which will be discussed at length in a later section. Once in the stream, the fate of these wastes, along with the wastes discharged by point sources, depends upon stream depth and velocity, impoundments and many other factors relating to the hydrological characteristics of the streams. Surface characteristics such as topography and soils are also contributing factors to water quality.

Stream velocity depends primarily upon the slope of the channel, a result of topography. Stream velocity influences several water quality parameters, notably sediment transport and organic assimilative capacity. While the swift, mountain-type streams in the eastern half of the basin have a greater sediment transport capacity, available data indicates that the suspended solids load is less in those streams than that in the slower, deeper streams in the western region. This is most likely due, however, to the nature of the soils and vegetation cover of the eastern area. Undisturbed forest lands, such as characterize the area east of the Grand Neosho, produce much less sediment than do cultivated farms and pasture areas such as characterize other parts of the basin. Stream beds eroded in the rock formations of the eastern part are also more stable than the soil channels in the prairie region.

The flow volume of streams is an important factor in water quality. Not only does the quantity of water available for dilutional purposes directly influece the amount of pollution which can be safely added to streams, but the increased surface area and the added turbulence from increased velocity enhance the regenerative capacity with respect to organic loads. The fact that many of the tributaries in the basin are dry, or have very low flow during parts of the year, is one of the most significant factors affecting water quality in the basin.

The reservoirs located on the main streams and on some of the tributaries in the basin probably constiture another major factor in water quality. Not only do these impoundments help in maintaining flow during dry periods, but they act as equalization basins for minerals and other conservative pollutants. This is demonstrated quite dramatically by the decrease in total dissolved solids in the Verdigris River between Lenapah and Inola, a reach of the river containing Oologah Reservoir.

These reservoirs also serve as settling basin for the sediment in runoff water. This helps to improve quality in the present time frame. It is apparent, however, that this sediment build-up will have to be dealt with at some time in the future.

Groundwater Hydrology

Groundwater of sufficient quality and quantity for most uses is not available in most parts of the basin. In most sections of the basin, the yield and/or quality of the groundwater is such that most water supplies must be drawn from the surface waters.

High yields of water can be obtained from aquifers in the eastern one-third of the basin. The quality of waters from the deep aquifers in the northeastern part of the basin is good, but deteriorates to an unsuable quality toward the southern part. Shallow aquifers in the east-central part of the basin provide good water from wells and also feed springs which contribute significantly to the stream flow from this region.

Alluvium along the Arkansas River and some parts of the other main streams have a significant yield. In most cases, however, this water is hgih in chloride or bicarbonates. Groundwater along the upper reaches of the Bird Creek-Caney River watersheds in the western part of the basin is sufficient both in quantity and quality for most uses. As these waters flow southeastward, their quality changes such that they are no longer usable. (OWRB 1971, pp. 93-97) Table 4 on the following page presents a summary of groundwater quality in the basin.

Human-Related Characteristics

Such human-related characteristics as population and employment trends and land and water use may affect water quality and quantity in many inter-related ways. For example, the rural to urban shift with its correlative agriculture-to-industry move means higher concentrations of human and industrial wastes in metropolitan areas.

Furthermore, both the quantity and quality of waste produced by any area are influenced by the use to which the land is put. Finally, water use, which influences the quality and quantity of water remaining in streams, is directly influenced by land use.

While a thorough study of the nature and implications of human-related characteristics of the basin has not yet been attempted, the following paragraphs provide data which shows some trends in population, employment,

TABLE 4

SUMMARY OF CHEMICAL ANALYSES OF WATER FROM:

	Maximum	Median	Minimum	Number of Analyses
ALLUVIUM				
Hardness	540	185	34	18
Sulfate	519	26	0.0	17
Chloride	265	22	3.0	18
Nitrate	30	0.8	0.0	18
Total dissolved solids	1,140	335	105	17
ROUBIDOUX				
Hardness	420	146	118	32
Sulfate	124	16	0.3	32
Chloride	780	79	1.6	32
Nitrate	8.0	0.8	0.0	32
Total dissolved solids	1,570	276	140	32
SPRINGS				
Hardness	190	110	58	22
Sulfate	15	1.6	0.5	22
Chloride	49	5.4	2.8	22
Nitrate	16	4.0	0.1	22
Total dissolved solids	243	142	83	22
PENNSYLVANIAN & UPPER MISSISSIPPIAN				
Hardness	1,300	268	28	58
Sulfate	2,090	75	1.8	58
Chloride	1,520	37	1.8	58
Nitrate	228	1.4	0.0	58
Total dissolved solids	3,220	576	117	58
BURGEN SANDSTONE				
Hardness	404	118	9	20
Sulfate	166	16	0.6	20
Chloride	92	12	2.4	20
Nitrate	26	1.1	0.0	20
Total dissolved solids	900	221	118	20

*From: Appraisal of Water and Related Land Resources of Oklahoma, OWRB. 1971.

land use and water use, and attempts to relate these characteristics to water quality.

Population and Employment Trends

Information on present and projected population and employment trends is given in the subsections below.

Present Trends

The Middle Arkansas Basin contains 12,586 square miles or roughly 18 percent of Oklahoma's land area and 762,374 persons (Oklahoma Employment Security Commission 1972) or approxinately 30 percent of the state's population. The basin has a population density of 78.72 persons per square mile, higher than the state average, 36.60. However, the major portion of the population is in the south and west part of the basin. Three cities, Bartlesville, Muskogee, and Tulsa contain 72.7 percent of the area's population. Tulsa has dominated the basin's population and economic statistics with 60.4 percent of the population followed by Muskogee with 6.8 percent, and Bartlesville with 5.4 percent.

The three counties intersecting in the Tulsa metropolitan area exhibited significant changes over the ten-year period 1960-1970. For example, Tulsa County's population advanced 16.1 percent for a gain of 55,625 persons. Creek County increased its total 12.4 percent with the addition of 5,037 residents. Osage County, however, declined 8.3 percent, losing a total of 2691 inhabitants. The impressive gain registered in Tulsa County demonstrates that the rural-to urban shift does, in fact affect large segments of the state's population. Tulsa County, including the city of Tulsa, has the industrial base and urban facilities that attract rural people, often through the large variety of available job opportunities.

Gains were also evident among other counties in the region. Rogers County expanded its population 6490 for an increase of 41.4 percent, and smaller gains were posted by Delaware, Cherokee, and Sequoyah Counties. At the same time, declines were recorded in Nowata, Craig, Okmulgee, Muskogee, and Washington Counties. The long-term decline in the importance of agriculture as a major employer is a primary cause of reducing populations in many of these counties. Over the past decade, small farmers have continued to abandon their operations and move to the major urban areas in Oklahoma and elsewhere in search of industrial employment and employment of other types. Establishment of more manufacturing firms in these counties could do much to reverse the current trend of outmigration, as evidenced by the substantial growth recorded in most counties having a relatively greater share of manufacturing establishments.

The employment picture for the basin is heavily influeced by the Tulsa Standard Metropolitan Statistical Area (SMSA). In 1970, this area accounted for more than 70 percent of the wage and salary workers in the basin, and nearly three-fourths of the manufacturing workers were employed in the Tulsa area. An idea of the extent to which the SMSA dominates the region is gained by a closer look at manufacturing. This division showed an overall gain of 0.4 percent between 1968 and 1970. If the Tulsa area is removed from the calculation, the percentage increase in this division becomes 7.6 percent. In this case, the decline of 800 manufacturing workers that took place in the SMSA offset much of the gain that occurred in this division among other counties in the basin. It should be noted that manufacturing is the only industry division where the gain between 1968 and 1970 was moderated by a decrease in the SMSA, with aerospace reductions principally responsible for the Tulsa losses. All of the other industry divisions exhibited gains for the metropolitan area as well as for the basin as a whole.

Several of the counties in the basin have posted significant employment gains over the two-year span, particularly in manufacturing. Mayes County, for instance, showed an increase of nearly 30 percent in factory employment with a variety of new expanded plants. The addition of 400 manufacturing workers in Washington County came as a result of developments in diversified factories. Craig County's manufacturing employment rose 75 percent over the two-year period due to the establishment of a large furniture and fixture firm. It should be mentioned, however, that this company has suffered considerable layoffs since June 1970.

On the darker side, basin-wide unemployment rose 4470 between 1968 and 1970 to a level of 21,715 persons. This figure represents 6.5 percent of the area labor force compared to 5.3 percent two years earlier. Over 55 percent of the jobless workers were concentrated in the Tulsa SMSA where considerable job loss has occurred primarily in the aerospace industry. Continued layoffs in this industry, necessitated by cutbacks in federal expenditures, have also affected the counties adjacent to or within commuting distance of the metropolitan area. Completion of any construction projects associated with the Arkansas River Navigation Project has also tended to increase the number of unemployed in the basin. However, the establishment of this new inland waterway could do much in the way of creating the environment necessary for the attraction of a variety of new industrial concerns; and as a result, the employment situation in the basin should experience a substantial improvement. (Indian Nations Council of Governments 1969; Northeastern Counties of Oklahoma 1972a; Northeastern Counties of Oklahoma 1972b)

Projected Trends

Two sets of forecasts of population growth to the year 1990 have been made for the basin; one was made by the Oklahoma Employment Commission, the other by the Substate Planning Districts. As a general rule, the Substate Planning Districts projections anticipate higher growth than the OESC projections. The difference in growth rates is due to differences in projection methodology. OESC's projections are based on natural increase and migration while the Substate Planning Districts use more complex methods in an attempt to account for innovations and changes in economic patterns. As the official state statistical agency, the OESC projections are uniform for the state and are the data-base for the projections of employment, industrial, urban, and other growth, therefore, the OESC population projections will be used. Table on the following page shows the OESC population projections by county for the Middle Arkansas Basin. Table 5 below indicates the population of the basin will increase by 26 percent by 1990.

TABLE 5

POPULATION PROJECTIONS

Major Cities

City	1970	1975	1980	1990
Bartlesville	29,672	29,320	29,740	30,160
Muskogee	37,331	37,490	37,910	49,989
Tulsa SMSA	475,264	504,900	542,500	625,200
3 cities total	542,267	571,710	610,150	705,340
Basin Total	762,374	732,300	789,400	961,200
% of basin total in 3 cities	71.13	78.07	77.29	73.38
% of basin total in Tulsa	62134	68.95	68.72	65.04

*Oklahoma Employment Security Commission

TABLE 6

POPULATION PROJECTIONS BY COUNTY*

County	1970	1975	1980	1985	1990
Adair	15,141	15,700	16,400	17,000	17,500
Cherokee	23,174	23,700	24,300	24,000	25,500
Craig	14,722	14,000	13,600	13,400	13,200
Creek	45,532	48,000	50,900	54,100	57,800
Delaware	17,766	17,900	18,300	18,700	19,300
Mayes	23,302	24,800	26,300	27,500	28,700
Muskogee	59,542	59,200	59,200	60,100	62,000
Nowata	9,773	9,200	8,800	8,600	8,300
Osage	29,750	28,800	28,800	27,500	26,800
Ottawa	29,800	30,800	31,900	33,200	34,500
Rogers	28,425	32,000	36,300	41,500	47,500
Tulsa	399,982	428,100	462,800	500,300	540,600
Wagoner	22,163	24,900	26,100	32,000	36,500
Washington	43,302	42,600	42,900	43,000	43,000

*from the Employment Security Commission

The Tulsa SMSA is projected to make the largest population gains. The modest population gains taking place in the more rural portions of the basin are projected to be due to rural manufacturing, tourism, and service industries. Most of the rural manufacturing development is expected to take place along the Arkansas River Navigation System and near Tulsa. The Eastern Oklahoma Development District (southern portion of the basin) estimates that 92 percent of their population growth will be a consequence of manufacturing, the remaining 8 percent will come through tourism development. Rural area adjacent to the Tulsa SMSA (which may be slightly underbounded) should receive "fall out" effect from Tulsa stimulating rural industrial and residential development.

As a consequence of rising population and increasing industrialization, the proportion of the population residing in urban areas has been rising over the past decades and is expected to continue the same trend. Oklahoma's population distribution shift parallels the national trend, although Oklahoma remains more rural than the norm. The Middle Arkansas Basin is rural by land use but quite urban in terms of population distribution. Although the Tulsa SMSA contains 62.34 percent of the people of the basin and nearly all of the people live in a "town", only about 3½ percent of the land is contained in urban areas. However, due to rises in nonagricultural employment in rural areas of the basin, the population distribution is projected to stabilize. (NECO 1972a; Tulsa Metropolitan Area Planning Commossion 1969; Eastern Oklahoma Development District 1971)

Effects on Water Quality

Present and projected (to 1990) trends in population and employment in the Middle Arkansas Basin can serve as a basis for general predictions concerning the effects of these trends on water quality in the basin.

In all probability the projected increase in population will proportionally increase the volume of domestic waste generated by the area. Increases in some areas will be modest enough to allow communities to continue using, with various degrees of modification, present waste treatment facilities. Areas experiencing more significant growth may be required to construct new treatment facilities. For example, as population growth occurs in areas surrounding rural industrial parks, new or enlarged waste treatment facilities will be necessitated.

With the continued increase in industrialization, especially with the heavier concentrations of industries along the main stem of the Arkansas in Tulsa and Muskogee Counties, the overall waste loadings in this area will most likely show marked increases. The rate of these increases should be relatively lighter, since current predictions show that future industrialization will be primarily of conversion rather than raw-material processing type.

However, any increase in coal processing (such as the coal gasification project currently under consideration) could create significant local water quality problems, as could the nuclear power plants now being considered for the Muskogee area.

Land Use

Several phenomena are changing simmultaneously to shape the demography of the basin, and three of the most important are discussed below.

1) As urban areas expand, the expansion will be at the expense of prime agricultural land, since land with deep soil and gentle slopes is best for both uses. Therefore, as urban/suburban employment and population expand, agricultural cropland use will decline.

2) Major shifts are expected in employment. The oil and gas reserves

are depleting while coal mining, manufacturing, transportation, and recreation industries are rising in terms of employment and land use.

3) The Arkansas River Navigation Project has stimulated the location of industry in rural areas and is expected to cause shifts in population and economy.

Table 7 on the following page shows that agriculture is the largest land use category. This will continue to be the case in the basin; however, the character of agriculture will change. It should be noted that "urban buildup" and industry are not mutually exclusive categories. Industrial land includes both urban and rural land. A description of these three land use categories is followed by a discussion relating land use to water quality.

Description

Urban Land Use. Urban development patterns in the basin have been greatly influenced by major highways and railways traversing the region. The initial development was, in most cases, dependent on and adjacent to these transportation facilities, and the subsequent development was a contiguous enlargement of the original townsites. Strip development has since occurred along the highway routes. Other physical constraints that have had an effect on the community's growth patterns are the physical land forms and hydrologic features. Land speculation has resulted in the "leap-frog" placement of subdivisions which in some instances have been connected by strip development.

The present urban form of land use is one of comparatively low density population concentrations. The Tulsa area is experiencing extensive "low

EXISTING LAND USE BY COUNTY IN ACRES*

TABLE 7

County	Urban Buildup	Agriculture	Industry	Other	Totals
Adair	8,341	336,415	360.8	19,043.2	364,160
Cherokee	13,876	445,059	110.0	24,795	483,840
Craig	19,854	468,612	355.6	138.4	488,960
Creek	3,185	472,488	1,398	139,249	616,320
Delaware	10,389	446,311	438.2	461.8	457,600
Mayes	14,476	381,564	949.4	45,250.6	442,240
Muskogee	31,368	436,126	1,790	55,516	524,800
Nowata	10,841	336,279	365.8	12,214.2	359,700
Osage	1,542	1,411,862	1,417	65,711	1,480,532
Ottawa	14,865	273,929	1,172.2	5,073.8	295,040
Rogers	26,921	395,372	1,429.8	26,564.2	450,287
Tulsa	8,476	274,307	8,265	85,592	376,640
Wagoner	12,220	321,134	113.5	26,852.5	360,320
Washington	17,627	238,563	5,832	9,691	271,713
Totals	193,981	6,256,683	43,431.7	478,056.3	6,972,158

*Oklahoma Conservation Needs Inventory, U.S.D.A.

density urban sprawl" while the smaller communities are developing into more compact human settlements with abundant open space between communities.

The city of Tulsa devotes more than half of its developed land to residential use which indicates that Tulsa shares the suburban character of its neighboring communities. In general, commercial growth parallels residential development. The two principal forms which commerical growth have taken are the shopping center and the strip commerical auto-oriented franchise. There are numerous centers oriented to serving neighboring populations. These decentralized centers have captured the bulk of sales generated by the expanding population.

In small communities, storm and sewer service has rarely been extended beyond ridge lines because of the increased cost. This limiting factor has caused many small communities to develop as compact human settlements. The inability to provide this service has also severely handicapped the quality of development in many cases.

Some rural areas are experiencing rapid residential growth. Most of this growth is occurring along section line roads where rural water, electricity and gas are being supplied. The normal pattern in the rural areas has been to subdivide the roadside land areas into 2½ to 5-acre parcels, a pattern that will maintain the current trend of low-density sprawl.

Industrial Land Use. The Middle Arkansas Basin has more industry than any other part of Oklahoma, primarily because of the extensive oil, gas, and mineral resources in the area. Tulsa County alone has about 750 industries, and the basin includes three other heavily industrialized counties; Muskogee, Ottawa, and Washington. In addition, the recently completed McClellan-Kerr Arkansas River Navigation System is expected to bring even more industry to the area because of the cheaper transportation inherent in shipping by water compared to shipping by other means.

Manufacturing. Most industrial development has been in or near population centers such as Tulsa, Muskogee, and Bartlesville. There is a current trend toward the creation of rural industrial areas. To date two such industrial parks are being developed: the Mid-American Industrial Development (MAID) south of Pryor and the Port of Catoosa Industrial Park at Catoosa. Both developments are partially constructed and contain some industry; however, neither location is operating at full capacity. The success of such industrial parks should stimulate more development along the Arkansas River.

Extractive Industry. Mineral deposits of all types have a potential effect on water quality. A general description of the nature and location of the various deposits found in the Middle Arkansas Basin is given below.

(Oil and Gas) Oil and gas sources located in the western half of the basin have been under production since the turn of the century. The Middle Arkansas Basin boasts Oklahoma's first commercial oil well, the Cudahy Oil Company 1 Nellie Johnstone located in Bartlesville in the western part of Washington County. This well, completed in April 1897, delivered 50 to 75 barrels of oil per day when it began production in 1903.

During 1970 the commercial oil and gas wells in the basin produced 6.8 percent of the state's petroleum output. During that year 21 million barrels of oil and 5.1 trillion cubic feet of natural gas were produced.

The oil production comes mainly from the Pennsylvanian formation sandstones and Mississippian, Devonian/Siloriam, and Ordovician limestone. In recent years, exploratory drilling to locate new reserves of oil and gas has been largely unseccessful and, unless new reserves are found, it is only a matter of time before the presently operating fields are depleted. Currently, yields from the approximately 300 active secondary-recovery projects represent more than 50 percent of all production within the basin.

The basin's two oil refineries are both located in Tulsa, Six petrochemical plants are located within the basin. (OWRB 1971, p. 134)

(Coal) Mineable coal reserves are located in the southern portion of the Middle Arkansas Basin. Coal beds have been noted in Pennsylvanian rocks, occurring in 36 different beds ranging from the Bloyd to the Vamoss formations having a thickness of up to six feet in some areas. In 1970, about 2.52 million short tons of coal were mined in Oklahoma, about half of which were produced in four strip mines in the basin.

Peak coal production occurred in the 1930's and coal production has been on the decline ever since. The most recent constraint on Oklahoma's coal production has been the implementation of rigid regulations on the amount of admissible surphur content in the coal. The average sulphur concentration of the coal in the basin ranges from 0.7 and 5.6 percent which does not come close to meeting the new federal standards of 0.3 percent sulphur. (OWRB 1971, p. 131) Until recently, these standards made the development of new sulphur-stripping methods imperative if the state's coal reserves were to be utilized.

Demand for coal to meet the needs of the coal gasification project currently proposed for the basin would probably lead to great increases in area mining operations.

(Lead-Zinc) The last four lead and zinc mines of the Middle Arkansas Basin were shut down in October of 1970. Through 1969, the Miami-Picher area of northern Ottawa County featured 16 operating mines which produced about 605 short tons of lead ore and 2744 short tons of zinc ore in that year. Total value of these ore yields was $980,000.

A 1968 price-drop for both lead and zinc plus more stringent pollution control requirements led to the shut down of the Ottawa County mines. Although Mayes, Adair and Craig Counties have areas which would probably be suitable for zinc and lead mines, new mines are not likely to be started nor old ones reopened until ore prices rise or pollution control devices become better and less expensive.

(Other Minerals) Although the majority of the Middle Arkansas Basin's $100 million total mineral production in the year 1968 was oil and gas, several million dollars worth of other minerals were produced during that year. Arranged alphabetically, some of these minerals were cement, chat, clay, dimension sandstone, dolomite, germanium (including cadmium and indium), glass sand, granite, limestone, sand, and gravel and tripoli.

Cement is produced from limestone at two locations, one near Pryor in Mayes County and the other in the southwestern corner of Rogers County. Chat, a material mainly composed of the crushed chert, limestone and dolomite, resulting from the mining of lead and zinc ores, was still being produced by five companies in Ottawa County, despite the shut down of lead and zinc mines in the area. Chat is used as concrete aggregate, railroad ballast and road material.

Clay, obtained from the Hindsville formation in Mayes County and the upper Boggy formation in Muskogee County and slate obtained from the

Nowata Shale in Rogers County, are used for making general clay products, i.e., cement, brick, tile, lightweight aggregate, pottery, ceramaics, and lightfiring refactory products. Brick is also produced from the Coffeyville and Seminole Formations, and expanding clay is produced from the Coffeyville Formation. Pottery is produced mainly from clays of the Coffeyville Pleistocent Terrace, Hindsville and Hartshorne Formations. Refractory clays have been noted in the Hartshorne and Fayetteville Formations.

Dimension sandstone is produced from the Hale Sandstone in Mayes County. Dolomite has been produced from the Wildhorse Dolomite Lentol about twenty feet below the Bigheart Sandstone of the Barnesdall Formation. Germanium, cadmium, and indium have been recovered from residues produced by two of the basin's zinc mines which are now shut down. Glass is produced mostly from glass sand mined from the Simpson group in the Arbuckle Mountain area; however, one deposit is noted in northeastern Cherokee County. Pleistocene river sand found in Muskogee County is also used for glass production.

Granite (Spavinaw Granite) occurs in five outcroppings along Spavinaw Creek in Mayes County, but it has not yet been quarried. Limestone, produced by fourteen companies in 1970 from the many limestone formations found in the basin, is used mainly for road material, concrete aggregate, cement and soil conditioner.

Sand and gravel are produced from Pleistocene terrace materials and recent alluvium deposits by many companies throughout the basin. The material is used for concrete aggregate in building and paving and for fill purposes.

Tripoli is weathered chert occurring in the Meramecian and other limestones. Although deposits have been noted in Cherokee, Mayes and Craig Counties consisting of cherty, Osagean Limestone, it has been quarried mostly from Meramecian rocks in Ottawa County. It is used in buffing compounds and in foundary processes. (OWRB 1971, pp. 129-133)

Agricultural Land Use. Agriculture has remained an economically important activity in the Middle Arkansas Basin, in spite of the region's sharp increase in industry. A decrease in the number of farms within the basin has been accompanied by an increase in the size of remaining farms. (OWRB 1971, p. 108)

During the Oklahoma opening period at the turn of the century, a large number of farmers established homesteads and engaged in subsistence farming. Poor conservation practices resulted in the erosion of over 75 percent of the topsoil in many parts of the Middle Arkansas Basin. (U.S. Government Printing Office 1956) This decline in soil productivity probably helped to eliminate marginal farmers and to encourage a move from subsistence cropping to commercial range, pasture and silviculture.

As indicated in Table 8 on page 56, approximately 18 percent of the basin's agricultural land is still devoted to crops. The land remaining in cultivation principally supports corn, hay, sorghum, and soybeans; barley and oats are secondary crops of the region. Corn production has steadily decreased, hay acreages have remained fairly constant and sorghum and soybean production have steadily increased over the years from 1920 to the present.

In 1969 Osage and Craig ranked in the top ten counties in the state in cattle production, and Mayes, Muskogee and Adair ranked in the state's top ten producers of dairy cows. Meeting the needs of a growing cattle industry has necessitated an increase in the number of acres of improved

AGRICULTURAL LAND USE

TABLE 8

County	Cropland	Pasture	Range	Forest	Other	Totals
Adair	29,829	51,532	16,132	232,205	6,717	336,415
Cherokee	27,514	103,010	14,285	295,802	4,448	445,059
Craig	133,492	94,279	210,973	25,285	4,583	468,612
Creek	74,325	90,787	176,218	221,988	5,489	368,807
Delaware	63,512	60,695	62,772	254,200	5,132	446,311
Mayes	65,536	115,705	75,665	112,800	11,858	381,564
Muskogee	140,761	136,547	100,500	54,365	3,953	436,126
Nowata	79,927	41,907	181,736	29,029	3,680	336,279
Osage	123,807	81,525	703,020	445,497	14,683	1,368,532
Ottawa	102,443	64,680	28,406	78,400	5,563	279,492
Rogers	60,477	91,469	174,625	61,133	7,668	395,372
Tulsa	80,693	106,057	42,203	45,922	8,091	282,966
Wagoner	115,471	89,793	68,320	44,140	3,410	321,134
Washington	45,625	36,366	138,945	24,894	5,832	251,662
Totals	1,143,412	1,164,352	1,993,800	1,925,660	91,107	6,318,331

*Oklahoma Conservation Needs Inventory; U.S.D.A.

pasture and of range or uncultivated land covered with native vegetation suitable for grazing. (OWRB 1971, p. 108) As shown in Table 8 on page 56, pasture and range lands occupy about one-half of the agricultural land in the basin.

Approximately 25 percent of the state's total land use area is covered by forest land. This represents nearly 10,000,000 acres of which one-half is considered commercial forest. (United States Department of Agriculture 1970, p. 36) These commercial forests are located principally in 17 northeastern counties. (Oklahoma University 1972, p. 1) As indicated by Table 8 on page 56, about 32 percent of the agricultural land in the Middle Arkansas Basin is forest. Over one-half of this area is commercial forest, and in some counties nearly all of the forested land is commercial forest. Several forest areas lie within the region's state parks. (OWRB 1971, p. 141)

Effects on Water Quality.

The use to which a land area is put can have a marked effect on the quality of the water produced by the area. Both point and nonpoint sources of pollution stem from land use. Point sources associated with land use were discussed earlier in connection with present and projected trends in population and employment. Nonpoint sources are discussed below.

The extent to which land use affects the quality of water produced by runoff in an area has only recently been fully realized. Studies have revealed that surface wash from urban land areas exhibits many of the same characteristics as sanitary waste water. Rain water falling on the disturbed surfaces of strip mined areas carries metals and other deleterious dissolved and suspended substances into surface waters. Runoff from agricultural and grazing areas may contain large amounts of sediment, organics, nutrients and pesticides. Even areas relatively undisturbed by Man's activities have been found to contribute in some manner to water pollution.

Urban Land Use. Urban land areas, which include residential, commercial and industrial tracts, are usually engineered to drain as quickly as possible after periods of rainfall. Flowing rapidly across land surfaces, paved areas and through drainage systems, this water has been found by several investigators to carry a significant load of pollutants (Dawdy 1967; Guy and Ferguson 1962; Geodreich 1967; Weibel etal 1964; Bullard 1966; APWA 1969; Cleveland etal 1969; Bryan 1970; Peavy 1970) This runoff contains large quantities of sediment, particularly during the construction phase of urbanization. Organics such as grass and vegetative clippings, paper and other biodegradable substances find their way into the drainage system in substantial quantities. Nutrients from lawn cultivation have also been found in significant quantities in urban storm runoff. Bacteria and toxic substances have also been reported.

Urban land areas constitute less than 5 percent of the total land area of the Middle Arkansas Basin, most of it being concentrated in the Tulsa and Muskogee areas. No data is available to indicate the instream effects of runoff from these areas. While a large volume of pollution may be carried from the urban area by storm runoff, in most instances it is quite probable that this waste is diluted by the large volume of flood flow from the urban and surrounding rural areas. The area of most concern would be instances where urban runoff is contained by a relatively small reservoir downstream.

Industrial Land Use. The problems associated with point source pollution from both manufacturing and extractive industries have been discussed previously. Nonpoint source pollution is also presenting difficulties, especially in the areas of oil field production (brines), coal mining (sulfates-acids), and lead-zinc mining (heavy metal toxicants). These problems are discussed below.

Oil Field Pollution. The brines associated with oil-well operation probably make a significant contribution to the total dissolved solids (TDS) occurring in certain streams, particularly in Segment 1-D of Basin One. For example, as a probable result of oil field brines, the low flows of Hominy Creek, lower Caney River, lower Bird Creek, lower Verdigris as well as some smaller tributaries such as Delaware, Coon, and California Creeks are too highly mineralized to be suitable for most municipal and industrial uses.

The Water Quality Evaluation Section of this paper discusses both historical and recent sampling data for the basin. Tables B1, B2, and B3 of Appendix B show historical and recent instream values of selected quality parameters for some of these streams.

The total dissolved solids in the Arkansas River at Sand Springs is slightly higher than the value of 1000 mg/l listed as the maximum permitted USPHS Drinking Water Standards of 1962. However, it is not possible to determine how much of this concentration comes from oil field brines because of the high natural mineral content in the Arkansas River and its tributaries (Cimarron and Salt Fork) upstream of the basin.

Coal Mine and Coal Field Drainage. Pollution from mining operations may occur when the earth's crust is disturbed to gain access to minerals held within. Water quality deteriorates when water is contaminated with soluble products generated from mining wastes. In some cases the quality is also affected because natural drainage patterns for surface and subsurface waters are altered. Water from abandoned coal pits may be a source of local groundwater contamination. (United States Geological Survey 1971a)

A recent EPA document (EPA 1973a) pertaining to the pollutants generated by mining operations notes that:

> The most serious pollutant arising from mining activities is the mine drainage generated by oxidation of pyritic materials with air in the presence of water; this drainage is an acidic mixture of iron salts, other salts and sulfuric acid. Mine drainage arises from both underground and surface mining sources and from coal and many metal mining operations. Coal deposits and so-called hard rock mineral deposits are commonly associated with pyrite and marcasite, which are disulfides of iron. Acid mine drainage can find its way into surface waters, where the acid and sulfate may result in severe deterioration in stream quality. The acid can react with clays to yield alluminum concentrations sufficient for fish kills, and with limestone to yield very hard waters expensive to soften. The acid can also selectively extract heavy metals present in trace quantities in mineral and soil formations, resulting in toxic conditions in lakes and streams.
>
> Mining activities have a pronounced effect on groundwater supplies. The various operations used to mine the mineral deposits can result in alteration of groundwater distribution patterns. Aquifers containing good water can become contaminated because some mining may disturb bedrock formations, which permit mixing of contaminated water with good.

An estimate of the total land area in Oklahoma that has been disturbed by strip and surface mining for coal as of 1965 was 23,500 acres. As of 1968, there were 251 abandoned coal mines and 283 abandoned metal mines. (EPA 1973a, p. 171) A breakdown of the location of the land areas or the number of abandoned mines on a county basis is not available. However, considering the location of Oklahoma's coal fields, a significant portion of the disturbed land area and abandoned mines must lie with the Middle Arkansas Basin.

In 1970, about 2.52 million short tons of coal were mined in Oklahoma, about half of which were produced by four operators operating strip mines in the Middle Arkansas Basin. These four companies were:

1) Briarton Coal Company of Stigler stripping coal in Section 35-1DN-19E, Muskogee County

2) Bill's Coal Company of Welch, stripping coal in Section 14-28N-20E, Craig County

3) NiNabb Coal Company of Catoosa, stripping coal in Section 23-21N-15E, Rogers County

4) Peabody Coal Company of St. Louis, Mo., stripping coal in Section 31-26N-18E, Craig County and in Section 16-23N-17E, Roger County

(OWRB 1971, pp. 129-130)

In these counties the high-sulfate content of the groundwater is likely caused by its contact with strip mining areas, both active and abandoned, As shown in Table B3, Appendix B, certain streams having high TDS content, notably Cloud Creek and Broken Arrow Creek in Segment 1-A (407 and 635 mg/l respectively), also have high values of dissolved sulfates (199 and 290 mg/l respectively). The sulfate content measured in Broken Arrow Creek is above the maximum permitted value of 250 mg/l, listed in the USPHS Drinking Water Standards of 1962.

Referring again to Table B3 of Appendix B, several observations can be made concerning the acidity aspect of mine drainage. The two streams mentioned above Cloud Creek and Broken Arrow Creek have measured pH values that lie within the allowable range of 6.5 to 8.5 as specified in the Oklahoma Water Quality Standards of 1973. (Appendix A) It is noted, however, that several streams in Segment 1-C have measured pH values that are at or below the recommended minimum value of 6.5. These include Spring Creek (6.2), Big Cabin Creek (5.9), Pryor Creek (6.2), and Chouteau Creek (6.5). Also in Segment 1-D, Sand Creek (6.3) and in Segment 1-A, Dirty Creek (6.5) have measured pH values that are marginal.

The fact that for the streams listed in Table B3 only one sample was taken and that one was taken during the period of February through March, 1973, raises some question as to whether or not these relative values are representative of the true average stream values, particularly due to the dilution effect of the abnormally high precipitation (10 inces above normal) occurring during the year the measurements were taken.

Conversely, if a measurement is made in a certain stream into which a sudden, large runoff occurs in an area of waste pyrite rock piles from a strip mine, the leachate would likely contain high concentrations of iron salts and sulfuric acid. These compounds remain in the waste area between periods of excessive precipitation and runoff and constitute a "chemical factory" which can periodically pollute streams. (EPA 1973a, p. 171)

As these two examples indicate, more extensive sampling would be desirable, though such sampling may not be possible with present resources.

Lead-Zinc Mine Drainage. The third grouping of pollutants, the heavy metal toxicants, assumes importance because of recent investigations that show certain synergistic as well as cummulative effects on aquatic life. Although most of the pollutants containing heavy metal toxicants are considered to be of industrial origin and in the form of point sources, in the areas where lead and zinc are mined, the ores and waste piles usually contain coumpounds that are soluble to some degree in water and as such constitute nonpoint sources.

The sixteen lead-zinc mines operative in the Miami-Picher area of the northeast section of the basin prior to 1969 have all been shut down as of 1970. The high cost of pollution controls as well as the low price of lead and zinc were given as reasons. (OWRB 1971, p. 132) While it is not possible to establish with certainty whether the relatively high concentrations of lead (Pb) and zinc (Zn) given in Table B2 for Spring Creek near Quapaw are due to mine drainage, it is noted that the values given (Pb = 0.37 mg/l and Zn = 0.43 mg/l) are significantly high. However, Table B2 also indicates that similar concentration levels of these two metals are found in every main stream reported in Segment 1-B, 1-C, and 1-D in the basin. It is possible that the marginal sensitivity of the measuring techniques used is responsible for the high concentrations reported for these metals. In any event, additional measurements using more sensitive measuring techniques, should be made for all possible metal toxicants to aid in determining whether mine drainage is a possible source of heavy metal toxicants as well as the more established source of sulfates and acids.

Agricultural Land Use. The trends in modern agriculture is toward the ever-increasing use of fertilizers, pesticides, irrigation systems and confined animal feedlots. The resulting pollutional load from agricultural discharges and runoff include sediment, salts, nutrients, pesticides, organics, and pathogens.

It has been estimated that as much as 50 percent of the total sediment in inland waterways is the result of erosion from agricultural croplands. (EPA 1973b) In addition, soils eroded from pasture, range and forest lands also contribute sediment to the streams. Forest areas where recent timber harvest has occurred is a prime source of sediment.

Nutrients from agricultural land may consist of organics from animal waste or grain processing and from chemical fertilizers added to crop or pasture lands. There is evidence that runoff of chemical fertilizers, particularly after a heavy rainstorm, can be significant. It is estimated that approximately 60 percent of nitrogen applied as fertilizer is used by plants. The fate of the remaining 40 percent is not completely known. Given an excess of water this nitrogen may be leached into groundwater or in runoff to surface streams. (EPA 1971b, p. 10)

The bosphorus content of chemical fertilizers not used by plants becomes adsorbed to soil particles and are not easily leached by water. This nutrient may still find its way into surface waters if the particle to which it is adsorbed is eroded. While the amount of phosphorus in true solution in agricultural runoff may be small, the total amount of the element entering the surface water attached to sediment may be quite significant. (EPA 1971b, p. 13)

Approximately 70 percent of the pesticides manufactured are in agriculture. These substances may enter the surface waters by missapplication, runoff from sprayed areas or attached to eroded soil particles. These toxicants degrade very slowly and many are cummulative in the food chain.

Organic waste from agricultural areas include vegetative matter and animal wastes. Confined feeding operations are probably the most significant sources of organic pollution from rural areas. Waste from these areas are readily biodegradable and usually exert a high initial oxygen demand due to a high ammonia content.

As shown in Table 7 on page 49, approximately 90 percent of the Middle Arkansas Basin is composed of agricultural lands. Table 8 on page 56 shows that approximately one-sixth of these agricultural lands are crop lands while another one-sixth is cultivated pasture lands. This area is sufficiently large to be a significant factor in sediment production. Heavy sediment loads ogenic problems from feedlots in the basin do not appear to be significant.

At the present, sufficient data does not exist to evaluate the existence or extent of pesticide problems in the Middle Arkansas Basin.

Water Use

The Middle Arkansas Basin uses both ground and surface water supplies to meet agricultural, municipal, industrial, and recreational needs of its population. The following pages discuss the basin various uses of water and the probable effect of each use on water quality.

Description

Current and projected water use in the counties of the basin has been tabluated by the Oklahoma Water Resources Board. This data which appears as Tables 9 and 10 pages 67 and 68 of this report, shows that three major categories; agriculture, municipal, and industrial, account for over 99 percent of total water use in the basin.

Agricultural

In slightly less than five percent of the basin's water use was agricultural or irrigational in nature. Agricultural water use ranged from ten or less acre-feet/year in Craig and Nowata Counties to over 2,000 acre-feet/year in Tulsa and Osage Counties. These two counties use a great deal of groundwater for irrigation because surface water for irrigation is deficient in quantity and quality. (OWRB 1971, p. 107)

Municipal

Thirty-seven percent of the basin's water use is attributed to municipal demands. Tulsa County, the basin's largest population center, is the

WATER USE IN ACRE FEET

TABLE 9

County	Agriculture Irrigation		Municipal		Industry		Other		Recreational & Wildlife		Totals	
	Ground	Surface	Ground	Surface	Ground	Surface	Ground	Surface	Ground	Surface	Ground	Surface
Adair	1	1521	327	2710	0	1282	0	0	0	0	328	5513
Cherokee	0	948	0	1570	0	0	0	247	0	5	0	2770
Craig	0	10	41	1247	0	0	0	3	0	0	41	1260
Creek	7	70	0	3114	212	258	0	0	0	0	219	3442
Delaware	2	1497	10	19	0	0	60	65	0	0	72	1581
Mayes	65	65	0	2776	0	11100	0	22	0	0	65	13963
Muskogee	491	1345	26	6071	9	144108	0	0	0	0	526	151524
Nowata	0	0	0	630	0	547	0	0	0	38	0	1215
Osage	1664	557	561	7352	4347	507	26	1	0	243	6598	8660
Ottawa	0	468	3878	0	276	0	77	0	0	0	4231	468
Rogers	0	225	0	2930	0	6856	0	426	0	0	0	10437
Tulsa	1817	289	0	70509	1459	4463	95	7	0	0	3371	75208
Wagoner	0	1094	0	2689	0	0	0	5	0	0	0	3788
Washington	0	1446	0	5137	0	24	0	0	0	0	0	6607
Totals	4047	9535	4843	106754	6303	169085	258	776	0	286	15451	286436

*Reported Water Use In Oklahoma, 1971; OWRB

PROJECTED WATER USE IN THOUSANDS OF ACRE-FEET/YEAR*

TABLE 10

County	1970 Municipal Domestic	1970 Industry	1970 Irrigation	1970 Total	1980 Municipal Domestic	1980 Industry	1980 Irrigation	1980 Total	1990 Municipal Domestic	1990 Industry	1990 Irrigation	1990 Total
Adair	1.4	2.4	1.8	5.6	1.8	2.8	2.6	7.2	2.3	3.1	2.9	8.3
Cherokee	2.3	1.1	4.9	8.3	3.0	1.1	5.5	9.6	3.5	1.1	6.0	10.6
Craig	1.5	0.2	0.0	1.7	1.6	0.2	0.9	2.7	1.8	0.3	1.8	3.9
Creek	5.3	5.6	0.1	11.0	6.9	5.8	1.4	14.1	8.8	6.0	2.8	17.6
Delaware	1.7	0.3	2.1	2.2	2.1	0.3	0.3	2.7	2.5	0.3	0.5	3.3
Mayes	2.5	9.5	0.0	12.0	3.3	10.6	0.7	14.6	4.0	11.9	1.4	17.3
Muskogee	6.9	11.1	1.5	21.7	7.9	12.3	3.5	40.3	9.3	13.6	4.4	59.5
Nowata	1.0	1.0	0.0	2.0	1.0	1.1	0.7	2.8	1.2	1.2	1.3	3.7
Osage	3.1	2.6	2.6	8.3	3.4	2.6	5.7	11.7	3.7	2.6	9.2	15.5
Ottawa	3.5	1.9	0.2	5.6	4.2	2.1	0.3	6.6	5.2	2.3	0.3	7.8
Rogers	2.9	1.0	3.1	12.4	4.6	1.2	1.4	15.1	7.1	1.2	1.7	25.4
Tulsa	50.6	76.8	1.9	135.3	66.3	87.3	2.2	162.0	86.3	99.1	3.7	201.1
Wagoner	3.1	0.7	0.7	4.5	3.4	0.8	1.6	5.8	5.2	0.9	3.2	9.3
Washington	5.2	6.1	1.0	12.3	5.9	8.9	2.1	16.9	6.6	11.8	2.4	20.8
Totals	91.0	120.0	47.8	242.9	115.4	137.1	28.9	312.1	147.5	166.2	67.7	404.1

*Comprehensive Water Plan; OWRB

heaviest user of water for municipal needs. Tulsa's municipal supply comes from two lakes on Spavinaw Creek and from Lake Hudson on the Grand Neosho.

Surface waters provide the chief source of municipal water for all counties within the basin except Ottawa, since these counties have insufficient supplies of groundwater suitable for domestic use. A list of municipal water supply lakes for the basin appears in Table 3, page 35 of an earlier section of this report.

Industrial

Industrial accounts for about 58 percent of the basin's water use each year. Muskogee County has the highest amount of industrial water usage in the basin, probably due to the large amount of heavy manufacturing located on the Arkansas River in and near the city of Muskogee. Mayes County is increasing in industrial water use due in large part to the Pryor Industrial Park. Industrial water use is expected to rise in Tulsa, Mayes, Rogers, and Muskogee Counties as a result of predicted industrial growth.

The industrial water supply needs of all but five counties in the basin are met almost entirely by surface water sources. For example, Muskogee draws heavily on Lake Fort Gibson on the Neosho River (Duncan 1968, p. 99) and Bartlesville in Washington County uses water from Lake Hudson on Butler Creek and Hulah Reservoir on Caney River (Duncan 1968, p. 95)

Effects on Water Quality

Most of the use described above is non-consumptive, allowing water to be returned to the basin's streams and made available for reuse. However, many of the uses within the three major water-use categories described above may have significant effects on water quality, often these effects are serious enough to prevent untreated reuse of the water or to render it aesthetically displeasing. The effects which various uses have on water quality are discussed below.

Agricultural

As noted in an earlier section, runoff from agricultural lands can pose serious problems in disperse pollution. Just as runoff from rainfall can carry high sediment, nutrient, and pesticide loads into receiving streams, so might runoff from irrigation carry these. While the sediment bearing potential of irrigation runoff might be negligible, its ability to leach out nutrients and toxicants is great enough to be cause for concern. For example, according to an FWPCA study, fertilizers, insecticides, and herbicides were factors in fish kills across the nation from 1964-1967. (Todd 1970, p. 335) Other aspects of agricultural water use should also be considered. For example, manure-silage drainage was also a significant factor in nationwide fish kills from 1964 to 1967 (Todd 1970, p. 335)

Municipal

Approximately forty-one percent of the water used in an average American home is used to flush away wastes and an additional fifty-one percent is used for bathing, washing and other cleaning purposes (Todd 1970, p. 243) Thus ninety-two percent of the water supply that enters a home in potable state leaves in a state that is unfit for human consumption, but is also unfit for discharge into streams already carrying maximum desirable waste loads.

Biological contaminants (from human waste), nutrients (from detergents, soaps, and other cleansers), toxicants (from drain cleaners and insecticides) and other pollutants are added to water during its journey through the average home. Thus, while a large percentage of municipal water is recoverable, quality of the recovered water has been so greatly reduced that treatment of varying degrees is necessary before such water is ready for reuse.

Industrial

As noted earlier, industry accounts for the largest percentage of water use in the Middle Arkansas Basin. Both manufacturing and extractive industries within the basin tend to require large amounts of water; the extent to which the quality of that water deteriorates with use depends on the nature of the industrial processes in which it is involved.

Raw Water supplies for cooling purposes may often be of lesser quality than that put to other industrial purposes. For example, while Keystone Reservoir on the Arkansas does not impound water suitable for municipal use by the city of Tulsa, it does yield water acceptable for the city's industrial cooling (Dover 1968, p. 91) Such water generally can be returned to its source with only slightly altered quality.

Potable water is sometimes required in actual processing of a manufacturing or extractive nature. The quality of this water is often significantly lowered as a result of its use in such processes.

III. WATER QUALITY EVALUATION

Water Quality Standards

Water Quality Standards for the State of Oklahoma were revised by the Oklahoma Water Resources Board and, after a public hearing, were adopted by the Board on September 11, 1974. These standards set forth the designated use of each stream and state specific criteria for in-stream water quality. A copy of the Water Quality Standards is included as Appendix A of this paper. Appendix A and B referenced in the Standards are omitted but are summarized in Table A1 and A2 in Appendix A.

The summary of water quality criteria presented in Table A2 includes those parameters which vary from stream to stream and for which specific values exist. In cases where historical records of mineral quality do not exist for tributaries, the values for the receiving stream of the next higher order should be used.

Parameters for which numerical limits are not established or which do not vary from stream to stream are covered in the narrative of the standards and are not included in Table A2. These include oil and grease, suspended solids, color producing substances, taste and odor producing substances, pH, species diversity index, nutrients, and toxic substances. The limits for the first six of these parameters are fairly well established by the Water Quality Standards as minimum values or a range of values and will not be allocated in this plan.

The last two parameters will have to be examined more closely, however. The standards for nutrients read as follows:

> The total phosphorous concentration and Nitrogen/Phosphorous ratio shall be limited to prevent eutrophication problems. If sufficient nutrient data becomes available specific numerical limits will be included in the water quality standards revision scheduled for October 18, 1975.

It is reasonable to assume that some restriction should be placed on the discharge of nutrients to the surface water. However, exact concentrations which will cause problems under varying stream conditions in Oklahoma are not known. Since the Middle Arkansas Basin does not have a known problem of extensive eutrophication, allocation of nutrients will be made on the basis of present discharge quantities. A net increase in nutrients should not be allowed unless such an increase can be shown to be harmless to the aquatic environment.

Toxic substances constitute another group of parameters which must be given special attention. The standards specify that toxic substances should not be discharged in quantities which would cause the waters to be toxic to aquatic life or to be detrimental to designated beneficial uses. The potential harm from toxic substances is so great that the discharge of these materials should be specifically addressed in a water quality management plan. An allocation of toxic substances is, therefore, necessary.

If an allocation of toxic substances is to be made, the maximum allowable levels must be determined. Although much work has been done in the area of toxic limits of various elements, a universally accepted standard apparently does not exist. A survey of the states surrounding Oklahoma revealed that a wide range of values are being used for toxic parameters. A review of the literature also reveals a wide descrepancy in maximum values. A recent study (National Academy of Engineering 1972) completed by the National Academy of Science appears to be the most comprehensive study to date. This study was commissioned by the U.S. Environmental Protection Agency and the results adopted by EPA as their official toxic standards.(EPA 1973c) In view of the restraints mentioned in the introduction that plans be compatible with state and federal requirements, it is recommended that these values be used in the planning effort.

Table 11 on the following page shows recommended maximum values for a selected list of toxicants. The first column lists the maximum value for water used for irrigation or livestock watering while the second column contains the maximum values alowable in waters used for raw water supplies or for support of fresh water aquatic life and recreation.

Existing Quality

Water quality in the Middle Arkansas Basin varies from stream to stream and also in time for each stream. While natural mineral deposits upstream from the basin have a significant effect on stream quality, the major factors within the basin which affect instream quality appear to be natural low flow volumes coupled with waste discharges.

TABLE 11

MAXIMUM PERMISSIBLE CONCENTRATIONS OF SELECTED MATERIALS IN OKLAHOMA WATERS

Metals	In Effluent*	Instream
Aluminum	5.0	0.1
Arsenic	0.1	0.1
Barium	5.0	1.0
Cadmium[a]	0.01	0.004
Hard Water[b]	0.01	0.01
Chromium	0.1	0.05
Cobalt	0.05	0.05
Copper	0.2	0.006
Hard Water[b]	0.2	0.2
Lead[c]	0.1	0.03
Iron	5.0	0.3
Manganese	0.2	0.05
Mercury[c]	0.002	0.0002
Nickel	0.2	0.1
Hard Water[b]	0.2	0.2
Selenium	0.02	0.01
Silver	0.05	0.05
Zinc[a]	2.0	0.05
Compounds		
Ammonia	--	0.03
Boron[d]	0.75	0.75
Cyanide		0.005
Fluoride	1.0	1.0
Phenols		0.001
PBD		0.002 mg/l
ABS		0.02
LAS		0.02
Sulfides		0.002
Nitrate	100	10.0
Nitrite	10	1.0

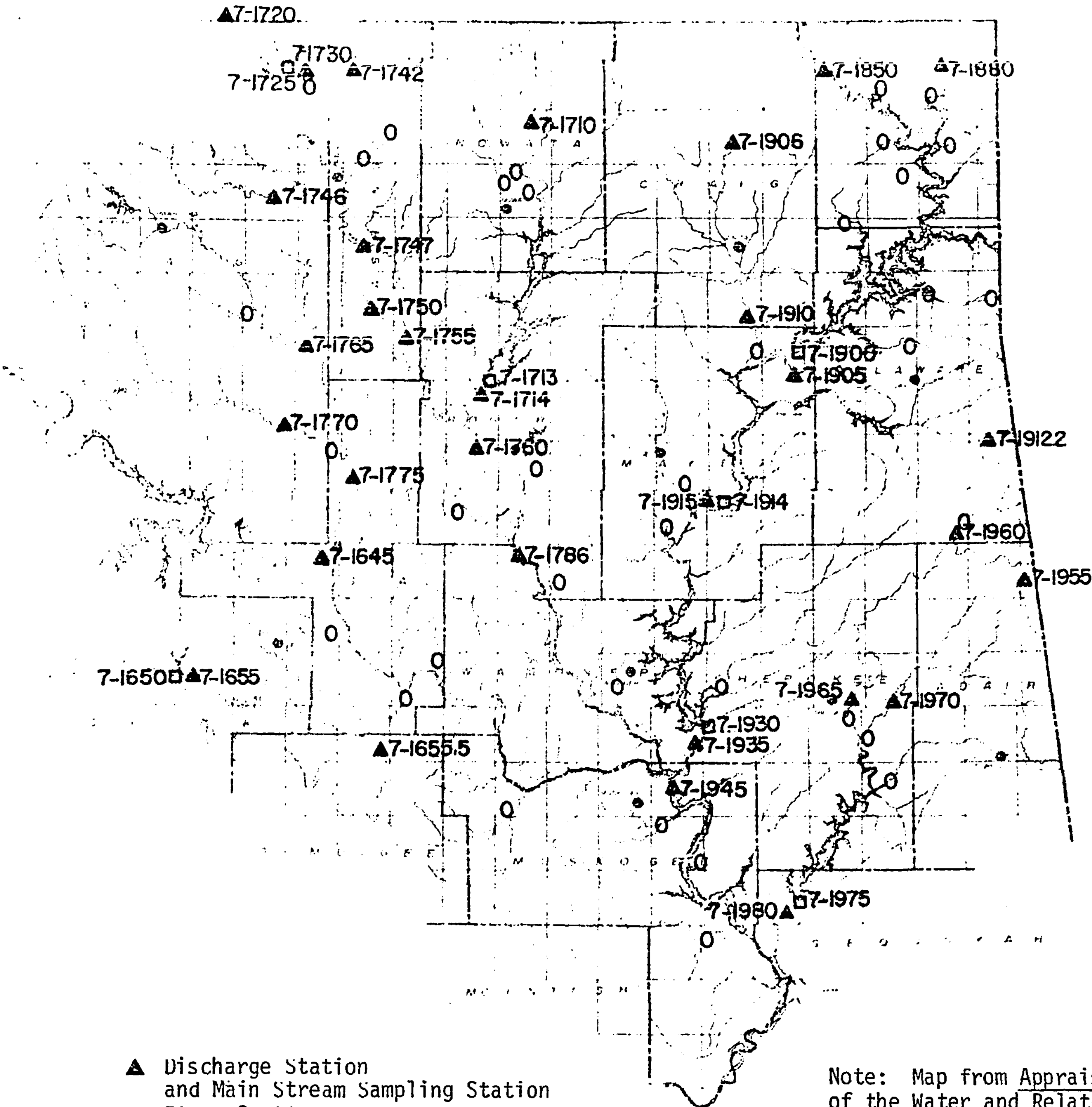
*Includes return flow streams, mixing zones, and special mixing zones as defined by the Water Quality Standards.
[a]Known Synergistic effects
[b]Hard Water is defined as having a "total hardness" of greater than 100mg/l $CaCO_3$
[c]Cumulative
[d]Found as compounds in nature

From: United States Environmental Protection Agency, Proposed Water Quality Criteria, Washington, D.C. 1973c.

The United States Geological Survey and the Oklahoma Water Resources Board cooperate in operating water quality monitoring stations on several of the main streams in Oklahoma. The location of these stations are shown on the map on page 77. Data from these stations is available in computer print-out form and has been summarized for stations on the Illinois, Grand - Neosho, Verdigris, and Arkansas Rivers, and on some of the major tributaries to these streams. These summaries are presented in the segment analysis of water quality which follows in this section of the plan.

In addition to this historical data, a monitoring program was initiated to obtain recent in-stream water quality data. Data was collected from the main stream stations by the Oklahoma Water Resources Board and from the tributary streams by the Oklahoma State Department of Health. Tributary sampling stations are also shown on the map referenced above. Main stream data is an average of six monthly samples taken during the period of February through July of 1973. Tributary data is obtained from a single sample taken at some time during the period of February through March of 1973. This data is presented in a subsequent part of this section.

It should be noted that the precipitation record for Oklahoma over the past year was approximately ten inches above normal. Therefore, the values obtained by the monitoring program are recordings of in-stream concentrations for flows that are significantly greater than normal. This fact becomes very important when considering the deleterious effects on the in-stream water quality period of low flow. A summary of



▲ Discharge Station
and Main Stream Sampling Station
□ Stage Station

O Tributary Sampling Station

Note: Map from <u>Appraisal of the Water and Related Land Resources of Oklahoma, Region Nine</u>, Oklahoma Water Resources Board, 1971

FIGURE 15

Gaging and Sampling Stations

the available water quality data is given in Appendix B and an analysis of this data is made by segments on the following pages.

Segment 1-B

Historically, water quality in the Illinois River and its tributaries has been exceptionally good. As shown in Table A1, all streams in Segment 1-B have been designated for use as public and private water supplies, primary body contact recreation and small mouth bass streams. In addition, the lower part of the river is designated as a trout fishery.

Historical data on the main stem of the Illinois is shown in Table B1 in Appendix B. Monitoring program data obtained by the Oklahoma Water Resources Board and the Oklahoma State Health Department is shown in Table B2 and B3 of Appendix B. A comparison of the in-stream water quality as shown in these tables with the quality criteria in Tables A1 and A2, Appendix A, indicates that the quality of water in Segment 1-B is better than required by the standards, with the possible exception of the toxicants cadmium, chromium, copper, and lead. It should be noted, however, that values in Table A2 for these parameters are listed as a less-than value, indicating that the sensitivity of the test was such that lesser concentrations could not be measured. Discharge inventories for Segment 1-B show no discharges of these metals. Correspondence with officials in Arkansas indicates no significant discharges into the Illinois occur in that state either. The monitoring program carried out by the Arkansas Department of Pollution Control and Ecology indicates that no problem exists with these toxicants in the Illinois.* Since some question exists concerning these metals, it would be advisable to analyze additional samples from the Illinois using more sensitive test procedures.

Segment 1-C

Historically, the surface water quality in River Basin 1-C has been good to excellent. Five impoundments have been constructed within the basin which probably assist in maintaining quality. The first impoundment, Spavinaw Lake, was completed in 1924 by damming Spavinaw Creek. The primary function of Spavinaw Lake is its usage as a source of raw water by the city of Tulsa. In 1952, Eucha Lake was created on Spavinaw Creek about three miles above Spavinaw Lake. The primary function of Eucha Lake is to augment the municipal water storage requirements for the city of Tulsa. The corresponding beneficial use designation for Spavinaw Creek including Spavinaw Lake and Eucha Lake is given in Table A1, Appendix A.

Surface water developments on the main stream of the Grand Neosho River, from its confluence with the Arkansas River to the Kansas state line, include Fort Gibson Lake, Lake Hudson, and Lake O' the Cherokees (Grand Lake). All three lakes serve as multipurpose reservoirs and share the same beneficial use designation, given in Table A1.

*Telephone conversation with Everett Perrien, Chief Planner, Arkansas Department of Pollution Control and Ecology, November 30, 1973.

Nearly all the tributaries that flow into the Grand Neosho River have been designated as sources of public and private water supplies. The only two exceptions are Lost Creek and Tar Creek which have been designated as return flow streams.

Historical and monitoring program data on in-stream quality conditions in Segment 1-C are shown in Tables B1, B2, and B3 in Appendix B. An evaluation of the surface water quality in Basin Segment 1-C can be made by comparing these tables to the standards criteria in Table A2 in Appendix A. Generally, the water quality of Basin Segment 1-C is better than the proposed standards. The problem of the sensitivity of the test for metals is again noted. When time and resources permit, better information should be obtained.

Segment 1-D

The Verdigris River originates in Kansas and receives about half its total flow from that state. The quality of this water is good; the total mineral concentration is usually less than 500 ppm. The city of Coffeyville, Kansas, just across the state line, obtains its municipal supply from this stream. The Verdigris also is the source of municipal supply for Nowata and for smaller towns a few miles downstream in Oklahoma.

In general, water of sufficiently good quality for municipal, irrigation and many industrial uses can be found in sub-segment 1-D(1) which encompasses the Caney River and Hulah Reservoir, upper Bird Creek, the main stem of the Verdigris above Bird Creek, and some smaller tributary streams such as Dog, Candy and Sand Creeks. The low flows of Hominy Creek, lower Caney River, lower Bird Creek, lower Verdigris River and some smaller tributaries such as Delaware, Coon, and California Creeks are too highly mineralized as a result of pollution from oil field activities to be suitable for municipal and most industrial uses.

The Caney River, which joins the Verdigris River near Claremore, has its headwaters across the Kansas border. Its flow is impounded in Hulah Reservoir just inside Oklahoma. This reservoir has flood-control storage of 259,000 acre-feet, and of the 35,000 acre-feet in the conservation pool, Bartlesville has been allocated 15,400 acre-feet of storage for municipal use. This water supplements Bartlesville's primary source of supply from Lake Hudson on Butler Creek. Farther downstream, Collinsville withdraws its municipal water directly from the Caney River. Water at this point on the river is not entirely satisfactory for drinking purposes because of oil field pollution upstream.

Oil field pollution in the lower Bird Creek Basin limits the use of this water, and most of the towns in the area are served by the Tulsa municipal system. Water quality of the natural run-off in undeveloped areas of this Basin is excellent, and upstream from the source of pollution the creek serves as the municipal supply for Pawhuska and several small towns.

The Verdigris River from its confluence with the Arkansas River to the Kansas state line including the Oologah Reservoir has been designated for use as a source for public and private water supplies. All its tributaries share this beneficial usage designation with two exceptions, Birch Creek and an unnamed tributary from the city of Delaware, which have been designated as return flow streams.

The historical water quality data for Basin Segment 1-D listed in Table B1 in Appendix B shows that the quality of water in the Verdigris is satisfactory with respect to all parameters except the metals, for which no data exists. Recent monitoring data in Tables B2 and B3 bear this out. Recent data on the Verdigris and mainstem tributaries reflect the problems with instrument sensitivity.

Segment 1-A

Segment 1-A includes the Arkansas River and its tributaries, beginning just above the confluence of the Canadian River with the Arkansas and continuing upstream to the Keystone Reservoir damsite. The flow of the Arkansas River has been regulated by Keystone Reservoir since September, 1964.

The quality of the water in the Arkansas as it enters Oklahoma is rather poor, with high concentrations of calcium and magnesium sulfate and sodium chloride.

Prior to the completion of Keystone Reservoir, maximum chloride concentrations exceeding 5,000 ppm had been observed in the Arkansas River at Tulsa. With the completion of the dam, the chloride concentrations of released water varies insignificantly from 600 ppm. Below the damsite, the Arkansas River is diluted by its tributary inflow, the Illinois, Grand Neosho, and Verdigris Rivers, until the chloride concentration at Webber's Falls is less than 100 ppm.

The beneficial use designation for the reach of the Arkansas River from the mouth of the Verdigris Rivers to the Keystone Dam is shown in Table A1. The reason for its designation as an emergency source for public and private water supplies (B) is the River's high dissolved mineral concentrations from naturally occurring sources outside of the basin.

Although the historic stream quality data shown in Table B1 is very scant, a comparison with the current water quality in Table B2 reveals the beneficial effect of the Keystone impoundment by the significant reductions of chloride, sulfate, fluoride, nitrate, phosphate, and total dissolved solids concentrations.

Table B3 is a listing of the in-stream quality for certain tributaries to the Arkansas. In general, the stream quality is good. It meets or is better than the "beneficial use" quality requirements in Table A2. The problems with the sensitivity of the test for heavy metals is again noted. All the tributary streams meet the permitted U.S. Public Health Service (USPHS) Drinking Water Standards, 1962. The total dissolved solids (TDS) concentrations of Cloud Creek closely approaches the maximum Drinking Water Standards of 500 ppm recommended by the USPHS. Nearly one-half of the measured 407 ppm TDS is due to the presence of sulfates. There are no industrial discharges into Cloud Creek; nor are there any mapped sulfate deposits such as gypsum or anhydrite within its drainage basin. However, the streambed of Cloud Creek rests upon geologic formations that contain thin beds of coal. Commonly associated with coal deposits are iron disulfides (FeS_2), the most familiar pyrite. Iron dislufides when exposed to air and moisture are readily oxidized to sulfates.

The TDS concentration in Broken Arrow Creek is 635 ppm. This concentration, although greater than the desired 500 ppm, is well below the maximum permitted standard. Also, the corresponding sulfate concentration of 290 ppm is below the maximum recommended Drinking Water Standard. Broken Arrow Creek flows through an area that has been strip-mined for coal, this accounting for the higher concentrations of sulfates in the stream.

Segment Classification

The Federal Water Pollution Control Act Amendments of 1972 require that all stream segments in a planning basin be classified as either "effluent limited" or "water quality limited" according to the following definitions. An effluent limited segment is one in which the application of "best practical treatment" technology currently available (BPT) to all discharges within the segment will result in water quality sufficient to meet the water quality standards. Conversely, a "water quality limited" segment is one in which treatment better than BPT will be required for discharges and/or control of non-point source pollution will be required to meet water quality standards. (PL 92-500 1972, pp. 30-31)

Initially, all stream segment in Oklahoma were classified as "water quality limited" due to a lack of information on existing water quality and the inavailability of guidelines as to what level of treatment would constitute BPT. In essence, both of these questions remain unanswered. Historical data on stream quality is at best sketchy for the mainstreams and non-existent for the tributaries. The recent monitoring data obtained in support of the planning effort did not do much to elucidate instream conditions. The unusual amount of rainfall during the sampling period resulted in large volumes of runoff which precluded any estimation of water quality at critical flows.

When guidelines on BPT for minicipal waste treatment facilities have been finalized, those for most categories of industries have not yet been finalized. Almost all of the proposed guidelines have been written in terms of allowable discharge per volume of material processed or in terms of final product output. Since the volumes of water used and discharged per volume of production was not defined, and indeed usually varies from plant to plant within the same industrial category, an estimation of the concentration of waste in each effluent under BPT would be impossible. Considering the many instances where the volume of effluent closely approximates the volume of the receiving stream in the basin, it is impossible to predict the effects of the application of BPT on water quality in the Middle Arkansas Basin.

In view of the situations discussed above, it is the conclusion of the writer of this thesis that the existing classification of "water quality limited" be maintained for all stream segments in the basin. Consequently, waste load allocations for all dischargers in the basin will be made so as to insure the maintainance of water quality at the critical flow conditions. This analysis is made in the following section of this paper.

IV. WASTE LOAD ANALYSIS

Since all the segments in the basin are classified as water quality limited, waste load allocations will be made for all dischargers. In addition to the instream quality analysis presented earlier, necessary items required for a waste load allocation include an inventory of dischargers and a stream assimilative capacity analysis on each stream. Once the allowable loading capacity of each of the streams has been determined, this load can be allocated to the individual dischargers.

The next section of this paper will discuss several approaches to allocating waste loads. In each case, a knowledge of the location and the quality and quantity of each individual discharge would be required. This section of the plan will, therefore, present an inventory of all known point sources and will address the total load from nonpoint sources.

Point Sources

As used in this section of the plan, point sources will refer to municipal and industrial discharges only. Agricultural point source discharges from animal feed lots will not be included in the inventory since, by state statutes, these facilities are required to collect all runoff and process water and, except under extreme climatic conditions, prevent it from entering the streams.

Municipal Inventory

A Municipal Discharge Inventory has been compiled from data gathered on a routine basis by the Oklahoma State Health Department in order to comply with the state health standards. Data collection of this type began in late 1970 and is being continuously updated by OSHD and placed in the EPA STORET computer system under the call name, "Municipal Waste Facilities Inventory".

Appendix C is a summary presentation of OSHD's municipal waste discharge information. This table is arranged by segments. Column two contains the location number which corresponds to the municipality's discharge location shown on the map on page C1 of the Appendix.

Industrial Inventory

An Industrial Inventory has been compiled from the records of the Oklahoma Water Resources Board. In order that an industry receive a discharge permit, it must submit an application to the OWRB containing the volume of waste discharged and an independent laboratory analysis of the possible pollution parameters in the discharge. This independent laboratory analysis is substantuated by analyses conducted in the laboratories of the United States Geological Survey and the OWRB.

The data on industrial waste discharges have been collected over a period of three years, 1970 to the present (1973). The data collected by OWRB is summarized in Appendix D. The Inventory was compiled directly from the Industrial Inventory Sheet, which the OWRB uses to collect field data. The second column corresponds to the location number found on the map on page D1 and represents the discharge location.

Nonpoint Sources

The origin and nature of nonpoint sources of pollution were discussed at length in a previous section of the paper. It was noted in that section that nonpoint sources of pollution are dependent to a large extent on the natural characteristics of the basin and influenced greatly by the use made of the land by the human population.

An accurate estimation of the total nonpoint source pollution in the Middle Arkansas Planning Basin is impossible. Since most of the drainage area of the mainstreams lies outside the basin and in most cases outside Oklahoma, a rough estimate of the total quantity of nonpoint source pollution based on land use would be difficult and would probably not be cost effective. From the discussion of land use presented earlier in the paper, it is reasonable to assume that some organics, nutrients, minerals, toxicants, and sediment (probably a sizable amount of the latter) enter the streams in the basin through surface runoff. However, during periods of critical low flow this surface wash does not exist.

V. APPROACHES TO WASTE LOAD ALLOCATIONS

Discussion of Alternatives

There are many methods and combinations of methods which should be considered for use in allocating waste loads. These approaches include (1) design for complete resue and recycle of waste water (no discharge), (2) design for discharger to meet standards at critical stream flow conditions, (3) design for discharge to meet standards at median stream flow conditions with storage during lower stream flows and release during higher stream flows, (4) design for incremental treatment at progressive stream flow values, and (5) design for a given stream flow with flow augmentation at lower flows.

These approaches require varying degrees of difficulty in both planning and in plan implementation. Most of the approaches require the use of mathematical modeling at various degrees of sophistication. In choosing the appropriate approach for a given situation, the difficulties in both the planning phase, including the data requirements and availability for the modeling work, and the implementation program should be evaluated. Each of the five approaches mentioned above is examined to some degree below in light of planning and implementation resources of Oklahoma. Selection of the optimum approach is then made.

No Discharge

Under a no discharge approach, waste load allocations would simply be zero. This concept of complete reuse of waste water would greatly simplify the planning process but would require a vast commitment of implementation resources. No discharge can be accomplished in several ways; by total retention and evaporation to the atmosphere; by subsurface disposal; by irrigation of vegetated land surface (runoff being prevented); or by such extensive treatment that waste water can be recycled and reused.

No discharge is currently being practiced by several industries and a few municipalities in the Middle Arkansas Basin. Most of the industries involved use deep-well injection to dispose of small quantities of brines or toxic substances. Some industries and the municipalities use total retention lagoons.

While these methods work well for small quantities of waste, the broad application of no discharge to all sources of waste water in the basin would present many problems. Before waste water can be injected into deep aquifers, all suspended material must be removed to prevent clogging the pores of the aquifer. This alone would require extensive treatment of the waste. Other problems such as adequate volumes and porosity of deep formations, danger of polluting usable groundwater supplies, etc., make subsurface disposal highly questionable as a method of disposal for most of the waste generated in the basin. Similarly, total retention lagoons to evaporate large volumes of waste require large land areas. Suitable land areas close to the point of need is not available in most instances.

In many cases the treatment of wastewater to the point where it can be recycled and reused is an expensive process. In addition, recycling is not usually a closed loop since pollutants are concentrated with every reuse. Eventually some part of the used water must be discharged.

Perhaps the most promising of the total retention methods is irrigation. Unless the waste water contains material which is toxic to plants, direct application on vegetation land surfaces can be made after removing only the suspended matter which would clog pumps, nozzels and other mechanical equipment. Again a problem exists in that enough land suitable for irrigation is not always available close to the source.

Discharge Designed for Critical Stream Flow

Another approach would be to allocate waste loads based on stream assimilative capacity at critical flow conditions. As set by the Oklahoma Water Quality Standards, the critical flow for Oklahoma streams is the seven-day, two-year low flow. Under this approach, the waste assimilative capacity of each stream would be determined at this flow and allocations would be made such that this capacity would not be exceeded.

Mathematical models would be required to estimate the assimilative capacity of the streams with respect to various parameters. Unless adequate flow records were available, models would also be needed to estimate critical flow conditions for the streams. The inclusion of nonpoint sources in the allocations would make this approach more realistic but much more difficult.

The cost of implementation under this approach would be high. The low flow in most of the streams at critical conditions would necessitate a high level of treatment. This approach would maintain a quality in excess of that required by the standards most of the time, due to larger than critical flows.

Discharge Designed for Median Flow

This approach would require an allocation of waste loads based on the assimilative capacity of the streams at the median flow. Provisions would be made to store part of the treated waste during periods when stream flow is less than the median value, and to release this stored waste during periods when stream flow exceeds the median value. In reality, this would require a knowledge of the assimilative capacity at a wide range of flows in order to determine the rate of storage and the rate of release. Since nonpoint source pollution would influence the assimilative capacity, particularly at higher flows, contributions from these sources must be known.

The cost of implementing this approach might be less than the previous approach since a lesser degree of treatment would be required. However, a cost versus efficiency plot is not a smooth curve. Sharp increase in costs occur when a higher order of treatment is required to increase efficiency. For this approach to be more cost effective, the required treatment would have to be one order lower than required at the critical flow, e.g. secondary vs. tertiary.

Part of any such savings in treatment cost could be off-set by the cost of the storage facility. Should the storage facility receive biodegradable waste, aereation would have to be provided to prevent septic conditions.

Mathematical modeling under this approach would be extensive, models would be required to simulate stream response to both point and nonpoint sources within a wide flow range. A sub-routine would be required to estimate nonpoint contributions within the working flow range.

Discharge Designed with Incremental Treatment

Under this approach, waste load allocations would be made for the stream assimilative capacity at critical flow conditions, as in the second approach discussed. However, provisions would be made for incremental treatment efficiencies coinsiding with assimilative capacity of various stream flows. These increases in treatment efficiency would be consistent with additional orders of treatment, or with the addition of particular units within a treatment order. For example, the application of a tertiary treatment system to a secondary system effluent would increase the BOD removal efficiency from approximately 85 percent to approximately 98 percent. The addition of the tertiary system would be required only when the stream flow dropped below the value required to assimilate the effluent from the secondary system. Smaller increments in efficiency could be gained by the addition of another unit, such as another trickling filter or activated sludge tank, within the secondary treatment system. Thus, by selective operation of treatment units, a waste load equal to or less than the stream's assimilative capacity would be maintained at all times.

Planning for this approach would be similar to that of the previous approach. The flow volume required to provide the assimilative capacity required by the waste load produced by all possible combinations of the treatment units would have to be ascertained. Again, a knowledge of the extent and effects of nonpoint sources would be required.

Capitol cost of constructing facilities under this approach would be as extensive as those under approach number two, since the final effluent would have to be capable of meeting allowable stream loading at critical flow. Operating cost could be cut considerably, however, by closing down some of the facilties during higher flow.

Incremental biological treatment under this alternative would be a sensitive operation. The use of trickling filters or other methods of biological treatment requiring careful culturing of the treatment organisms would be ruled out in favor of operations such as activated sludge, where old sludge could be used as seed in the start-up operation.

This method would, perhaps, work best with the increment being from secondary treatment at high flows to tertiary treatment at lower flows. Chemical precipitation to remove nutrients and cell organics at low flow would be a prime example of the utility of this method.

Low Flow Augmentation

Under this approach, waste loads would be allocated based on the assimilative capacity derived for a specified minimum flow. This minimum flow would be maintained by augmentation from existing reservoirs and from reservoirs constructed specifically for supplementing stream flow during low flow periods. The optimum minimum stream flow in this scheme would be arrived at by minimizing the cost of augmentation facilities and waste treatment facilities.

This minimuzation procedure is a simple Operations Research Technique. However, costs for increments in dilution water and costs for treatment efficiencies must be determined. These parameters are not independent since the treatment requirements are based upon assimilative capacities which in turn is based upon stream flow. Thus, what appears at first to be a relatively simple approach is complicated very quickly with requirements for sub-models to determine assimilative capacity and cost analysis associated with storage capacity and waste treatment facilities.

Selection of Approach

In selecting an optimum approach from among the alternates, several factors must be considered. These include statutory restraints, data resources for required modeling effort, available capital for construction, operating costs, availability of trained manpower, and many others. The various approaches discussed previously are evaluated below in light of these factors.

The application of no discharge regulations on a basin-wide basis does not appear to be feasible at this time. The cost of constructing facilities to treat waste water to the point of recycle and reuse would exceed the the available resources. The problems of large scale subsurface injection and the cost and inavailability of land for total retention ponds or irrigation fields near the major dischargers rules this option out. However, this alternative has great merit and should be considered on a case by case basis for each discharger.

The design for discharge to meet the standards at median flow and the design for incremental treatment alternates would have statutory restraints. In the case of municipalities, no discharges in excess of best secondary treatment could be allowed, nor could industries discharge in excess of best practical treatment standards. These standards are set by EPA and are generally quite low. Best secondary treatment is designated as 30 mg/l BOD, 30 mg/l suspended solids, and 200 fecal coliform organisms per 100 ml. Best practical treatment will be established for individual categories of industry. These limitations on discharge quantities limit the utility of these approaches to special cases only. They would , perhaps be viable alternatives where low stream flow necessitates a high rate of treatment for only short periods of time.

The low flow augmentation approach is, for all practical purposes ruled out by the philosophy enunciated in Section 102 (b) (1) of the Federal Water Pollution Control Act Amendments that "...storage and water release shall not be provided as a substitute for adequate treatment or other methods of controlling waste at the source". Although existing low flow augmentation is being practiced by regulated discharges from several of the major reservoirs within the basin, this regulation is in conjunction with existing uses and changes in discharge practices to coincide with waste releases would probably not be possible even if it were permitted.

This leaves only the approach whereby discharges would be designed to meet the water quality standards at critical flow (seven-day, two-year low flow). Although this method will be expensive to implement, it appears to be the only viable alternative. Judicious use of no discharge systems, storage facilities and temporary chemical treatment facilities on case by case basis could help reduce the cost of some facilities.

As mentioned earlier in the discussion of this approach, the inclusion of nonpoint sources of pollution in this approach would make it more realistic. However, these pollutants enter the stream primarily in surface runoff, a phenonomena which would not be occurring to any extent simultaneously with the seven-day, two-year low flow. Since allocations to point sources are being made at the seven-day, two year low flow, no assimilative capacity will be reserved for nonpoint sources. This is not to say that nonpoint sources are not an important factor in the basin, even at the low flow, but that any attempt at this point to allocate a certain portion of the stream's assimilative capacity to nonpoint sources would be guesswork. Later planning activities should focus more attention on compiling a nonpoint source inventory for the basin.

Having selected this approach, waste load allocations for point sources will be made such that instream quality as specified by the standards will be met at the critical flow conditions. The following section of this plan will describe the procedures for determining the allowable stream loading and for allocating this load to individual dischargers.

VI DEVELOPMENT OF SELECTED APPROACH

Using the approach selected in the previous section of this paper, waste load allocations will be made to each individual discharger. Before this can be done, the ability of the stream to dilute, transport and assimilate the various types of pollutants must be known. As used in this paper, the assimilative capacity of a stream will refer specifically to the stream's ability to recover from a discharge of biodegradable waste and this assimilative capacity will be used for allocating BOD. The dilution capacity will be used for allocating conservative elements.

A requirement for the determination of assimilative capacity and dilution capacity is a knowledge of the critical flow in the stream. This low flow has been calculated for each stream in the Middle Arkansas Basin which receives waste discharges. This low flow analysis along with the theoretical development of the assimilative capacity and dilution capacity models are included below. Also included in this section is a description of the calibrating data for the models and a description of the procedure used in their application. Finally, the results of the modeling are used to allocate waste loads to point source discharges.

Low-Flow Analysis

The two most important parameters associated with stream flow are quality and quantity. These parameters are not independent. This is particularly true in Oklahoma where the concentrations of naturally occurring minerals vary significantly with flow volume. The volume of stream flow also determines, to a large extent, the allowable waste discharge. The critical condition with reference to waste assimilation capacity is the low flow conditions. It is, therefore, necessary to determine low flow conditions before proceeding with a waste load allocation analysis.

The Oklahoma Water Quality Standards cites the seven-day, two-year low flow as the flow above which the standards are to remain in effect. This flow is also specified as the design-flow for determining allowable discharge loads to the stream. Seven-day, two-year low flow is interpreted to mean the lowest seven-day flow, taken as a moving average, which has a recurrence interval of two years.

A method for obtaining this low flow data was recently devised by the U.S.G.S. (Riggs 1972) and is outlined as follows:

1. A moving average is taken of each year's record using a window width of seven days. The lowest seven-day average is selected for each year.

2. These seven-day low flow averages are then arrayed in order or magnitude of the flow value, with the lowest value first and the highest (nth) value, last.

3. The following recurrence formula is utilized: $R = \frac{n+1}{m}$

   Where: R = recurrence interval
   n = number of years recorded
   m = order number corresponding to the flow with recurrence interval selected

This can be rearranged to read: $m = \frac{n+1}{R}$

For this case setting, R equal to two years, the value m can be obtained.

4. Returning to the ordered array, the mth value is found and is taken as the seven-day, two-year low flow.

As an example, if nine years of record exists, the lowest seven-day moving average for each year would be calculated and arrayed in ascending order:

$$m = \frac{n+1}{R} \qquad \frac{9+1}{R} \qquad = \quad 5$$

The fifth in the ordered array becomes the seven-day, two year low flow.

This method has been used to calculate low flows at all of the U.S. G.S. gaging stations. Since only the major streams in the basin have gaging stations, it was necessary to extrapolate these low flows to the tributaries and to other points in the main streams. The U.S.G.S. paper referenced above also suggests a method for accomplishing this.

The flow at the gaging station is associated with the drainage area, A. From this relationship a flow per unit area, Q/A, can be determined. However, this flow per unit area cannot be applied directly to every tributary in the basin to determine the flow for that tributary. If at all possible, a gaging station in the same basin downstream of the tributary of interest should be selected. If there is no gaging station in the basin of interest, the nearest station should be used. The following equation may then be used to calculate low flow values for ungaged streams:

$$Q_a/_A = [Q_b/_{A_b}] \; [A/A_b]^c \qquad [1]$$

Where: Q_b = measured flows, cfs, at existing gaging stations

A_b = drainage area above existing gaging site, square miles

Q_a = flow in cfs of ungaged tributary or stream of interest

A = area of ungaged tributary or stream of interest square miles (above point where flow is desired)

c = dimensionless parameter

Once the appropriate areas have been established and the low flow value calculated for the gaged station, the only problem left is determining the value for c This value has been estimated to be one for the entire state of Oklahoma by Seeley of the U.S. Agricultural experiment station at Chickasha, Oklahoma. This equation, with c=1 was used in estimating seven-day, two-year low flows at all discharge points in the basin.

This equation should only be applied to areas of a tributary upstream from the gaging station. When extrapolating the flow for a tertiary stream, a gaging station on the receiving secondary stream, if the gage exists, should be used instead of a gage on the primary stream.

This technique of station selection will minimize flow differences due to evaporation, precipitation, physical characteristics such as stream bed slopes and geological characteristics such as topography and soil types. With this precaution, the reliability of the empirical relationship of equation [1] increases. Of course, when low flows are very small, geology plays a more important part in determining the quantity of flow than it does at high flows.

Segment 1-B

While flow in the main stem of the Illinois River varies seasonally, the river is a perennial stream and has substantial flow most of the time. The U.S.G.S. maintains five gaging stations and one lake gaging station within this segment. Data from stations are recorded by U.S.G.S. and published annually in Water Resources Data for Oklahoma, Part I, Surface Water Records. (USGS 1971b) Flow downstream from Tenkiller is regulated to a large extent while flow upstream varies seasonally and from year to year depending upon climatological conditions. An example of this variation was shown on page 28 in the form a flow-duration curve for the main stem of the river at Tahlequah, just upstream from the backwater of Lake Tenkiller. It is apparent from the flow-duration curve that flow in the stream is substantial with the exception of a very small percentage of the time.

A list of low flows for streams in Segment 1-B which receive discharges is included below. An asterisk (*) beside the flow indicates that it is calculated directly from gaging station data. The remaining flows were calculated using formula (1) discussed earlier.

TABLE 12

Low Flow Data for Segment 1-B

Stream	Seven-Day, Two-Year Low Flow
Illinois River	117*
Barren Fork	10.8
Caney Creek at Stilwell	.09
Shell Creek at Westville	1.84

It can be noted from the flow duration curve that the seven-day, two-year low flow of the Illinois River is equaled or exceeded approximately 87 percent of the time.

Segment 1-C

Low flow data for the Grand Neosho River cannot be accurately calculated because most of the U.S.G.S. gaging stations have been inundated by the backwaters of the reservoirs. The following low flow values represent the best estimates based on 1) the minimum discharges allowed by the Army Corps of Engineers from the reservoirs, 2) data from gaging stations not yet inundated, and 3) historical data for inundated gaging stations (wherever available).

The low flow volume of the Grand Neosho River entering Oklahoma is 136 cubic feet per second (cfs). This low flow is increased to approximately 310 cfs at its confluence with Spring River (169 cfs) and Lost Creek (4.6 cfs) near Wyandotte, Oklahoma. Historical water data collected prior to 1957 near Grove, Oklahoma, establishes the low flow at 408 cfs below the confluence of the Elk River. Big Cabin Creek contributes a low flow of 1 cfs to the Grand Neosho below Grand Lake (Lake O' the Cherokees) damsite. Therefore, the minimum flow into Lake Hudson should be at least the sum of the two flows (409 cfs).

Lake Hudson receives flow from Spavinaw Creek. Spavinaw Creek is completely regulated by Tulsa's two municipal water supply reservoirs, Spavinaw Lake and Eucha Lake. The low flow entering Lake Hudson from Spavinaw Creek is not known and for the design purposes of this plan will be considered insignificant.

The low flow discharge from Lake Hudson is unavailable at this time. The minimum discharge is assumed to equal the minimum inflow value of 409 cfs.

The minimum low flow from Ft. Gibson Reservoir is 1000 cfs. This value was established by phone conversation with the Army Corps of Engineers' office in Tulsa, Oklahoma.

An eighteen year record of discharges from Ft. Gibson Reservoir was displayed in a duration curve of daily discharge, on page 25. The curve is a relection of the dam authorities discharge procedures. The fact that the two-year, seven-day low flow value is equalled or exceeded only seventy-two percent (72%) of the time might indicate that a change in discahrge procedures has occurred since construction of this curve.

Low Flows for streams in Segment 1-C are shown in the table on the following page. Flows marked with an asterisk (*) indicate that this value was taken directly from nearby gaging stations. Other values were obtained using equation (1).

Segment 1-D

The Verdigris River enters Oklahoma with a low flow of 11.4 cfs. By the time it reaches Lenapah, Oklahoma, the low flow has increased to 12.5 cfs. Below Lenapah, the Verdigris River is impounded into Oologah Lake. Low flow data from a gaging station below the lake near Claremore establishes the low flow to be 16.5 cfs. This value includes the contribution from Caney River (1.2 cfs). Both Bird Creek (2.0 cfs) and Spunky Creek (0.3 cfs) enter the Verdigris River near the Port of Catoosa increasing

TABLE 13

Low Flow Data for Segment 1-C

Stream	Two-Year, Seven-Day Low Flow(cfs)
Lytle Creek @ Picher	0.0
Tar Creek	
@ Cardin	0.17
@ Commerce	0.178
@ Miami	0.25
Grand Neosho River @ Commerce	136.0*
Spring River @ Quapaw	169.0*
Lost Creek @ Seneca, Mo.	4.6*
Horse Creek @ Afton	0.0
Little Cabin Creek	0.0
Bull Creek	0.0
Big Cabin Creek	1.0*
Okeeche Creek @ Fairland	0.0
Hudson Creek	0.0
Muskcrat Creek @ Jay	1.05
Grove Spring @ Grove	7.5
Grand Creek @ Locust Grove	0.0
Coal Creek @ Wagoner	0.0
Bitter Creek @ Adair	0.0
Chouteau Creek @ Chouteau	0.0
Pryor Creek	0.0
Grand-Neosho River @ PICC	> 409.
Grand Neosho River b/l Ft. Gibson	1000.

*Low flow value actually calculated using data from U.S.G.S. gaging stations.

the low flow value to greater than 18.1 cfs at this point. The last tributary in Segment 1-D to make a minimum low flow contribution to the Verdigris River is Dog Creek adding 1.15 cfs for a total low flow greater than 19.95 cfs at its confluence with the Arkansas River.

It is interesting to note from the duration curve of daily discharge, shown on page 26, a low flow of zero is exceeded 99.7 percent of the time in the Verdigris River, yet the two-year, seven-day low flow is exceeded approximately ninety-two percent (92%) of the time. Likewise, it is also of interest that the two-year, seven-day low flow is nearly the same before and after construction of reservoirs on the Verdigris River in Kansas.

Low flow data on streams receiving waste discharges in Segment 1-D are shown on the following page. Again, those flow values which were obtained directly from gaging station data are marked with an asterisk (*).

Segment 1-A

The minimum flow released from Keystone Reservoir into Segment 1-A of the Arkansas River is 200 cfs. This value was established by phone conversation with the Tulsa District Army Corps of Engineers. Two hundred cubic feet per second will, therefore, be considered to be the two-year, seven-day low flow discharged from the Keystone Reservoir. This reservoir regulates the Arkansas River from the damsite to the river's confluence with the Verdigris and Grand Neosho Rivers near Muskogee.

U.S. Geological Survey gaging station #7-1945 has been inundated by the backwaters of the Webber's Falls Reservoir. Using the historical data from this gaging station gives a two-year, seven-day low flow

TABLE 14

Low Flow Data for Segment 1-D

Stream	Two-Year, Seven-Day Low Flow (cfs)
Hominy Creek	
@ Hominy	0.02
@ Sperry	0.1
Bird Creek	
@ Wynona	0.0
@ Pawhuska	0.0
@ Barnsdall	0.91
@ Avant	1.87*
@ Sperry	2.0 *
Spunky Creek	
@ Tulsa	0.0
@ Rolling Hills	0.23
@ Catoosa	0.3
Black Jack Creek @ Tulsa	0.0
Dog Creek @ Claremore	1.15
Pea Creek @ Inola	0.0
Western Branch Creek @ Nowata	0.0
Little Caney Creek @ Copan	0.0
Fourmile Creek @ Dewey	0.0
Caney River @ Bartlesville	1.2 *
Verdigris River	
@ South Coffeyville, Kansas	11.4
@ Lenapah	12.5*
@ Claremore	16.5*

*Low flow value actually calculated using data from U.S.G.S. gaging stations.

figure of 1921 cfs. The daily discharge duration curves on page 23 shows that this low flow value is equalled or exceeded ninety percent (90%) of the time.

A two-year, seven-day low flow equal to 2010 cfs was supplied by the Army Corps of Engineers for the Arkansas River near Gore. This value includes the low flow contribution of the Illinois River (117 cfs).

Low flow data for other streams in Segment 1-A is given in the Table on the following page. Gaging station data is marked with an asterisk(*).

BOD Assimilative Capacity

Several models are currently being used for predicting the assimilative capacity of streams. The original model was developed by H. W. Streeter and E. B. Phelps (Streeter etal 1958) in 1925 for a portion of the Ohio River. Their model is discussed in detail in a later publication by Phelps (Phelps 1944).

The Streeter-Phelps model is based on the interrelationships of the biochemical oxygen demand (BOD) and oxygen deficit (D) in the stream. The oxygen deficit is defined by the following equation:

$$D = C_s - C$$

Where: C_s = dissolved oxygen (DO) concentration at saturation

C = dissolved oxygen concentration at any time (t)

TABLE 15

Low Flow Data for Segment 1-A

Stream	Two-Year, Seven-Day Low Flow (cfs)
Arkansas River	
@ Sand Springs	200.0
@ Tulsa	200.0
@ Jenks	200.0
@ Bixby	201.62
@ Muskogee	1921.0*
@ Gore	2010.0
Illinois River @ Gore	117.0
Polecat Creek @ Sapulpa	1.18
Rock Creek @ Sapulpa	0.44
Elk Creek @ Checotah	0.0
Sand Creek @ Braggs	0.0
Dirty Creek @ Conners State College	0.0
Dirty Creek (South Fork) @ Porum	0.0
Cloud Creek @ Boynton	0.0
Childer's Creek @ Keifer	0.0
Snake Creek @ Mounds	0.0
Broken Arrow Creek @ Broken Arrow	0.0

*Low flow value actually calculated using data from currently operating U.S.G.S. gaging stations.

When a load of biodegradable material is discharged into a stream, two natural phenomena occur simultaneously. One involves the decrease in the Bod with a resulting depletion of the DO, while the other involves an increase in the DO due to the reaeration of the stream. The biological processes and physical mechanisms involved in these two reactions are quite complicated and a detailed discussion of these will not be included. The equations which are generally assumed to approximate these reactions are described below.

The equation describing the deoxygenation reaction (and subsequent reduction in BOD) was postulated by Streeter-Phelps to be:

$$\frac{dL}{dt} = -k_1 L \qquad (2)$$

which is a linear, first order differential equation, the solution to which is:

$$L = L_a e^{-k_1 t} \qquad (3)$$

Where: L = BOD load at time, t

L_a = initial BOD load at $t = 0$

k_1 = the first order deoxygenation rate constant

The reaeration process was also postulated to be a first order reaction, proportional to the oxygen deficit. This process is represented by the following equation:

$$\frac{dD}{dt} = -k_2 D$$

WhereL D = oxygen deficit at time, t

k_2 = first order reaeration rate constant

Equations (2) and (4) can be combined to represent the sum of the effects of deoxygenation and reaeration in the stream as follows:

$$\frac{dD}{dt} = k_1L - k_2D \tag{5}$$

The first term on the right of the equation represents the deoxygenation reaction which increases the deficit, while the second term represents the reaeration reaction which decreases the deficit.

Substituting the value of L from equation (3) into equation (5), a solution can be obtained which reduces to the classical form of the Streeter-Phelps equation, written in either natural or base 10 logarithms as follows:

$$D = \frac{k_1L_a}{k_2 - k_1} (e^{-k_1t} - e^{-k_2t}) + D_ae^{-k_2t} \tag{6a}$$

$$D = \frac{k_1La}{k_2 - k_1} (10^{-k_1t} - 10^{-k_2t}) + D_a10^{-k_2t} \tag{6b}$$

Where:
- D = oxygen deficit at time, t
- L_a = original BOD load
- e = base of natural logarithm
- t = time between the measurement of D and the discharge of L_a
- k_1 = deoxygenation rate constant (different values for the two equations)
- k_2 = reaeration rate constant (different values for the two equations)

If the deficit, D, in equation (6) is expressed in terms of percent saturation and plotted against time, the resulting curve is similar to Figure 16 on the following page. The dip in the curve is responsible for equation (6) being called the Streeter-Phelps DO sag equation. The deoxygenation and reaeration components of th sag equation are plotted separately in Figure 16 to illustrate that the dissolved oxygen curve is the sum of the two at all points.

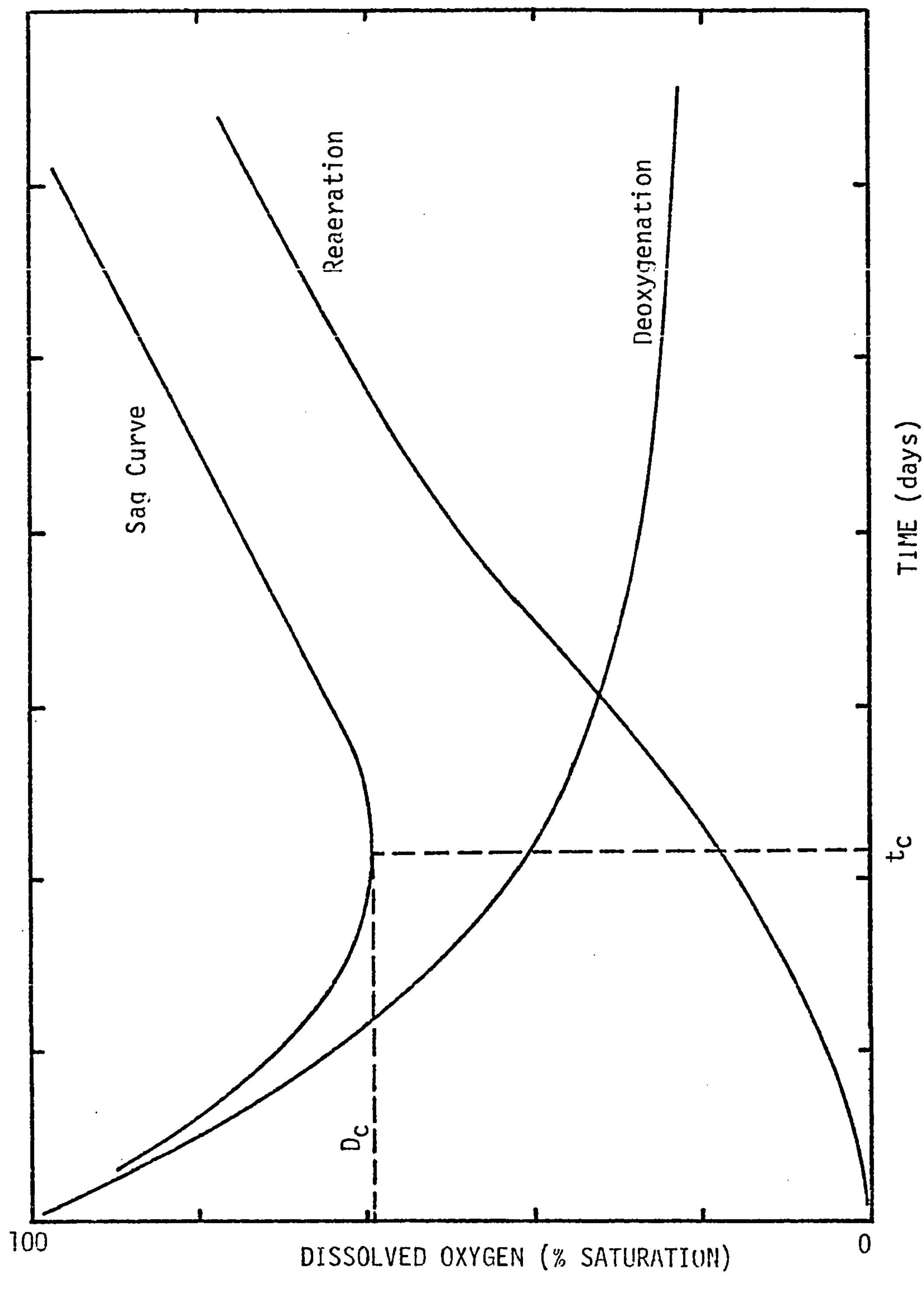


Figure 16

STREETER-PHELPS OXYGEN SAG CURVE

The maximum deficit represented by the minimum of the sag may be found by differentiating equation (6) and setting the results equal to zero. This critical deficit, and the corresponding time of its occurrence, t_c, are important factors in determining the assimilation capacity of a stream. Equations for D_c and t_c are given below:

$$D_c = \frac{k_1}{k_2} L_a 10^{-k_1 t_c} \quad . \tag{7}$$

$$t_c = \frac{1}{k_2 - k_1} \log k_2/k_1 \left(1 - \frac{D_a(k_2 - k_1)}{L_a k_1} \right) \tag{8}$$

Substituting the critical deficit, D_c, and the critical time, t_c, back into equation (6) and solving for L_a yields the following equation:

$$L_a = \frac{(k_2 - k_1)}{k_1} \left(\frac{D_c - D_a 10^{-k_2 t_c}}{10^{-k_1 t_c} - 10^{k_2 t_c}} \right) \tag{9}$$

This value of L_a is the maximum allowable load that can be imposed upon a stream without exceeding the critical deficit, D_c, in the stream models. Some of these models are examined in detail in Appendix G. A close examination of these models, however, reveals that they are variations of the Streeter-Phelps model, some being simplified viersions, while others are more sophisticated.

The more sophisticated models are intended to utilize data more specific to the stream being modeled. While they would probably simulate instream conditions more closely than simpler models, they require extensive input data of the type not routinely gathered by state pollution control agencies. To obtain this data on a state-wide basis would require a sampling program beyond the means of the state agencies. Therefore, the present modeling effort in Oklahoma must of necessity be rather simplistic.

Selection of Models

Two variations of the Streeter-Phelps model given in equation (9) will be used to assess the assimilative capacity of streams in the Middle Arkansas Basin. The two basic types of streams in the basin and the version of the model used on each are described below.

The two basic types of streams in the basin are "return flow-special mixing zone" streams and "perennial" streams. A "speical mixing zone" is defined by the Oklahoma Water Quality Standards (page 10 of Appendix A) to be a stream in which the combined stream and waste flow is less than four times the waste discharged to the stream. In other words, the dilution ratio, the ratio of stream flow to waste flow, is less than three to one. Although no clear definition of a return flow stream is given by the Standards, Table A1 of Appendix A shows three streams in the basin to be designated as such. It is believed that the intent of the Standards was to designate as return flow streams all streams which are composed entirely of waste effluent during critical flow conditions, i.e., when the natural low flow is zero. If this is the case, the low flow analysis made in conjunction with this study reveals that many other streams in the basin should have been designated as return flow streams. It is suggested that the revision of the Standards planned for 1976 inlcude designation of all return flow streams and special mixing zone streams. These designations are included in Table A1 and are enclosed in parenthesis to distinguish them from the original designations.

Model for Return Flow - Speical Mixing Zone Streams

The standards set for the minimum DO for return flow and special mixing zone streams at 2 mg/l. The most critical condition would exist if the waste was discharged containing only 2 mg/l of DO and little or no natural flow existed in the stream for dilution. This would correspond to the critical deficit, D_c, in the Figure 16. Since the change in the deficit with respect to time is zero at this point, equation (5) can be rewritten as follows:

$$\frac{dD}{dt} = 0 = k_1L - k_2D$$

or

$$k_1L = k_2D$$

or

$$L = \frac{k_2}{k_1D}$$

substituting Fair's (1939) purification constant, f, (see Appendix G) for k_2/k_1, this equation becomes:

$$L = fD \qquad (10)$$

where L is the allowable instream BOD concentration expressed in mg/l, D is the deficit at a DO of 2 mg/l and f is a dimensionless parameter.

The value of L in equation (10) represents the maximum concentration of waste which can be discharged into a return flow stream, or into a special mixing zone stream where the volume of dilution water is insignificant when compared to the waste discharge. The assimilative capacity of all return flow-mixing zone streams in the basin were calculated using equation (10) and values for f and D which will be discussed in a later part of this section.

Models for Perennial Streams

Streams with a dilution ratio of greater than three to one do not fall in the return flow-special mixing zone category and must maintain a higher

DO concentration. Warm water streams are required to have a minimum DO of 5 mg/l while small mouth bass and trout streams are required to have a minimum DO of 6 mg/l. The model used for estimating the assimilative capacity of these streams is equation (9) modified with Fair's constant. This equation is given below:

$$L_a = (f - 1)\,\frac{D_c - D_a 10^{-fk_1 t_c}}{10^{-k_1 t_c} - 10^{1fk_1 t_c}} \qquad (11)$$

Data on the dissolved oxygen deficit upstream from points of discharges is not available. It is reasonable to assume, however, that some deficit already exists due to benthic deposits and organic matter falling or being blown into the stream. Lacking further knowledge, an initial deficit, D_a, or 1.0 mg/l is used as recommended by EPA. (1971a) Since 10 raised to any negative exponent is less than unity, the term in the numerator of equation (11) which describes the initial deficit, D_a, can be simplified conservatively by assigning it a value of one. This reduces equation (11) to the following form:

$$L_a = \frac{(f-1)(D_c-1)}{10^{-k_1 t_c} - 10^{-fk_1 t_c}} \qquad (12)$$

Equation (12) and the appropriate f, D_c, and t_c factors were used to calculate the assimilative capacity of all perennial streams in the basin.

In each case, the retention time in the stream from the point of discharge to its confluence with the next highest order streams was calculated. This calculation was made using the velocity for the streams obtained through a special stream survey conducted by the Oklahoma Water Resources Board for this study. Whenever a BOD remained at the point of confluence, this BOD residual was applied to the receiving stream and routed downstream until all BOD was satisfied.

Calibration of Models

The use of equations (10) and (12) in the assimilative capacity analysis depends upon selecting appropriate f value and critical deficit values. The values of D_c are obtained by subtracting the minimum allowable DO concentration from the saturation DO at $90^{o}F$ for warm water streams, $84^{o}F$ for small mouth bass streams and $68^{o}F$ for trout streams. The resulting D_c values are shown in Table 16 on the following page.

Values for the purification constant, f, were estimated by Fair (Fair 1939) for several different types of streams. These values have been subsequently reported by several authors (Phelps 1944; Fair 1939; Fair etal 1968) in their work. Fair's f values are shown in Table 17 on the following page.

The values in Table 17 were derived emperically for streams in other parts of the country and may not be appropriate for streams in Oklahoma. A special grant was obtained from EPA to determine f values on several Oklahoma streams for comparison. These studies were conducted by the Oklahoma State Department of Health and will be published at a future date. The results of their study has been taken from the pre-publication draft and is reported in Table 18 on page 119.

TABLE 16

CRITICAL OXYGEN DEFICITS

Type of Stream	Maximum Temperature F°	Saturation DO mg/l	Minimum DO mg/l	D_c mg/l
Return Flow- Special Mixing Zone	90	7.4	2.0	5.4
Warm Water Perennial	90	7.4	5.0	2.4
Small Mouth Bass	84	7.8	6.0	1.8
Trout	68	9.2	6.0	3.2

TABLE 17

f Factors Recommended by Fair

Nature of Receiving Water	Magnitude of f @ 20°C
Small Ponds and Backwaters	0.5 - 1.0
Sluggish Streams and Large Lakes	1.0 - 1.5
Large Streams of Low Velocity	1.5 - 2.0
Large Streams of Moderate Velocity	2.0 - 3.0
Swift Streams	3.0 - 5.0
Rapids and Waterfalls	5.0

TABLE 18

f Factors for Selected Streams in Oklahoma
(values corrected for 32°C (90°F))

STREAM	f
Spring Creek	6.0
Tributary to Choctaw Creek	11.0
Cow Creek	5.5
Chisholm Creek	6.0
Ogeechee Creek	3.0
Choctaw Creek	4.0
Deer Creek	4.5
Horse Creek	3.0
Tar Creek	3.0

All nine streams in Table 18 fall in the category of return flow-special mixing zone streams. Thus, an average value of the f factors would be a valid estimate of values to be used in assimilative capacity analysis. Rejecting the higher value of 11 for the Choctaw Creek tributary as being non-representative with respect to the others, the average f factor for these streams is 4.4. This value is considerably higher than the values reported in Table 15, but is probably more representative of Oklahoma return flow-speical mixing zone streams. It is therefore proposed that a value of 4.0 be used on all return flow-special mixing zone and warm water streams on the Middle Arkansas Basin. The value of 4.0, corrected to 84°F and 68°F will be used on small mouth bass streams and trout streams. A reduction of 0.4 from the average value is slightly conservative for the return flow-mixing zone streams, and extrapolating this value to perennial streams is quite conservative since the larger flows in these streams would tend to create a higher reaeration rate.

Temperature corrections for small mouth bass streams and trout streams were made using the following formula from Fair, Guyer, and Okun. (1968)

$$f = f_{(20^{o}c)} e^{-0.022(F^{o^{C}} - 20)} \qquad (13)$$

These are rounded off conservatively to 4.0 and 5.0 respectively.

All the information is now available to calculate the allowable loading to each stream. The calcuations for a return flow-special mixing zone stream is simply:

$$L_a = fD$$
$$= 4.0 \times 5.4$$
$$= 21.6$$

This value was rounded off to 20 mg/l for the purpose of allocation.

The allowable loading, L_a, for perennial streams is somewhat more complicated. Combining equations (8) and (12) gives an equation for L_a which is independent of k_1. Assuming the term $D_a/L_a(f-1)$ to be sufficiently less than one and omitting it from equation (8) yields an expression for L_a involving only f and D_c. Solving this equation for each type of stream yields the following instream concentrations.

Type of Stream	L_a
Warm water streams	9 mg/l
Small mouth bass streams	5 mg/l
Trout Streams	16 mg/l

These values represent the allowable instream concentrations after mixing. The critical condition for perennial streams occurs when the dilution ratio is three to one, or the total flow is the stream (natural flow plus effluent) is four times greater than the effluent alone. Therefore, the concentration in the effluent could be four times greater than the above figures without exceeding the allowable load in each type of stream. In view of the 30 mg/l BOD maximum imposed by EPA secondary treatment guidelines, dischargers to all perennial streams will be allocated no more than 30 mg/l. Dischargers to small mouth bass streams will be restricted to four times the instream value shown above, or 20 mg/l BOD.

Toxic Substance Dilution Capacity

As mentioned earlier in the section on water quality standards, the limits on discharges of all conservative elements except toxicants are covered in Table A2 or in the narrative of the Water Quality Standards. Limits for a selected list of toxicants were presented in Table 11 on page 75.

A search of discharge inventories reveals that the following toxicants are discharged in the Middle Arkansas Planning Basin.

TABLE 19

Toxicant Discharges

Toxicant	Number of Point Sources Discharges
Ammonia Nitrogen	16
Cadmium	3
Chromium	13
Cyanide	5
Fluoride	8
Lead	3
Nickel	3
Phenols	3
Zinc	10

The method used for allocating these toxicants consists of a simple dilution model:

$$C_t = C_s\frac{Q_s}{Q_t}$$

or (13)

$$C_t = C_s D_r$$

Where: C_t = concentration of toxicant allowable in the effluent, mg/l

C_s = allowable, instream value for the toxicant (from Table 13), mg/l

Q_s = flow in stream (mgd)

Q_e = flow in effluent (mgd)

D_r = Q_s/Q_e = dilution ratio (dimensionless)

Further constraints are placed on the maximum allowable discharge of toxicants. When more than one discharge of a toxicant occurs in a segment, the discharges are summed and checked against the total flow downstream from the last discharge to insure that the combination of discharges do not violate Water Quality Standards. Also, the discharge inventory is consulted and no discharger is allocated a higher concentration of toxic substances than presently being discharged. This constraint satisfied the non-degradation clause on page A4 of the Water Quality Standards.

An exception to the above procedure is made in the case of return flow streams and speical mixing zone streams.

The Standards exempt return flow streams and special mixing zones from use as public and private water supply, fish and wildlife progpagation, and primary recreation. Thus, the highest remaining use is for irrigation and livestock watering. Table 11 on page 75 list the maximum suggested concentrations for water designated for use in irrigation or livestock comsumption. These concentrations are used as the allocations to dischargers on return flow or special mixing zone streams. Again, a check is made to insure that standards in a subsequent receiving stream are not violated and that each discharger is not allocated a higher concentration than he is currently discharging.

Allocation to Dischargers

Municipal

Based on the assimilative capacity discussed earlier, allocations have been made to all municipal dischargers in the basin. The only three parameters being allocated to municipal dischargers by EPA in their National Pollution Discharge Elimination System (NPDES) permit program, are BOD (5 day, carbonatious), suspended solids, and fecal coliform bacteria. Consistent with the practical philosophy discussed earlier, only those parameters which will be permitted and enforced by EPA through their NPDES program will be allocated in this plan.

The die-off rate of the coliform organism depends on several factors and any attempt to quantify these factors in this plan would be of questionable value. It is suggested that all permits be written on the basis of 200 organisms per 100 ml, the maximum amount allowed under EPA's Secondary Treatment Standards.

It is the recommendation of this plan that all municipal dischargers be restricted to a discharge of 30 parts per million of suspended solids. This is the maximum allowed under the secondary treatment guidelines. This recommendation is based upon the rationale that the BOD exerted by the suspended cells will be exerted gradually over a period of several days. Since the retention time of the tributary streams is considerably less than a day, the major part of the BOD associated with the suspended solids will be exerted in the larger streams such as the Verdigris, Grand Neosho and Arkansas Rivers. The large flow in these streams, coupled with the low BOD loading should be more than sufficient to prevent any problem associated with the suspended solids. With regard to turbidity caused by the suspended solids, the natural turbidity in most of Oklahoma's streams is such that the effect of an additional 10 to 15 parts per million or suspended solids will not be significant.

The only parameter to be allocated to municipal dischargers is BOD. This allocation is based on the assimilative capacity discussed earlier. All dischargers on return flow-special mixing zone streams are allocated a concentration of 20 mg/l in their effluent. If the DO in the effluent is at least 2 mg/l, the minimum instream DO will be maintained according to the model.

Nearly all of th dischargers on perennial streams have been allocated 30 mg/l in their effluent. Although the model described earlier indicates that, with a three to one dilution ratio, a value in excess of 30 mg/l in the effluent could be assimilated, the allocations have a ceiling of 30 mg/l to correspond to the maximums allowed by EPA's secondary treatment guidelines.

Some exceptions to the above allocations have been made. A few municipalities discharge directly to impoundments, or to streams at a very short distance from their confluence with the impoundments. The fate of biodegradable material in impoindments depends upon the dispersion characteristics of the waste in the lake waters, the depth of the lake, and many other factors. Since the reaeration reaction must depend primarily upon the diffusion of oxygen through the air-water interface instead of mixing through a turbulent flow mechanism at is the case in streams, it is reasonable to assume that the f factors for impoundments is considerably less than for streams. This assumption appears to be validated in Table 17 where Fair reported the fa value for ponded streams to be significantly less than for flowing streams. Since lakes and reservoirs are an important resource in Oklahoma, it is recommended that discharges to these bodies of water be restricted to a concentration of 10 mg/l. There are two such discharges in the Middle Arkansas Basin; Seneca, which discharges into Lost Creek just upstream from Grand Lake, and Hulbert which discharges to a tributary of Fourteen Mile Creek close to Ft. Gibson Reservoir. Both of these municipalities have been allocated 10 mg/l BOD.

Another exception was made in the case of discharges upstream from a water supply reservoir. The State Health Department has several basins upstream from municipal lakes protected by special regulations. One such water shed in the basin has a municipal discharge located within it, the town of Colcord which discharges to a tributary of Spavinaw Creek. At the request of the State Health Department, this municipality will be limited to a discharge of 10 mg/l in their effluent.

Appendix E contains a listing of the allocations to each Municipal Discharger in the Middle Arkansas Basin. This allocation is given in mg/l and, based upon the projected 1980 flow, in lbs/day and kilograms/day. These last two values are included for convenience in writing permits under the NPDES Program.

Industrial

The allocation of BOD to industrial dischargers is based on the assimilation capacity of the receiving stream in the same manner as that used for municipal discharges. However, arbitrary ceilings of 30 parts per million were not set for industry. Since many industries generate waste an order of magnitude stronger than domestic waste, and since industry must use private capital for constructing treatment facilities, discharges greater than 30 ppm of BOD are allowable where the stream's assimilative capacity is sufficient. In each case, the assimilative capacity was compared to the discharge quantity reported in the inventory. If the industry is curretnly discharging less than the full assimilative capacity, allocations were made for the amount that the industry has indicated that it has the present capability of meeting.

Allocations of organic suspended solids were also made to industries with a BOD discharge. An amount equal to the BOD has been allocated, with an upper limit of 150 ppm. Amounts in excess of this could cause localized sludge blankets downstream from the discharge, creating nuisance conditions.

The other materials allocated to industrial dischargers are considered to be conservative materials and the recommended discharge concentrations are based on dilution capacities as described earlier.

Allocation to industries consist only of those parameters which the discharge inventories show are currently being discharged by that particular industry. It is anticipated that any additional parameter added at a later date would require the permit to be rewritten and an allocation of this substance would be made at that particular time.

Appendix F contains the waste load allocations to industries. This table is also arranged to show the recommended discharges in mg/l, lbs/day, and kg/day.

VII SUMMARY, CONCLUSION, AND RECOMMENDATIONS

This paper has attempted to demonstrate an approach to water quality management planning which would optimize the resources available to the state's water pollution control agencies for preparing basin plans persuant to the Federal Water Pollution Control Act Amendments of 1972. An approach was sought which would restrict waste discharges sufficiently to protect the intergrity of the surface waters, while at the same time placing the smallest demand on the state's stream monitoring resources.

Toward this end, a description was made of the natural characteristics which would help in understanding the problems relating to natural quantity and quality of the waters within the chosen basin. An assessment was made of the existing quality of the basin's surface waters, along with an analysis of the waste load currently being imposed. Several approaches to waste load allocations were examined and the optimum approach selected. Models were examined for use in assessing the assimilative capacity of streams. Two models were selected which appear to adequately represent waste assimilative phenomena and for which the data requirements are simple enough to be obtained quickly and without great expense. These models were calibrated by field studies to more closely represent reactions in Oklahoma streams. Finally, these models were used to estimate the maximum amounts of waste which each discharger can deposit in the receiving stream without violating water quality standards.

Several conclusions may be reached from the above study. While the assimilative capacity models may be the best available under present circumstances, more work needs to be done in the area of calibration. The f factors appear to be in reasonable range, but data from more streams should be analyzed. Also more data on the initial dissolved oxygen deficit should be obtained at established sampling points upstream from points of discharge. This information should be added to the data bank from each sampling run.

Another apparent area of weakness is the absence of data on non-point sources. Using the thorough description of the natural and man-influenced characteristics that exist, a sampling program could be designed to obtain data reflecting the contribution of non-point sources. This project should be intergrated into lists of priority projects.

To the writer of this paper, one of the most obvious conclusions to be drawn from this study is the fact that the priorities established by Federal Water Pollution Control Acts Amendments or 1972 and subsequent administrative decisions by EPA are not consonant with effective planning and plan implementation. The decision by EPA to allocate one set of parameters to municipal dischargers and a different set to industries, even though they share common receiving streams, is a case in point. The time table for the completion of interrelated programs is sometimes reversed. A case in point is the fact that permits, which should be guided by planning, are all scheduled for issuance by December 31, 1974 while the planning program will not be completed until FY 1976. These are factors which must be taken into consideration, however, and consistent with the"practical" philosophy expressed throughout the plan, the model has been adjusted to balance the administrative and scientific goals of the planning process.

Several recommendations can be made for improving the plan at a future planning date. One would be the initiation of the program to identify and qunatify the non-point sources contribution identified earlier. Non-point sources are scheduled for emphasis in FY 1976 and information should be available for the 1977 plan update. Additional work on k factors should be done. A study has been proposed and funds are being allocated for surveys to obtain k values on twenty streams in various parts of the state. These values should be used to update the model. In the meantime, the 10, 20, and 30 mg/l values allocated to BOD dischargers are considerably lower than the present quantities being discharged.

Prior to the 1977 planning update, an effort should be made to reconcile the parameters in the waste load allocations for municipal and industrial dischargers. This would benefit instream water quality and at the same time probably assist in improveing public acceptance of the allocation programs by providing a more fair and equitable distribution of the effort involved in the pollution abatement program.

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APPENDIX A

WATER QUALITY STANDARDS

O K L A H O M A ' S

WATER QUALITY STANDARDS

SEPTEMBER 1973

OKLAHOMA WATER RESOURCES BOARD
2241 N. W. 40th Street
Oklahoma City, Oklahoma 73112

TABLE OF CONTENTS

INTRODUCTION

Pursuant to the authority contained in 82 O.S. Supp. 1972, § 926.6(c) which authorizes the classification of waters consistent with best present and future use and the adoption of standards of quality, the Oklahoma Water Resources Board effectuated these standards on September 11, 1973.

It is the purpose of these rules and regulations to designate the uses for which the various waters of the State shall be maintained and protected and to prescribe the water quality standards required to sustain the designated uses.

ANTIDEGRADATION STATEMENT

It is recognized that certain of the waters under consideration possess an existing quality, which is better than the minimum standards established. The quality of those waters will be maintained, unless and until it has been affirmatively demonstrated to the State through public hearings that other uses or different standards are justifiable as a result of necessary economic or social development. This will require that any industrial, public, or private project or development which would constitute a new source of pollution or an increased source of pollution to high quality waters will be required, as part of the initial project design, to provide the highest and best degree of waste treatment.

BENEFICIAL USE DESIGNATIONS

The designated present and potential beneficial uses of the waters of the State are A, C_1, D, F_1, F_2, G_1, G_2, and I, and the general water quality standards apply unless otherwise noted in Appendix A. Published data for some streams are limited. However appropriate beneficial uses to be protected are specified even though low flow conditions may for the most part prevent such uses as primary body contact recreation. Beneficial uses of Oklahoma surface waters designated herein specify quality objectives of lakes and streams. The designation does not limit beneficial use nor prohibit beneficial uses other than those listed nor does it indicate by the order listed any preference of uses. It is recognized that beneficial uses may be protected where corresponding activities are otherwise prohibited by law or by private ownership. This would include primary body contact in some public water supplies as well as recreational use of some privately owned waters. All reservoirs are protected for primary and secondary body contact recreation.

CODE	BENEFICIAL USE
A	Public and private water supplies
B	Emergency public and private water supplies
C_1	Fish and wildlife propagation
C_2	Fish and wildlife propagation to the extent allowed by specifically stated water quality parameters
D	Agriculture (includes livestock watering and irrigation)
E	Hydroelectric power
F_1	Industrial and municipal cooling water
F_2	Receiving, transporting and/or assimilation of adequately treated waste
G_1	Recreation, primary body contact (includes recreational uses where the human body may come in direct contact with the water to the point of complete body submergence)
G_2	Recreation, secondary body contact (includes recreational uses, such as fishing, wading and boating, where ingestion of water is not probable)
H	Navigation
I	Aesthetics
J	Small-mouth bass fishery excluding lake waters
K	Trout fishery (put-and-take)

CODE	LIMITATION
(a)	All streams and reservoirs designated (a) are protected by prohibition of any future discharge of pollutants.
(b)	All streams designated (b) are return flow streams for which special water quality standards have been established.
(c)	Streams or stream systems in which advanced waste treatment of all waste discharges is required are designated (c).

GENERAL STANDARDS

The instream numerical criteria limits shall be maintained at all times with the exception of when the flow is equal to or less than the seven-day, two-year low flow value or times when the flow rate is not significant or discernable by the naked eye. The numerical criteria limits apply at all times to lakes and reservoirs unless otherwise exempted.

Minerals: For chlorides, sulfates and total dissolved solids the arithmetic mean of the concentrations of the samples taken for a year at any point shall not exceed one standard deviation greater than the arithmetic mean of the historical data generated at that point. Not more than one in twenty samples randomly collected shall exceed two standard deviations greater than the arithmetic mean of the historical data generated at that point. Mineralization from other parameters such as calcium, boron, magnesium and sodium from other than natural sources shall be maintained so as to not restrict the beneficial uses. For those stations for which historical data exists, mineral limits have been established and are listed in Appendix B. The values are in milligrams per liter (mg/l). The stations are organized in accordance to basin number with each station's number corresponding to those on Map 2. Mineral standards will be established for other stations as data becomes available. The term "yearly mean standard" listed on the table is defined as that value which the yearly arithmetic mean shall not exceed. The term "sample standard" is used on the table and is defined as that value which not more than one in twenty samples shall exceed. Mineral limits for intermediate locations between listed sample points shall be determined by allowing reasonable gradients between the numerical limits listed for those stations.

Bacteria: In areas designated as G_1 (recreation, primary body contact) or A (public and private water supply), bacteria of the fecal coliform group shall not exceed a monthly geometric mean of 200/100 ml, as determined by multiple-tube fermentation or membrane filter procedures and based on a minimum of not less than five samples for any 30-day period, nor shall more than ten percent (10%) of the total samples during any 30-day period exceed 400/100 ml.

In areas designated G_2 (secondary body contact) bacteria of the fecal coliform group shall not exceed a monthly geometric mean of 1000/100 ml, as determined by multiple-tube fermentation or membrane filter procedures, nor shall more than ten percent (10%) of the total samples during any 30-day period exceed 2000/100 ml.

Oil and Grease: Essentially free of floating or emulsified oil and grease.

<u>Solids</u>: Free of floating debris, bottom deposits, scum, foam and other materials of a persistent nature from other than natural sources.

<u>Turbidity</u>: Turbidity of other than natural origin shall be restricted to the following in-stream numerical values:

Warm Water Streams	50 Jackson Units
Warm Water Lakes	25 Jackson Units
Cold Water Streams (those designated as small-mouth bass fisheries or trout fisheries)	10 Jackson Units

In waters where the natural occuring backgrounds exceeds these values, turbidity from other than natural sources shall be restricted to maintain the naturally occuring background.

<u>Color</u>: Color producing substances of a persistent nature from other than natural sources shall be limited to concentrations which will not be detrimental to beneficial uses.

<u>Temperature</u>: During any month of the year, heat shall not be added to any stream in excess of the amount that will raise the temperature of the water more than 5° F. In lakes, the temperature of the epilimnion shall not be raised more than 3° F above that which existed before the addition of heat of artificial origin. The normal daily and seasonal temperature variations that were present before the addition of heat due to other than natural causes shall be maintained. The maximum temperature due to man-made causes shall not exceed 68° F in trout streams, 84° F in small-mouth bass streams, or 90° F in all other streams and lakes except for the following:

Arkansas River from Kaw Reservoir Dam to the headwaters of Keystone Reservoir 94° F.
Arkansas River from Keystone Reservoir Dam to Coody Creek near Muskogee, Oklahoma 93° F
Salt Fork Arkansas River 93° F
Red River excluding Lake Texoma 93° F
North Fork Red River 91° F

No artificial heat shall be added such that the receiving water temperature exceeds the maximums specified above.

Privately owned lakes and reservoirs used in the process of cooling water for industrial purposes are exempt from these restrictions provided the water released from any such lake or reservoir shall be subject to the temperature requirements.

Maximum temperature determination shall be made by averaging representative temperature measurements of the cross sectional area of streams and rivers.

<u>Taste and Odor Producing Substances</u>: Taste and odor producing substances from other than natural origin shall be limited to concentrations that will not interfere with the production of potable

water by modern treatment methods or impart off-color or unpalatable flavor to flesh of fish, or result in offensive odors in the vicinity of the water, or otherwise interfere with beneficial uses.

Dissolved Oxygen: The dissolved oxygen concentration shall not be less than 5 mg/l for all warm waters, and 6 mg/l for those waters designated as small-mouth bass or trout fisheries. Under extreme conditions, the diurnal variations may cause the dissolved oxygen concentration to be as much as 1 mg/l below the above values for short periods (not to exceed 8 hours) during any 24-hour period provided that the water quality is favorable in all other respects.

Nutrients: The total phosphorous concentration and Nitrogen/Phosphorous ratio shall be limited to prevent eutrophication problems. If sufficient nutrient data become available specific numerical limits will be included in the water quality standards revision scheduled for October 18, 1975.

Toxic Substances: Toxic substances shall not be present in such quantities as to cause the waters to be toxic to human, animal, plant or aquatic life, nor detrimental to any beneficial use including continued ingestion by livestock or continued use for irrigation. For aquatic life, using bioassay techniques, the toxic limit shall not exceed one-tenth of the 96-hour median tolerance limit for the most sensitive species common to the stream. In the absence of information on the most sensitive species the concentration shall not exceed one-tenth of the 96-hour median tolerance limit to *Pimephales promelas* (Fathead Minnow) and/or *Lepomis macrochirus* (Bluegill).

Toxic substances shall not be present in quantities which allow long term toxic effects in the food chain or accumulation of toxic substances in fish or wildlife.

The following materials may have synergistic effects: ammonia, cadmium, hexavalent chromium, trivalent chromium, copper, cyanide, lead, mercury, nickel, selenium, silver and zinc. These substances shall not be present in sufficient concentration to allow the cumulative relationship value to exceed the numerical value of one.

The cumulative relationship value (CRV) is defined as:

$$CRV = \frac{C_a}{L_a} + \frac{C_b}{L_b} + \ldots + \frac{C_n}{L_n}$$

where: C_a, C_b, . . . C_n are the measured concentrations in the streams and L_a, L_b, . . . L_n are respective maximum permissable concentrations if each constituent were present alone.

Species Diversity Index: A diversity value ($\overline{d}$) for benthic (bottom dwelling) macroinvertebrate organisms shall be maintained at a minimum of three (3) unless natural conditions or phenomena cause the value to be less.

Enumeration and classification techniques of sampled benthic organisms shall be utilized to acquire information which will be subjected to mathematical interpretation from which is derived an index of species diversity ($\bar{d}$). Biological information incorporated into the diversity index includes: number of species samples (s), total number of individuals (n), and number of individuals per species (n_i); with diversity specifically expressed mathematically as:

$$\bar{d} = - \sum_{1}^{s} (n_i/n) \log_2 (n_i/n)$$

Where the logarithm is expressed in terms of the base z. This expression is dimensionless and includes numbers of individuals representing each species. The species diversity index shall not be determined on a count of less than 100 individuals per sample.

<u>pH</u>: The pH shall be between 6.5 and 8.5. pH values below 6.5 and above 8.5 must not be due to waste discharge.

<u>Other Substances</u>: The control of other substances not heretofore mentioned will be guided by the U.S. Public Health Service Drinking Water Standards of 1962, or latest revision thereof, and accumulated scientific data on limits above which injury to use occurs. Pollutional substances will be maintained below maximum permissible concentrations for public water supplies, recreation requirements, agricultural needs and other beneficial uses.

SPECIAL STANDARDS

Return Flow Streams:

a. Dissolved Oxygen: The dissolved oxygen content of a return flow stream shall not be less than 2 mg/l. The dissolved oxygen concentration just above the point where the flow of the stream combines with the flow of a stream of higher designated use shall not be less than 3 mg/l.

b. Species Diversity Index: The species diversity index shall not apply to return flow streams.

Mixing Zones and Zones of Passage

a. Mixing Zones: Except as indicated below, mixing zones shall be no larger than one-fourth (1/4) the cross sectional area of the stream or no more than one-fourth (1/4) the volume of flow, whichever is most restrictive. The remaining portion of the stream's cross section or flow shall constitute a zone of passage for free swimming and drifting organisims. Where more than one effluent enters a stream and the mixing zones would overlap, the combined mixing zones shall not exceed the one-fourth (1/4) value described above. The mixing zone shall begin at the point of discharge and extend downstream to the point of complete mixing.

Special mixing zones shall be designated where return flows exceed one-fourth (1/4) of the combined stream and return flows.

Mixing zones in lakes shall be designated on a case by case basis.

b. Exceptions to beneficials uses: Mixing zones may be assigned all of the beneficial uses for which the natural waters of that stream would be satisfactory with the exception of the following:

(1) Public and private water supply, A
(2) Emergency public and private water supply, B
(3) Fish and wildlife propagation, C_1
(4) Recreation (primary and secondary body contact), G_1, G_2

c. Dissolved Oxygen: The dissolved oxygen shall not be less than 2 mg/l within the mixing zone.

TESTING PROCEDURES

All methods of sample collection, preservation, and analysis used in applying any of the rules and regulations in these standards shall be in accordance with those prescribed in Standard Methods for the Examination of Water and Wastewater, Thirteenth Edition, or any subsequent edition or other generally accepted procedures approved by the Oklahoma Water Resources Board.

TABLE A1

BENEFICIAL WATER USES

Segment 1-B

Stream	A	B	C_1	C_2	D	E	F_1	F_2	G_1	G_2	H	I	J	K	Special Designations
Lower Illinois River: headwaters Robt. S. Kerr res. to Tenkiller Dam	X		X		X				X	X		X	X	X	a
Uper Ilinois River: Tenkiller Dam to U.S. Highway 62 bridge	X		X		X	X	X	X	X	X		X	X		
Upper Illinois River: above U.S. Highway bridge	X		X		X				X	X		X	X		a
Flint Creek	x		x		x				x	x		x	x		a
Barren Creek	X		X		X		X	X	X	X		X	X		
Caney Creek	x		x		x		x	x	x	x		x	x		(smz)
(Shell Creek)															(smz)

TABLE A1

BENEFICIAL WATER USES

Segment 1-C

Stream	A	B	C_1	C_2	D	E	F_1	F_2	G_1	G_2	H	I	J	K	Special Designations
Grand-Neosho River: mouth to Kansas state line (incl. all lakes)	X		X		X	X	X	X	X	X		X			
Tar Creek				X	X		X	X		X		X			b
Hudson Creek	X		X				X	X	X	X		X			(b)
Spring River	X		X		X		X	X	X	X		X	X		
Cave Springs	X		X		X		X	X	X	X		X			
Honey Creek	X		X		X				X	X		X			a
Ogeechee Creek	X		X		X		X	X	X	X		X			(b)
Horse Creek	X		X		X		X	X	X	X		X			(smz)
Drowning Creek	X		X		X		X	X	X	X		X			
Lost Creek				X			X	X		X		X			b
Big Cabin Creek	X		X		X		X	X	X	X		X			(smz)
Rock Creek	X		X		X		X	X	X	X		X			

TABLE A1

BENEFICIAL WATER USES

Segment 1-C

Stream	A	B	C_1	C_2	D	E	F_1	F_2	G_1	G_2	H	I	J	K	Special Designations
Salina Creek	X		X		X		X	X	X			X			
Pryor Creek	X		X		X		X	X	X	X		X			(b)
Chouteau Creek	X		X		X		X	X	X	X		X			(b)
Spring Creek	X		X		X		X	X	X	X		X		X	
Clear Creek	X		X		X		X	X	X	X		X			
Fourteen Mile Creek	X		X		X				X	X		X		X	
Ranger Creek	X		X		X		X	X	X	X		X			
Ross Creek	X		X		X		X	X	X	X		X			
Spavinaw Creek including Spavinaw Lake and Eucha Lake	X		X		X				X	X		X	X		a

TABLE

BENEFICIAL WATER USES

Segment 1-C

Stream	A	B	C_1	C_2	D	E	F_1	F_2	G_1	G_2	H	I	J	K	Special Designations
(Bull Creek)															(b)
(Grand Creek)															(b)
(Little Creek - tributary of Tar Creek)															(smz)
(Sulfur Creek)															(b)
(Bitter Creek)															(b)
(Chelsea Creek)															(b)
(Tributary to Spavinaw Creek)															(b)
(Tributary to Fourteen Mile Creek)															(b)
(Muskrat Creek)															(smz)
(Little Cabin Creek)															(b)

TABLE A1

BENEFICIAL WATER USES

Segment 1-D

Stream	A	B	C_1	C_2	D	E	F_1	F_2	G_1	G_2	H	I	J	K	Special Designations
Verdigris River: mouth to Kansas SE line, including Oologah	X		X		X		X	X	X	X	X	X			
California Creek	X		X		X		X	X	X	X		X			
Snow Creek	X		X		X		X	X	X	X		X			
Big Creek	X		X		X		X	X	X	X		X			
Salt Creek	X		X		X		X	X	X	X		X			
Lightning Creek	X		X		X		X	X	X	X		X			(b)
Blue Creek	X		X		X		X	X	X	X		X			
Buck Creek	X		X		X		X	X	X	X		X			
Coon Creek	X		X		X		X	X	X	X		X			(b)
Little Caney River	X		X		X		X	X	X	X		X			(b)
Sand Creek	X		X		X		X	X	X	X		X			
Rabb Creek	X		X		X		X	X	X	X		X			
Caney River: mouth to Kansas state line	X		X		X		X	X	X	X		X			(smz)

TABLE A1

BENEFICIAL WATER USES

Segment 1-D

Stream	A	B	C_1	C_2	D	E	F_1	F_2	G_1	G_2	H	I	J	K	Special Designations
Birch Creek				X	X		X	X		X		X			a (b)
Candy Creek	X		X		X		X	X	X	X		X			
Hominy Creek	X		X		X		X	X	X	X		X			(smz)
Spunky Creek	X		X		X		X	X	X	X		X			(b)
Dog Creek	X		X		X		X	X	X	X		X			(smz)
Pea Creek	X		X		X		X	X	X	X		X			(b)
Delaware Creek	X		X		X		X	X	X	X		X			
Mingo Creek	X		X		X		X	X	X	X		X			(b)
Bird Creek	X		X		X		X	X	X	X		X			(smz)
Adams Creek	X		X		X		X	X	X	X		X			
Captain Creek	X		X		X		X	X	X	X		X			(b)
Western Branch Creek	X		X		X		X	X	X	X		X			(b)
Unnamed tributary: return flow - city of Delaware				X	X		X	X		X		X			b

TABLE

BENEFICIAL WATER USES

Segment 1-D

Stream	A	B	C_1	C_2	D	E	F_1	F_2	G_1	G_2	H	I	J	K	Special Designations
(Claremore Creek)															(b)
(Double Creek)															(b)
(Spencer Creek to Oologah Reservoir)															(b)
(Mingo Creek)															(b)
(Flat Rock Creek)															(b)
(No Name Creek to Bird Creek)															(b)
(Blackjack Creek)															(b)
(Horsepen Creek)															(b)
(Unnamed Tributary to Caney River (Ochelata))															(b)
(Coal Creek)															(b)
(Eliza Creek)															(smz)

TABLE A1

BENEFICIAL WATER USES

Segment I-A

Stream	A	B	C_1	C_2	D	E	F_1	F_2	G_1	G_2	H	I	J	K	Special Designations
Arkansas River: mouth of Canadian River to mouth of Verdigris		X	X		X	X	X	X	X	X	X	X			
Polecat Creek	X		X		X		X	X	X	X		X			(smz)
Snake Creek	x		X		X		X	X	X	X		X			(b)
Broken Arrow Creek	X		X		X		X	X	X	X		X			(b)
Cloud Creek	X		X		X		X	X	X	X		X			(b)
Coody Creek	X		X		X		X	X	X	X		X			
Sand Creek	X		X		X		X	X	X	X		X			(b)
Dirty Creek	X		X		X		X	X	X	X		X			(b)
Greenleaf Lake & Creek	X		X		X		X	X	X	X		X			
Bayou Manard Creek	X		X		X		X	X	X	X		X			
Pecan Creek	X		X		X		X	X	X	X		X			
Ash Creek	X		X		X		X	X	X	X		X			

TABLE

BENEFICIAL WATER USES

Segmant 1-A

Stream	A	B	C_1	C_2	D	E	F_1	F_2	G_1	G_2	H	I	J	K	Special Designations
(Rock Creek)															(smz)
(Elk Creek)															(b)
(Coweta Creek)															(b)
(Unnamed Tributary of Arkansas River one mile from confluence)															(b)
(Childers)															(b)
(Dirty Creek (south))															(b)
(No Name Creek to Polecat Creek (Sapulpa))															(b)
(No Name Creek to Arkansas River (Tulsa))															(b)
(Cherry Creek)															(b)
(No Name Creek to Arkansas River (Muskogee))															(b)
(Berryhill Creek to Arkansas River (Tulsa))															(b)

TABLE A2

WATER QUALITY CRITERIA

Stream	Minerals						Bacteria: not to exceed a monthly geometric mean of:		Turbidity Jackson Units:	Temp F^{o} not to exceed:	D.O. mg/l
	Chloride		Sulfate		T.D.S.						
	Sample	Yr.$\bar{X}$	Sample	Yr.$\bar{X}$	Sample	Yr.$\bar{X}$	200/100	1000/100			
Lower Illinois River (near Gore) 1-B	17.2	12.1	15.9	12.5	144	127	x		10	68^{0}	6
Upper Illinois River (Tenkiller dam to US bridge) 1-B							x		10	84	6
Upper Illinois River (above US hwy bridge) 1-B							x		10	84	6
Flint Creek 1-B							x		10	84	6
Barren Creek 1-B							x		10	84	6
Caney Creek 1-B							x		10	84	6

TABLE A 2

WATER QUALITY CRITERIA

Stream	Minerals: Chloride Sample	Chloride Yr.$\bar{X}$	Sulfate Sample	Sulfate Yr.$\bar{X}$	T.D.S. Sample	T.D.S. Yr.$\bar{X}$	Bacteria: not to exceed a monthly geometric mean of: 200/100	1000/100	Turbidity Jackson Units:	Temp F^{o} not to exceed:	D.O. mg/l
Grand Neosho River (near Commerce) 1-C	29	23	109	83	406	336	x		50	90^{o}	5
Grand Neosho River (below Ft. Gibson Lake) 1-C	139	120	47		221	195	x		50	90	5
Tar Creek 1-C								x	50	90	5
Hudson Creek 1-C							x		50	90	5
Spring River 1-C							x		10	84	6
Cave Springs Branch 1-C							x		50	90	5
Honey Creek 1-C							x		50	90	5
Ogeechee Creek 1-C							x		50	90	5
Horse Creek 1-C							x		50	90	5
Drowning Creek 1-C							x		50	90	5
Lost Creek 1-C								x	50	90	5

TABLE A 2

WATER QUALITY CRITERIA

Stream		Minerals						Bacteria: not to exceed a monthly geometric mean of:		Turbidity Jackson Units:	Temp F° not to exceed:	D.O. mg/l
		Chloride		Sulfate		T.D.S.						
		Sample	Yr.$\bar{X}$	Sample	Yr.$\bar{X}$	Sample	Yr.$\bar{X}$	200/100	1000/100			
Big Cabin Creek (near Big Cabin)	1-C	16	12	192	142	376	300	x		50	90°	5
Rock Creek	1-C							x		50	90	5
Salina Creek	1-C							x		50	90	5
Pryor Creek at Pryor	1-C	107	69	97	77	390	300	x		50	90	5
Pryor Creek (below Sulphur Creek near Pryor)	1-C	158	103	177	131	570	426	x		50	90	5
Chouteau Creek	1-C							x		50	90	5
Spring Creek	1-C							x		10	68	6
Clear Creek	1-C							x		50	90	5
Fourteen Mile Cr.	1-C							x		50	90	5
Ranger Creek	1-C							x		50	90	5
Ross Creek	1-C							x		50	90	5

TABLE A 2

WATER QUALITY CRITERIA

Stream	Minerals						Bacteria: not to exceed a monthly geometric mean of:		Turbidity Jackson Units:	Temp F° not to exceed:	D.O. mg/l
	Chloride		Sulfate		T.D.S.						
	Sample	Yr.$\bar{X}$	Sample	Yr.$\bar{X}$	Sample	Yr.$\bar{X}$	200/100	1000/100			
Spavinaw Creek (including Spavinaw Lake and Eucha) 1-C							x		10	84°	6

TABLE A2

WATER QUALITY CRITERIA

Stream		Minerals						Bacteria: not to exceed a monthly geometric mean of:		Turbidity Jackson Units:	Temp F° not to exceed:	D.O. mg/l
		Chloride		Sulfate		T.D.S.						
		Sample	Yr.$\overline{X}$	Sample	Yr.$\overline{X}$	Sample	Yr.$\overline{X}$	200/100	1000/100			
Verdigris River (near Oologah)	1-D	112	82	275	167	652	475	x		50	90°	5
Verdigris River (near Inola)	1-D	106	80	57	45	453	367	x		50	90	5
California Creek	1-D							x		50	90	5
Snow Creek	1-D							x		50	90	5
Big Creek	1-D							x		50	90	5
Salt Creek	1-D							x		50	90	5
Lightning Creek	1-D							x		50	90	5
Blue Creek	1-D							x		50	90	5
Buck Creek	1-D							x		50	90	5
Pond Reek	1-D							x		50	90	5
Unnamed tributary (return flow - Delaware)	1-D							x		50	90	5

TABLE A 2

WATER QUALITY CRITERIA

Stream		Minerals: Chloride Sample	Minerals: Chloride Yr.$\bar{X}$	Minerals: Sulfate Sample	Minerals: Sulfate Yr.$\bar{X}$	Minerals: T.D.S. Sample	Minerals: T.D.S. Yr.$\bar{X}$	Bacteria: not to exceed a monthly geometric mean of: 200/100	Bacteria: not to exceed a monthly geometric mean of: 1000/100	Turbidity Jackson Units:	Temp F° not to exceed:	D.O. mg/l
Coon Creek	1-D							x		50	90°	5
Little Caney River (near Copan)	1-D							x		10	84	6
Sand Creek	1-D							x		50	90	5
Rabb Creek	1-D							x		50	90	5
Caney River (near Ramona)	1-D							x		50	90	5
Birch Creek	1-D								x	50	90	5
Candy Creek	1-D							x		50	90	5
Hominy Creek	1-D							x		50	90	5
Spunky Creek	1-D							x		50	90	5
Dog Creek	1-D							x		50	90	5
Pea Creek	1-D							x		50	90	5
Delaware Creek	1-D							x		50	90	5

TABLE A2

WATER QUALITY CRITERIA

Stream		Minerals: Chloride Sample	Chloride Yr.$\bar{X}$	Sulfate Sample	Sulfate Yr.$\bar{X}$	T.D.S. Sample	T.D.S. Yr.$\bar{X}$	Bacteria: not to exceed a monthly geometric mean of: 200/100	1000/100	Turbidity Jackson Units:	Temp F$^{\circ}$ not to exceed:	D.O. mg/l
Mingo Creek	1-D							x		50	90°	5
Bird Creek (near Sperry)	1-D	204	152	66	54	640	519	x		50	90	5
Adams Creek	1-D							x		50	90	5
Captain Creek	1-D							x		50	90	5
Western Creek	1-D							x		50	90	5

TABLE A2

WATER QUALITY CRITERIA

Stream	Minerals: Chloride Sample	Chloride Yr.$\overline{X}$	Sulfate Sample	Sulfate Yr.$\overline{X}$	T.D.S. Sample	T.D.S. Yr.$\overline{X}$	Bacteria: not to exceed a monthly geometric mean of: 200/100	1000/100	Turbidity Jackson Units:	Temp F° not to exceed:	D.O. mg/l
Arkansas River (at Sand Springs) 1-A	860	665	172	139	1876	1487	x		50	93°	5
Polecat Creek 1-A							x		50	90	5
Snake Creek 1-A							x		50	90	5
Broken Arrow Cr 1-A							x		50	90	5
Cloudy Creek 1-A							x		50	90	5
Coody Creek 1-A							x		50	90	5
Sand Creek 1-A							x		50	90	5
Dirty Creek 1-A							x		50	90	5
Greenleaf Lake and Creek 1-A							x		50	90	5
Bayou Manard Cr 1-A							x		50	90	5
Pecan Creek 1-A							x		50	90	5
Ash Creek 1-A							x		50	90	5

APPENDIX B

WATER QUALITY DATA

TABLE B1

HISTORICAL IN-STREAM QUALITY

Water Quality Parameters \ Stream	Illinois River (near Gore) 1-B					
Temp (^oC)	11					
pH (Max/Min)	8.2/6.9					
Color (Units)						
Turbidity (JTU)						
BOD (mg/l)						
DO (mg/l)	11.2					
Hardness (mg/l)	82					
Alkalinity (mg/l)	74					
Chloride (mg/l)	7					
Sulfate (mg/l)	9					
Fluoride (mg/l)						
Nitrate (mg/l)	22					
Total Phosphate (mg/l)	0.05					
TDS (mg/l)	110					
TSS (mg/l)						
Cd (mg/l)						
Ca (mg/l)						
Cr (mg/l)						
Cu (mg/l)						
Fe (mg/l)						
Pb (mg/l)						
Mg (mg/l)						
Mn (mg/l)						
K (mg/l)	5					
Na (mg/l)	4					
Zn (mg/l)						

TABLE B1

HISTORICAL IN-STREAM QUALITY

Water Quality Parameters / Stream	Neosho River (near Commerce) 1-C	Big Cabin Creek (near Big Cabin) 1-C	Pryor Creek at Elliot Stream (near Pryor) 1-C	Pryor Creek below Sulphur Cr (near Pryor) 1-C	Grand Neosho R (below Ft. Gibson Lake) 1-C	
Temp (^{o}C)	15	17	14	17	17	
pH (Max/Min)	8.8/6.0	8.8/6.7	8.8/6.2	9.3/4.3	8.3/7.0	
Color (Units)	43					
Turbidity (JTU)	36					
BOD	3					
DO	9.7		0.0			
Hardness	203	141	88	126	125	
Alkalinity	156	86	72	47	92	
Chloride	16	8	31	47	10	
Sulfate	61	81	56.6	84	34	
Fluoride	0.24					
Nitrate		1	11.7	18	1	
Total Phosphate	0.11	0.12	2.27	0.34	0.06	
TDS		223	210	281	167	
TSS						
Cd	0.07					
Ca						
Cr	0.11					
Cu	0.13					
Fe	0.32					
Pb	0.14					
Mg						
Mn	0.47					
K						
Na	16	13	23	38	9	
Zn						

TABLE B1

HISTORICAL IN-STREAM QUALITY

Water Quality Parameters \ Stream	Bird Creek (near Catoosa) 1-D	Bird Creek (near Sperry) 1-D	Little Caney R. below Cotton Cr. (near Copan) 1-D	Caney River (near Ramona) 1-D	Verdigris River (near Inola) 1-D	Verdigris River (near Oologah) 1-D
Temp (^{o}C)	16			7	16	13
pH (Max/Min)	8.3/6.8	9.1/6.9	8.6/7.4	9.9/7.0	9.4/6.8	8.4/7.0
Color (Units)						
Turbidity (JTU)						
BOD					13	
DO						
Hardness	169	197	205	191	0.77	188
Alkalinity	102	121	116	121	110	122
Chloride	100	149	181	117	55	51
Sulfate	41	26	31	31	33	59
Fluoride						
Nitrate	14	1	1	2	3	1
Total Phosphate	7			0.45	0.77	0.15
TDS	397	448	530	408	280	297
TSS						
Cd						
Ca						
Cr						
Cu						
Fe						
Pb						
Mg						
Mn						
K						
Na	59	74	91	58	33	30
Zn						

TABLE B1

HISTORICAL IN-STREAM QUALITY

Water Quality Parameters \ Stream	Arkansas River (at Sand Springs bridge) 1-A					
Temp (^{o}C)	12					
pH (Max/Min)	9.4/7.4					
Color (Units)						
Turbidity (JTU)						
BOD	3					
DO						
Hardness	242					
Alkalinity	133					
Chloride	471					
Sulfate	105					
Fluoride	2					
Nitrate	2					
Total Phosphate	11					
TDS	1098					
TSS						
Cd						
Ca						
Cr						
Cu						
Fe						
Pb						
Mg						
Mn						
K						
Na	313					
Zn						

TABLE B2

IN-STREAM QUALITY

Main Streams

Water Quality Parameters \ Stream	Illinois River 1-B					
pH (Max/Min)	8.2/6.0					
Specific Conductance (Micromhos at 25°C)	160					
Color (Units)	11					
Turbidity (JTU)	6					
BOD	2					
COD	12					
Hardness	70					
Alkalinity	80					
Chloride	9					
Sulfate	16					
Fluoride	0.09					
Nitrate	0.43					
Ortho Phosphate	0.04					
TDS	89					
TSS	100					
Cd	< 0.08					
Ca	26					
Cr	< 0.1					
Cu	< 0.5					
Fe	0.35					
Pb	< 0.5					
Mg	2					
Mn	< 0.06					
K	1					
Na	5					
Zn	< 0.1					

TABLE B2
IN-STREAM QUALITY
Main Streams

Water Quality Parameters \ Stream	Spring River (near Quapaw) 1-C	Grand-Neosho R (near Commerce) 1-C	Elk River (near Tiff City, Mo.) 1-C	Grand-Neosho R (near Langley) 1-C	Grand-Neosho R (near Chouteau) 1-C	Grand-Neosho R (near Ft. Gibson) 1-C
pH (Max/Min)	7.4/6.5	7.5/6.0	7.9/6.5	7.7/6.0	7.7/6.0	7.6/6.5
Specific Conductance (micromhos at 25°C)	323	357	229	250	240	230
Color (Units)	9	39	8	20	19	27
Turbidity (JTU)	20	102	4	17	23	24
BOD	15	2	2	2	2	2
COD	13	28	27	9	10	10
Hardness	140	196	111	107	107	56
Alkalinity	104	89	118	97	97	90
Chloride	7	12	5	11	9	9
Sulfate	38	44	7	30	24	27
Fluoride	0.28	0.3	0.16	0.16	0.17	0.12
Nitrate	1	0.55	0.77	0.76	0.40	0.66
Ortho Phosphate	0.16	0.02	0.04	0.06	0.26	0.06
TDS	172	233	168	177	167	165
TSS	55	229	28	26	98	91
Cd	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ca	41	35	32	31	32	36
Cr	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cu	< 0.1	0.15	< 0.1	< 0.1	< 0.1	< 0.5
Fe	11.	6	0.35	1	1	1
Pb	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Mg	6	12	3	6	6	6
Mn	0.24	0.24	0.65	0.11	0.14	0.05
K	4	7	3	4	4	2
Na	8	16	6	8	8	6
Zn	0.43	< 0.1	< 0.1	0.1	< 0.1	< 0.1

TABLE B2

IN-STREAM QUALITY

Main Stream

Water Quality Parameters \ Stream	Verdigris River (below Inola) 1-D	Bird Creek (near Avant) 1-D	Caney River (near Ochelata) 1-D	Little Caney R (near Copan) 1-D	Verdigris River (near Elgin, Kan.) 1-D	Verdigris River (near Oologah) 1-D
pH (Max/Min)	7.3/6.3	8.1/6.0	8.1/6.4	8.1/6.0	8.1/6.5	7.8/6.0
Specific Conductance (Micromhos at 25^{o}C)	302	342	497	605	535	314
Color (Units)	162	47	26	44	20	23
Turbidity (JTU)	107	41	76	47	23	16
BOD	2	3	3	3	1	2
COD	23	30	28	26	11	14
Hardness	121	130	174	206	239	137
Alkalinity	106	125	146	157	166	131
Chloride	32	43	46	95	41	21
Sulfate	27	20	25	24	26	24
Fluoride	0.25	0.02	0.25	0.23	0.22	0.16
Nitrate	0.59	0.34	0.29	0.16	0.37	0.31
Ortho Phosphate	0.04	0.42	0.06	0.01	0.04	ND
TDS	186	207	309	346	334	213
TSS	205	38	184	122	59	37
Cd	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ca	28	27	30	45	59	34
Cr	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cu	< 0.1	< 0.5	< 0.5	< 0.1	< 0.1	< 0.1
Fe	5	2	45	4	31	1
Pb	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Mg	7	9	9	10	13	8
Mn	0.18	0.11	0.31	0.22	0.16	0.12
K	6	5	6	5	4	4
Na	12	21	21	34	16	17
Zn	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

TABLE B2
IN-STREAM QUALITY
Main Streams

Water Quality Parameters \ Stream	Verdigris River (near Lenapah) 1-D					
pH (Max/Min)	8.0/6.5					
Specific Conductance (Micromhos at 25°C)	403					
Color (Units)	74					
Turbidity (JTU)	73					
BOD	5					
COD	2					
Hardness	172					
Alkalinity	154					
Chloride	31					
Sulfate	27					
Flyoride	0.35					
Nitrate	0.46					
Ortho Phosphate	0.09					
TDS'	409					
TSS	168					
Cd	< 0.1					
Ca	38					
Cr'	< 0.1					
Cu	< 0.1					
Fe	5					
Pb	< 0.5					
Mg	10					
Mn	0.19					
K	6					
Na	18					
Zn	0.1					

TABLE B 2

IN-STREAM QUALITY

Main Streams

Water Quality Parameters \ Stream	Keystone Res. (near Sand Sp) 1-A	Arkansas River (near Jenks) 1-A	Arkansas River (near Muskogee) 1-A	Arkansas River (near Webbers Falls) 1-A		
pH (Max/Min)	7.6/6.0	7.5/6.5	7.9/6.5	77/6.0		
Specific Conductance (Micromhos at 25°C)	1362	1825	1206	621		
Color (Units)	3	66	24	23		
Turbidity (JTU)	19	182	71	75		
BOD	2	4	3	2		
COD	13	28	20	14		
Hardness	281	289	222	137		
Alkalinity	170	143	100	99		
Chloride	286	383	256	97		
Sulfate	118	113	92	51		
Fluoride	0.24	0.22	0.19	0.21		
Nitrate	0.42	0.3	6	0.46		
Ortho Phosphate	0.05	0.06	0.12	0.02		
TDS	828	713	723	369		
TSS	28	575	160	164		
Cd	< 0.1	< 0.1	< 0.1	< 0.1		
Ca	36	44	37	51		
Cr	< 0.1	< 0.1	< 0.1	0.15		
Cu	< 0.5	< 0.5	< 0.5	< 0.5		
Fe	1	2	5	7		
Pb	< 0.5	< 0.5	< 0.5	< 0.5		
Mg	18	18	17	11		
Mn	< 0.1	0.1	0.18	0.18		
K	7	8	7	6		
Na	183	231	236	6		
Zn	< 0.1	< 0.1	< 0.1	< 0.1		

TABLE B3

INSTREAM QUALITY

Tributaries

Water Quality Parameters \ Stream	Flint Creek 1-B	Barren Creek 1-B	Caney Creek 1-B			
pH	7.1	7.2	7.0			
Temp (^{o}C)	17.0	12.0	15.0			
DO	12.0	8.0	10.0			
BOD	$<$ 4.0	$<$ 4.0	$<$ 4.0			
COD	0.4	$<$ 1.0	$<$ 1.0			
TDS	120.0	155.0	170.0			
Turbidity (JTU)	17.0	30.0	30.0			
Cl^-	8.0	8.0	8.0			
SO_4	32.0	56.0	56.0			
NO_3	1.0	1.2	1.0			
Total N	3.0	-	-			
PO_4	0.09	0.08	0.05			

TABLE B3

INSTREAM QUALITY

Tributaries

Water Quality Parameters \ Stream	Tar Creek 1-C	Hudson Creek 1-C	Spring River 1-C	Cave Springs Br. 1-C	Ogeechee Creek 1-C	Honey Creek 1-C
pH	6.8	6.6	6.2	6.9	7.4	7.2
Temp(^oC)	16.0	16.0	16.0	18.0	15.0	17.0
DO	8.0	5.0	4.0	12.0	11.0	12.0
BOD	5.0	7.0	8.0	5.0	4.0	< 4.0
COD	12.0	25.0	30.0	7.0	5.0	0.4
TDS	210.0	140.0	130.0	155.0	250.0	145.0
Turbidity (JTU)	50.0	50.0	125.0	10.0	15.0	25.0
Cl^-	5.0	10.0	10.0	26.0	10.0	13.0
SO_4	107.0	36.0	52.0	35.0	36.0	36.0
NO_3	1.5	0.7	0.7	1.1	0.3	0.2
Total N	3.7	3.4	3.1	3.6	0.3	1.7
PO_4	0.12	0.09	0.12	0.11	0.11	0.07
Ag	< 0.001		< 0.001			
Cd	0.009		0.002			
Cr	0.005		0.011			
Cu	0.008		0.007			
Fe	2.70		8.00			
Mn	0.120		0.31			
Pb	0.066		0.025			
Zn	2.150		0.365			

TABLE B3

INSTREAM QUALITY
Tributaries

Water Quality Parameters / Stream	Horse Creek 1-C	Drowning Creek 1-C	Lost Creek 1-C	Big Cabin Creek 1-C	Pryor Creek 1-C	Chouteau Creek 1-C
pH	6.4	6.7	6.8	5.9	6.2	6.5
Temp(^{o}C)	16.0	17.0	14.0	17.0	18.0	27.0
DO	8.0	12.0	4.0	10.0	8.0	5.0
BOD	5.0	< 4.0	< 4.0	5.0	5.0	8.0
COD	27.0	0.4	2.0	36.0	19.0	23.0
TDS	115.0	115.0	140.0	150.0	115.0	115.0
Turbidity (JTU)	50.0	10.0	20.0	160.0	60.0	60.0
Cl^-	10.0	8.0	5.0	8.0	10.0	8.0
SO_4	38.0	30.0	40.0	78.0	45.0	47.0
NO_3	0.9	0.5	1.0	0.6	0.6	0.9
Total N	3.8	2.5	2.0	3.9	2.5	3.9
PO_4	0.07	0.02	0.04	0.07	0.16	0.07
Ag					< 0.001	
Cd					< 0.001	
Cr					0.007	
Cu					0.004	
Fe					4.90	
Mn					0.120	
Pb					0.003	
Zn					0.018	

TABLE B3

INSTREAM QUALITY

Tributaries

Water Quality Parameters \ Stream	Fourteen Mile Cr 1-C	Ross Branch 1-C				
pH	7.0	7.3				
Temp(^{o}C)	12.0	14.0				
DO	10.0	10.0				
BOD	$<$ 4.0	$<$ 4.0				
COD	$<$ 1.0	$<$ 1.0				
TDS	115.0	130.0				
Turbidity (JTU)	20.0	8.0				
Cl^-	8.0	8.0				
SO_4	45.0	47.0				
NO_3	0.9	1.6				
Total N	-	-				
PO_4	0.01	0.10				

TABLE B3

INSTREAM QUALITY

Tributaries

Water Quality Parameters \ Stream	California Creek 1-D	Coon Creek 1-D	Little Caney R 1-D	Sand Creek 1-D	Birch Creek 1-D	Hominy Creek 1-D
pH	6.8	7.0	6.8	6.3	6.9	6.6
Temp (^{o}C)	17.0	13.0	13.0	14.0	15.0	14.0
DO	10.0	11.0	10.0	10.0	10.0	13.0
BOD	5.0	4.0	5.0	5.0	4.0	5.0
COD	22.0	13.0	27.0	30.0	26.0	49.0
TDS	220.0	235.0	210.0	175.0	175.0	250.0
Turbidity (JTU)	120.0	70.0	150.0	150.0	110.0	240.0
Cl^-	26.0	49.0	20.0	13.0	13.0	26.0
SO_4	72.0	40.0	67.0	50.0	78.0	110.0
NO_3	0.6	1.1	1.9	1.4	0.9	0.6
Total N	2.6	3.2	2.6	4.9	2.9	4.0
PO_4	0.05	0.08	0.07	0.07	0.03	0.02
Ag						
Cd						
Cr						
Cu						
Fe						
Mn						
Pb						
Zn						

TABLE B3

INSTREAM QUALITY

Tributaries

Water Quality Parameters \ Stream	Spunky Creek 1-D	Dog Creek 1-D	Pea Creek 1-D	Coal Creek 1-D	Captain Creek 1-D	Western Creek 1-D
pH	7.3	7.4	6.8	6.9	7.3	7.4
Temp(^{o}C)	14.0	16.0	14.0	13.0	18.0	17.0
DO	10.0	12.0	9.0	10.0	8.0	8.0
BOD	< 4.0	< 4.0	5.0	6.0	5.0	7.0
COD	4.0	8.0	17.0	15.0	37.0	35.0
TDS	230.0	140.0	120.0	180.0	380.0	275.0
Turbidity (JTU)	40.0	25.0	60.0	75.0	40.0	70.0
Cl^-	13.0	13.0	10.0	20.0	110.0	13.0
SO_4	52.0	48.0	45.0	58.0	47.0	56.0
NO_3	1.5	1.1	1.3	1.3	1.2	0.6
Total N	3.0	3.3	4.0	5.1	3.2	2.6
PO_4	0.04	0.07	0.06	0.07	0.07	0.14

TABLE B3

INSTREAM QUALITY

Tributaries

Water Quality Parameters \ Stream	Polecat Creek 1-A	Snake Creek 1-A	Broken Arrow Cr. 1-A	Cloud Creek 1-A	Coody Creek 1-A	Dirty Creek 1-A
pH	6.9	6.6	7.3	6.6	6.9	6.5
Temp(^{o}C)	16.0	16.0	17.0	14.0	15.0	15.0
DO	7.0	12.0	12.0	8.0	10.0	9.0
BOD	7.0	4.0	$<$ 4.0	4.0	$<$ 4.0	5.0
COD	21.0	10.0	6.0	22.0	5.0	11.0
TDS	285.0	190.0	635.0	407.0	175.0	150.0
Turbidity (JTU)	130.0	100.0	30.0	160.0	50.0	100.0
Cl^-	36.0	33.0	38.0	31.0	20.0	8.0
SO_4	110.0	56.0	290.0	199.0	54.0	74.0
NO_3	0.9	0.7	0.9	1.0	0.7	0.6
Total N	3.2	0.8	2.7	3.5	0.8	3.1
PO_4	0.01	0.03	0.1	0.07	0.09	0.01
Ag					$<$ 0.001	$<$ 0.001
Cd					$<$ 0.001	$<$ 0.001
Cr					0.012	0.011
Cu					0.008	0.005
Fe					3.60	8.75
Mn					0.190	0.170
Pb					0.013	0.004
Zn					0.029	0.023

TABLE B3

INSTREAM QUALITY

Tributaries

Water Quality Parameters \ Stream	Sand Creek 1-A					
pH	6.7					
Temp(^{o}C)	16.0					
DO	10.0					
BOD	< 4.0					
COD	2.0					
TDS	145.0					
Turbidity (JTU)	25.0					
Cl^-	8.0					
SO_4	52.0					
NO_3	0.6					
Total N	2.3					
PO_4	0.09					

APPENDIX C

MUNICIPAL DISCHARGE INVENTORY

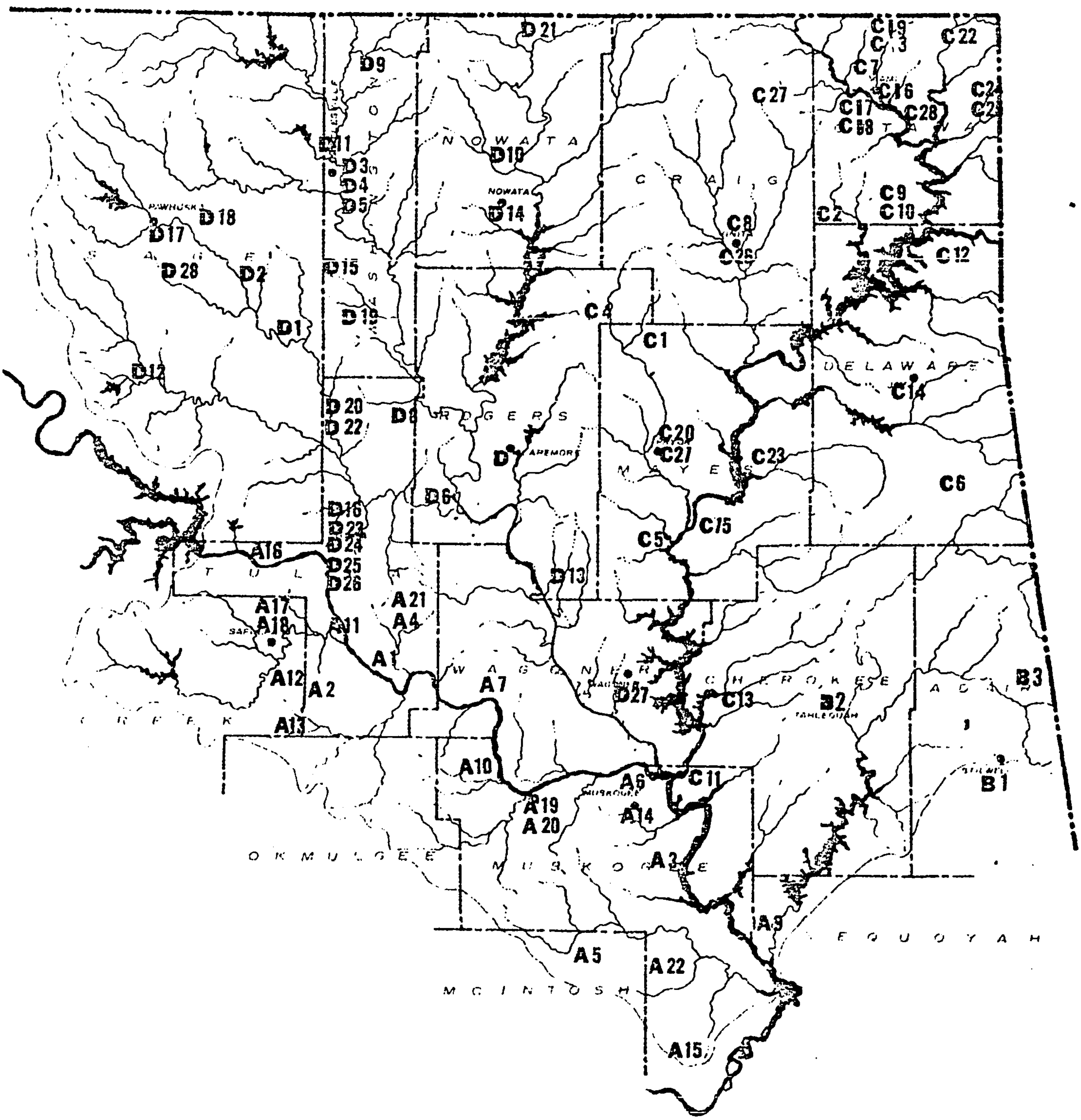

FIGURE C1

Location of Municipal Discharges

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Type of Treatment: Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-A	1	BIXBY (Tulsa)			BOD			430								x			
		Arkansas River			TSS			430											
	2	BOYNTON (Muskogee)	.045	.041	BOD		75		26		7.5							x	
		Cloud Creek			TSS		1008		344										
	3	BRAGGS (Muskogee)	.06	.026	BOD	440	40	95	9	91	7.4			x			x		
		Sand Creek			TSS	216	21	47	4.6										
	4	BROKEN ARROW (Tulsa)	1.0	.715	BOD	233	42	1390	250	82	8.0					x			
		Broken Arrow Creek			TSS	160	9	950	54										
	5	CHECOTAH (McIntosh)	.4	.307	BOD	181	65	463	166.4	64	7.6								
		Elk Creek			TSS	103	47	264	120.32										
	6	CONNER STATE COLLEGE	.08	.06	BOD		28		14		7.6							x	
		(Muskogee)			TSS		94		47										
		Dirty Creek																	
	7	COWETA (Wagoner)	.5	.196	BOD	578	18	944	29.4	97	9.7		x			x			
		Coweta Creek			TSS	388	10	634	16.3										

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER / Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-A	8.5	GLENPOOL (Tulsa)																	
		Total Retention																	
	9	GORE (Sequoyah)	.04	.038	BOD	99	31	32	10	68	8.9							x	
		Arkansas River			TSS	96	109	30.3	34.4										
	10	HASKELL (Muskogee)	.69	.165	BOD	240	25	330	34	90	9.9					x			
		Arkansas River			TSS	312	188	429	259										
	11	JENKS (Tulsa)	.22	.159	BOD	330	53	438	70	84	10.2							x	
		Arkansas River			TSS	108	104	143	138										
	12	KIEFER (Creek)	.04	.064	BOD		77		41		9.4							x	
		Childers Creek			TSS		84		45										
	13	MOUNDS (Creek)	.38	.061	BOD		140		71		7.2						x		
		Snake Creek			TSS		150		76										
	14	MUSKOGEE (Muskogee)	4.4	5.5	BOD	370	2012	16972	9220	46	7.1		x						
		Arkansas River			TSS	300	35	13761	1605										

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Type of Treatment: Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-A	15	PORUM (Muskogee) Dirty Creek	.072	.052	BOD TSS	31	 84	13.4	 36.4		9.3							x	
	16	SAND SPRINGS (Tulsa) Arkansas River	.2	.29	BOD TSS	182 127	76 111	440 307	184 268	58	7.7		x						
	17	SAPULPA (Creek) Rock Creek)	1.	.5	BOD TSS	353 240	39 34	1472 1002	168 147	89	7.2		x						
	18	SAPULPA (Creek) Polecat Creek	1.5	1.0	BOD TSS	251 180	15 60	2093 1501	125 500	94	7.8		x			x			
	19	TAFT (Muskogee) Arkansas River	.055	.042	BOD TSS	170 95	6 45	60 33.3	2.1 15.8	96	7.6						x	x	
	20	TAFT STATE SCHOOL (Muskogee) Arkansas River	.2	.08	BOD TSS	130 84	87 83		58 55	33	7.0	x	x	x					

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Type of Treatment: Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-A	21	TULSA (Tulsa)	25	15	BOD	240	140	30000	17505		6.9		x		x				
		Arkansas River			TDS	121	54												
		WAGONER (Wagoner)	.4	.75	BOD	205	51	1711	94		6.9							x	
		Coal Creek			TSS	182	85	1138	532										
	22	WARNER (Muskogee)	.2	.08														x	
		Dirty Creek																	
		WYNONA (Osage)	.048	.034	BOD		40		11.3		8.2		x					x	
		Tributary to Birch Creek			TSS		130		36.9										

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD)		Parameter	Quantity of Discharge				BOD Removal Efficiency (%)	pH	Type of Treatment							
						mg/l		lbs/day											
			Design	Operating		Influent	Effluent	Influent	Effluent			Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-B	1	STILWELL (Adair)	.4	.17	BOD	245	24	347	34	90	7.1		x						
		Caney Creek			TSS	88	10	125	11.5										
	2	TAHLEQUAH (Cherokee)	1.	1.5	BOD	168	120	2101	1500	29	6.7		x	x					
		Illinois River			TSS	34	30	425	375										
	3	WESTVILLE (Adair)	.206	.075	BOD	-	-	-	-	-	-			x					
		Shell Creek																	
	4	WESTVILLE (Adair)	.2	.059	BOD	693	90	341	44	87	8.6							x	
		Shell Creek			TSS	308	36	152	17.7										

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER / Receiving Stream	Flow(MGD)		Parameter	Quantity of Discharge				BOD Removal Efficiency (%)	pH	Type of Treatment							
			Design	Operating		mg/l Influent	mg/l Effluent	lbs/day Influent	lbs/day Effluent			Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-C	1	ADAIR (Mayes)	.04	.02	BOD		18		3										
		Bitter Creek			TSS		28		4.6	--	9.3							x	
	2	AFTON (Ottawa)	.196	.06	BOD	113	77	56	38	32	6.9			x					
		Tar Creek			TSS		54		27										
	3	CARDIN (Ottawa)	.015	.005	BOD	153		6.4		--	7.5	x						x	
		Tar Creek			TSS	52	7		.3										
	5	CHOUTEAU (Mayes)	.24	.084	BOD	135	20	94	14	85	10.6			x					
		Chouteau Creek			TSS	148	50	104	45										
	6	COLCORD (Delaware)	.029																
		Total Retention																	
	7	COMMERCE (Ottawa)	.24	.152	BOD	235	55	298	69	77	7.4			x					
		Tar Creek			TSS	124	61	157	77.3										
	8	EASTERN STATE HOSPITAL (Craig)	.48	.161	BOD	252	22	338	30	91	6.9			x					
		Bull Creek			TSS	148	29	199	38.9										

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER / Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	mg/l Effluent	lbs/day Influent	lbs/day Effluent	BOD Removal Efficiency (%)	pH	Type of Treatment: Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-C	9	FAIRLAND (Ottawa)	.075	.04	BOD	192	18	64	6	91	8.2							x	
		Horse Creek			TSS	180	35	60	11.7										
	10	FAIRLAND (Ottawa)	.12	.01	BOD	383	41	32	3.4	89	7.2			x					
		Ogeechee Creek			TSS	90	48	7.5	4										
	10.5	FT. GIBSON (Muskogee)	.12	.113														x	
		Grand River																	
	12	GROVE (Delaware)	.196	.113	BOD	186	61	174	58	6.7	7.4							x	
		Grove Springs			TSS	172	50	162	47.1										
	13	HULBERT (Cherokee)	.08																
		Total Retention																	
	14	JAY (Delaware)	.246	.394	BOD	300	30	986	98	90	9.7							x	
		Muskrat Creek																	
	14.5	KANSAS (Delaware)																	
		Total Retention																	

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Type of Treatment: Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-C		KETCHUM (Mayes)																	
	15	LOCUST GROVE (Mayes) Grand Creek	.24	.055	BOD TSS	65 34	6 18	30 15.6	2.8 8.26	90	9.5			x				x	
	18	MIAMI 1 (Ottawa) Tar Creek	.55	.35	BOD TSS	223 108	7 27	651 315	21 78.8	97	7.2				x				
	17	MIAMI 2 (Ottawa) Neosho River	1.096	.175	BOD TSS	130 124	2 23	190 188	2.9 33.6	98	6.5			x			x		
	16	MIAMI 3 (Ottawa) Total Retention	.24																
	19	PICHER (Ottawa) Lytle Creek	.104	.187	BOD													x	
	20	PRYOR TF (Mayes) Pryor Creek	.7	.5	BOD TSS	137 150	54 20	17 626	6.8 83.4	60	7.2			x					

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER / Receiving Stream	Flow(MGD)		Parameter	Quantity of Discharge				BOD Removal (%) Efficiency	pH	Type of Treatment							
			Design	Operating		mg/l Influent	mg/l Effluent	lbs/day Influent	lbs/day Effluent			Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-C	21	PRYOR (Mayes) Pryor Creek	.7	.5	BOD	260	55	1084	229	79								x	
	22	QUAPAW (Ottawa) Spring River	.12	.045	BOD TSS	217 324	62 38	81.4 122	23.3 14.3	71	7.5			x			x		
	23	SALINA (Mayes) Total Retention	.072																
	24	SENECA, MO. Lost Creek	.179	.015	BOD TSS	137 134	54 116	17 16.8	6.8 14.5	60	10.1							x	
	25	SENECA SCHOOL (Ottawa) Lost River	.035	.012	BOD TSS	150 82	21 22	15 8.2	2.1 2.2	86	9.7							x	
	26	VINITA (Craig) Big Cabin Creek	.936	.93	BOD TSS	231 178	24 40	1792 1381	186 310	90	7.2			x					
	27	WELCH (Craig) Little Cabin Creek	.045	.057	BOD TSS	240 124	39 318	114 60	18.5 151	84	8.6							x	

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Type of Treatment: Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-C	28	WESTERN HILLS LODGE (Cherokee) Neosho River		.3	BOD TSS	74 26	8 58	185 65	20 145	89	7.2						x	x	
	29	WEST SILOAM SPRINGS (Delaware) Total Retention																	
	30	WYANDOTTE (Ottawa) Lost Creek arm of Grand Lake Total Retention																	

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Type of Treatment: Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-D	1	AVANT (Osage) Bird Creek		.006	BOD	679	578	34	28.9	15			x						
	2	BARNSDALL (Osage) Bird Creek	.12	.107	BOD TSS		7 78		6.2 69.6		6.8							x	
	3	BARTLESVILLE-HILLCREST (Washington) Caney River	.072	.051	BOD TSS	103 148	16 8	43.8 63	6.8 3.4	84	7.8					x			
	4	BARTLESVILLE-1 (Washington) Caney River	2.18	2.7	BOD TSS	173 162	19 31	3896 3648	428 698	89	7.8				x	x			
	5	BARTLESVILLE-2 (Washington) Caney River	.57	.24	BOD TSS	142 204	14 30	284 408	28 60	90	7.3					x			
	6	CATOOSA (Rogers) Spunky Creek	.155	.056	BOD TSS	232 18	18 47	108 8.4	8.4 22	92	8.4							x	

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-D	4_D	CHELSEA (Rogers) Total Retention	.17	.13															
	7	CLAREMORE (Rogers) Dog Creek	2.11	1.28	BOD TSS	275 224	95 128	2936 2391	1014 1366	65	7.5			x					
	8	COLLINSVILLE (Tulsa) Total Retention	.55	.3															
	9	COPAN (Washington) Little Caney River	.067	.041	BOD TSS		49 22		16.8 7.5		8.7							x	
	10	DELAWARE (Nowata) Total Retention	.165	.035															
	11	DEWEY (Washington) Four Mile Creek	.75	.388	BOD TSS	199 156	27 47	644 505	87.4 152	86	7.5					x			
	12	HOMINY (Osage) Penn Creek	.305	.18	BOD TSS	209	50 252	314	75 278	76	6.7		x	x					

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-D	13	INOLA (Rogers)	.057	.069	BOD	358	50	206	29	86	9.5							x	
		Pea Creek			TSS	444	388	256	223										
	14	NOWATA (Nowata)	.319	.296	BOD	256	19	632	47	92	9.2		x	x					
		Western Br. Creek			TSS	222	10	548	24.7										
	15	OCHELATA (Washington)	.109	.04															
		Total Retention																	
	16	OWASSO (Tulsa)	.7	.33															
		Total Retention																	
	17	PAWHUSKA (Osage)	1.039	.308	BOD	121	24	311	61.6	80	8.5					x			
		Bird Creek			TSS	120	76	308	195										
	19	RAMONA (Washington)	.049	.042															
		Total Retention																	
	18	ROLLING HILLS (Wagoner)	.353		BOD	233	20			91	6.7				x				
		Spunky Creek			TSS	88	28												

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD) Design	Flow(MGD) Operating	Parameter	Quantity of Discharge mg/l Influent	Quantity of Discharge mg/l Effluent	Quantity of Discharge lbs/day Influent	Quantity of Discharge lbs/day Effluent	BOD Removal Efficiency (%)	pH	Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-D	20	SKIATOOK (Tulsa) Total Retention	.52	.232															
	21	SOUTH COFFEYVILLE (Nowata) Verdigris River	.14	.044	BOD TSS		20 100		7.3 36.7		9.2							x	
	22	SPERRY (Tulsa) Hominy Creek	.146	.112	BOD TSS		48 36		44.8 33.6		7.4		x	x			x		
	24	TULSA (Tulsa) N.S. Bird Creek	11.	10.	BOD TSS	127 55	22 15	10592 4587	1835 1251	83	7.2		x						
	23	TULSA FLAT ROCK (Tulsa) Bird Creek	4.	5.1	BOD TSS	134 76	38 69	5700 3233	1617 2934	72	7.4				x	x			
	26	TULSA COAL (Tulsa) Bird Creek	4.	3.5	BOD TSS	243 230	15 38	7093 6813	438 1109	94	7.4		x	x					
	25	TULSA ROSE DEW (Tulsa) Spunky Creek	.02	.016	BOD TSS		81 108		11 14.1		7.8							x	

TABLE C

MUNICIPAL DISCHARGE INVENTORY

Segment Number	Map Identification Number	DISCHARGER Receiving Stream	Flow(MGD)		Parameter	Quantity of Discharge				BOD Removal Efficiency (%)	pH	Type of Treatment							
						mg/l		lbs/day											
			Design	Operating		Influent	Effluent	Influent	Effluent			Screeing	Primary Clar.	Trickling Filter	Activated Sludge	Aerated Lagoon	Imhoff Tank	Lagoon	Other
1-D	27	WAGONER (Wagoner) Coal Creek	.4	.75	BOD TSS	205 182	15 85	1711 1138	94 532	93	6.9							x	
	28	WYNONA (Osage) Tributary to Birch Creek	.048	.034	BOD TSS		40 130		11.3 36.9		8.2		x					x	

APPENDIX D

INDUSTRIAL DISCHARGE INVENTORY

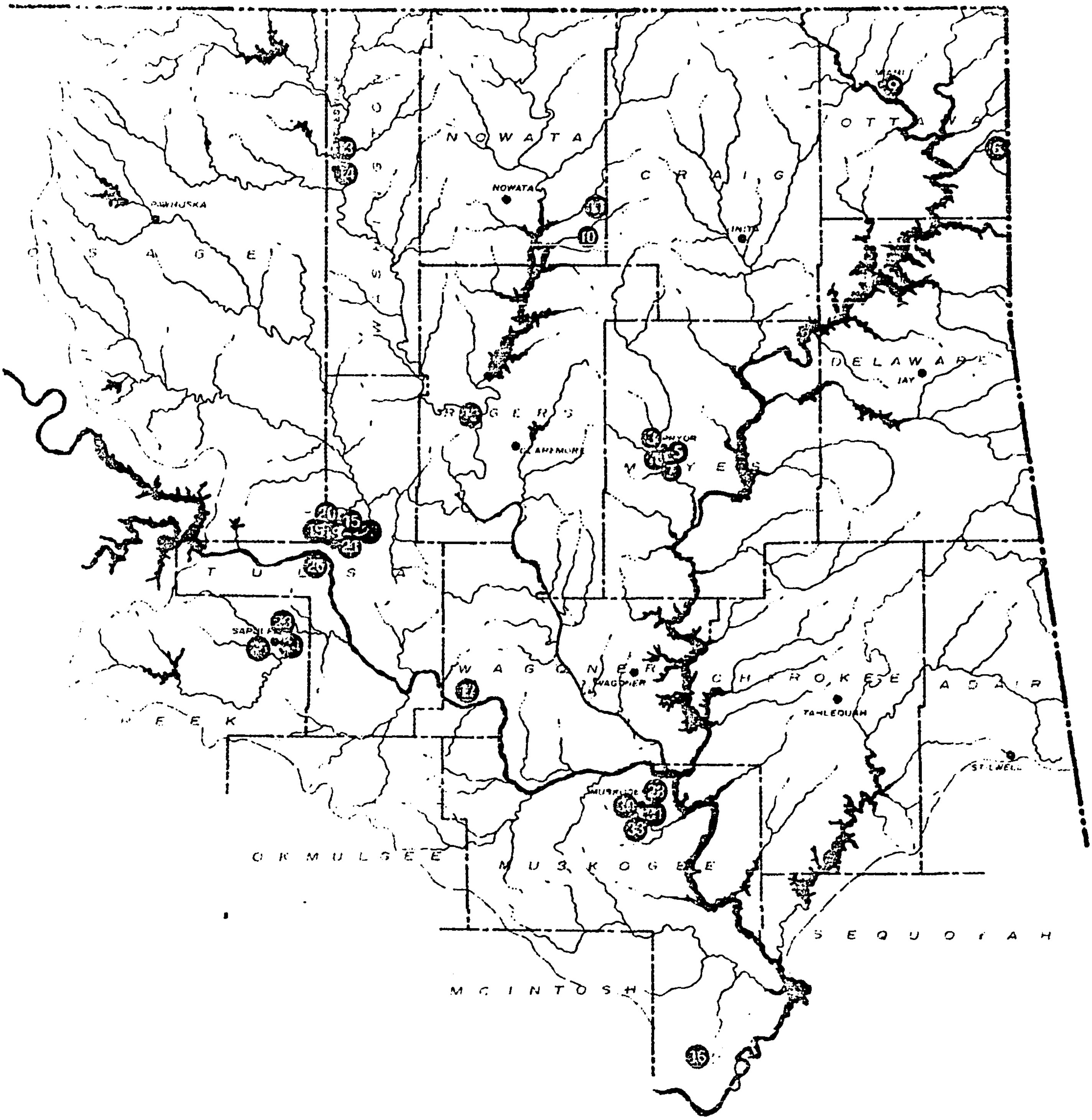

FIGURE D1

Location of Industrial Discharges

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED Mg/l	Lbs/day	Kg/day	REMARKS
1-B	1	Kerr-McGee Corp. Sequoyah Facility, OKC	Drainage Ditch Illinois R			1.64	COD	8.0	109		Three large stabilization ponds, raffinate pond, fluoride clarifying pond. They are installing submersion heaters in the two total retention ponds to speed up evaporation
							F	0.41	5.61		
							NH_3-N	0.1			
							NO_3-N	2.9			

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-C	2	Grand River Dam Authority Vinita	Pryor Creek Grand River			1.165	pH	1.5	1.5		No treatment. Discharge is highly acidic and carries excessive sulfate concentrations, an ineffective holding pond is unlined and shows evidence of leeching into soil.
							SO_4	5850	56839		
	3	ESCOA Corp Pryor	Pryor Creek Grand River			.0058	COD	4.4	.212		Small settling basin plus waste stabilization pond with gravel bottom. Capacity of stabilization pond is 0.5 mg.
							Cr	.21	0.01		
							NO_3	3.6	.174		
	4	Oklahoma Cement Co. Pryor	Sulphur Cr Grand River Pryor Creek				*				*Discharge data for Okla. Cement Co. is withheld pending settlement of complaint against the company's discharge.

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-C	5	Midwest Carbide Corp Pryor	Sulphur Cr Grand River Pryor Creek			.0173	$CaCO_3$	1540	222		Three settling basins and a waste stabilization pond
							NO_3	2.7	.39		
							pH	11.	11.		
	6	Milnot Co. Seneca, Mo.	Lost Creek Grand River			.108	BOD	21	18.9		Treatment handled by 44,000 equalization tank and 55'X6' deep trickling filter. 0.108 MGD run through treatment and 0.073 MGD bypassed receiving no treatment. Data shown is on effluent from treatment process.
							COD	95	85.6		
	7	Pryor Ind. Conservation Comm. Pryor	Grand River Arkansas R			2.2	BOD	578	10605		The PICC lagoons are the final treatment facilities for the various industries in the Pryor industrial complex. Total lagoon area is 224 acres.
							COD	233	4275		
							Oil & Grease	3	55		
							Total Solids	664	12183		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-C	8	B.F. Goodrich Tire Co. Miami	Grand River			0.8	BOD	4	26.7		Treatment consists of grease skimmer and settling pond. Pond capacity is 11.2 mg/
							Oil & Grease	2	13.3		
							Total Solids	338	2255		
	9	Eagle Picher, Inc Commerce	Tar Creek Grand River			0.0432	BOD	15	5.4		Treatment handled in 3 settling ponds with a total capacity of 8.35 M cu. feet.
							Zn	1.2	.0432		
	10	Peabody Coal Co St. Louis, Mo.	Lightning Cr Verdigris R			0.05	COD	24	10		No Treatment.
							Oil & Grease	10	4.17		
							Total Solids	4428	1846		

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SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED Mg/l	Lbs/day	Kg/day	REMARKS
1-D	11	Peabody Coal Co St. Louis, Mo.	Spencer Cr Oologah Res			0.05	COD	44	18.4		Treatment consists of settling basins. Discharge made up of coal mining and crushed wastes plus storm run-off. There is evidence of seepage from basins
							Oil & Grease	3.0	1.25		
							SO_4	485	202		
							Total Solids	1644	686		
	12	Tulsa Rendering Co. Collinsville	Black Jack C Penn Creek Caney River			0.05	BOD	40	16.7		Treatment consists of skimming and settling, 2 anaerobic lagoons. Effluent from final aerobic lagoon used for irrigation
							NH_3	3.2	1.33		
	13	Phillips Petroleum Research Bartlesville	Eliza Creek Sand Creek Caney River			0.06	BOD	1	.05		
							COD	20	.10		
							P	.16	.08		
							Total Solids	236	118		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-D	14	National Zinc Co Bartlesville	Eliza Creek Caney River			0.5	Cd	.26	1.08		Treatment handled by settling and oxidation lagoon, settling and neutralization lagoon, and final settling lagoon/
							Cr	.4	1.67		
							Pb	1.0	4.17		
							Total Solids	3850	16054		
							Zn	3.4	14.18		
	15₁	Public Service Co.-NE Station Tulsa	Verdigris R			1.21	NH_3	.6	6.05		There are four 0.016 mg capacity holding tanks and one 0.04 mg capacity neutralization basins. Treatment is primarily for 1.2 MGD cooling water.
							Total P	1.6	16.2		
							TDS	5660	57117		
	15_2	Chandler Materials Co. Tulsa	Bird Creek			0.0002	NH_4-N	2.8	0.047		Surface drainage autoclave blowdown
							Oil & Grease	3.6	0.06		
							Phenols	27	.045		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED Mg/l	Lbs/day	Kg/day	REMARKS
1-D	15_3	Kaiser Aluminum & Chemical Corp Tulsa	No Name Creek Mingo Creek Bird Creek			0.01	Oil & Grease	8	.67		Using stabilization ponds. (Lagoons)
							Ba^{++}	14	1.17		
	15_4	Byron Jackson, Div or Borg-Warner Corp Tulsa	Mingo Creek Bird Creek Verdigris R			0.00124	BOD	6	0.06		Boiler blowdown cooling water & storm water. No treatment.
							COD	19	0.196		
	15_5	Black, Sivalls, & Bryson Tulsa	Mingo Creek Bird Creek Verdigris R			0.018	BOD	1.4	0.21		Two discharge points. Spent acid is treated by limestone filtration & pH neutralization. No treatment for cooling water.
							COD	6	0.9		
							NH_3	1.96	.29		
							Oil & Grease	50	.75		
							P	4.6	.69		
	15_6	Leland Equipment Co. Tulsa	Mingo Creek Bird Creek Verdigris R			0.00024	BOD	4	.008		Treatment consists of grease trap, where sludge is hauled to Spartan dump.
							Oil & Grease	6.2	.012		

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SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-D	15_7	Hathaway Ind. Tulsa	Mingo Creek Bird Creek Verdigris R			.003	CN	180	4.5		Treatment consists of chlorine, $NaCO_3$, septic tank & sand filter
							Pb	2.72	.068		
							NH_4-N	166	4.15		
							pH	2.0	2.0		
	15_8	American Airlines, Inc. Tulsa	Mingo Creek Bird Creek Verdigris R			0.05	Total P	14.7	6.13		Two discharge points: #1 Mingo Creek #2 Bird Creek No treatment Injection well?
							Oil & Grease	11	4.59		
	15_9	Fram Corp Tulsa	No Name Creek Bird Creek Verdigris R			0.0394	BOD	74	24.3		Uses a filter process to remove solids and oil
							COD	203	66.7		
							Oil & Grease	8.4	2.76		
							Cr	.15	.05		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED Mg/l	Lbs/day	Kg/day	REMARKS
1-D	15_{10}	Lake Country Beverage, Inc Tulsa	Mingo Creek Bird Creek Verdigris R			0.0008	BOD	355	2.37		Discharges are entirely cooling & floor wash water. No treatment.
							COD	3668	24.47		
							Oil & Grease	37.5	.25		
							pH	7.8	7.8		
	15_{11}	North American Rickwell Corp Tulsa	Mingo Creek Bird Creek Verdigris R			0.05	Oil & Grease	572	238		No treatment for surface discharge of 0.05 MGD. An additional 0.07 MGD plating waste is disposed into an injection well
								3.1	1.29		
	15_{12}	McDonnell-Douglas Corp/ (Douglas Aircraft Co) Tulsa	Mingo Creek Bird Creek Verdigris R			0.0393	#2BOD	30	9.8		McD-D Corp has 4 discharging points into Mingo Creek. Points #1, #2, & #4 receive no treatment. Point #3 receives chlorination & reduction clarifier, recarbonation, & super chlorination.
							#2COD	63	19.8		
							$\#2NO_3$	5.26	1.72		
						0.078	#3BOD	50	32.5		
							#3COD	89	57.9		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
		continued:									
1-D	1512	McDonnell-Douglas Corp. Tulsa				0.078	#3F	2.9	1.89		
							#3NO_3	5.8	3.77		
						0.344	#4BOD	30	86.1		
							#4COD	58	166.4		
							#4F	2.05	5.88		
						0.00167	#1				

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-D	15_{13}	Dowell, a div of Dow Chemical Co. Tulsa	Flatrock Cr Bird Creek Verdigris R			$1.2X10^{-4}$	#1BOD	7	.007		Discharge occurs at 2 points. Point #1 receieves the effluent from the equipment testing area. This effluent is treated by one grease trap & two settling tanks. Point #2 effluent originates in equipment washing area & is treated by 2 separator tanks to remove oil & grease.
							#1COD	180	.18		
							#1 Oil &Grease	1.6	.0006		
						$2X10^{-4}$	#2BOD	66	.02		
							#2COD	600	1.0		
							#2 Oil &Grease	111	.19		
							#2 Totl Solids	686	1.14		
	15_{14}	Bumper Service of Tulsa, Inc. Tulsa	Coal Creek Mingo Creek Bird Creek Verdigris R			0.09	Cr	2.2	.165		Chrome and nickel are precipitated by pH adjustment. The cyanide is recirculated thru system, they are presently developing a new treatment process to reduce discharge.
							CN	0.12	0.09		
							Ni	8.4	6.3		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-D	15_{15}	Tulsa Chrome Plating Co. Tulsa	Spunky Creek Verdigris R			0.02	Cr SO_4 COD	1.7 165 71.8	0.03 2.75 1.19		Treatment is a batch process (0.002 MG/batch). The CrO_4 is precipitated & the sludge is disposed of by US Pollution Control. The supernatant is pumped into holding ponds & treated with sodium disulfite. pH 12
	15_{16}	Yuba Heat Transfer Division Tulsa	No Name Creek Bird Creek Verdigris R			0.00743	BOD COD Oil & Grease	20 124 4.6	2.5 15.5 .58		Treatment consists of a sludge & oil separator from which the grit & silt is placed into an on-site landfill, and the liquid is pumped into an oxidztion lagoon along with domestic wastes.

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED Mg/l	Lbs/day	Kg/day	REMARKS
1-A	15_{17}	Coca-Cola Bottling Co. Tulsa	Storm sewer-Arkansas R			0.0003	BOD	16	1039		Discharge consists of wash water from floor & bottling area, and storm runoff.
							COD	320	.8		
							NO_3	2.4	.006		
							pH	9.1	9.1		
	15_{18}	St. Louis-San Fransisco RR Co Tulsa	Arkansas R			0.0216	BOD	54	9.73		Traps are used to remove oil & solids before discharging into sewer system.
							COD	83	14.95		
							Oil & Grease	41	7.39		
							P	2.3	.414		
	15_{19}	Warren Petroleum Co. Tulsa	Arkansas R			0.003	BOD	6	.15		Discharges into storm sewer system. No treatment of cooling water & boiler blowdown
							COD	40	1.		
							Cr	.22	.006		
							Zn	.52	.013		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15_{20}	Thermal Systems, Tulsa	Arkansas R			0.0216	BOD	50	9.01		No Treatment. Discharges into storm sewer system. Discharge is cooling tower water.
							COD	89	16.03		
							P	2	.36		
							Total Solids	1300	234		
	15_{21}	Dover Corp Norris-O'Bannon Division Tulsa				0.2	Cd	0.25	.417		No Treatment. Waste stream goes into storm sewer system. Interim permit expires August 14, 1973.
							CN	6.2	10.34		
							Cr	4.2	7.01		
							Zn	2.55	4.25		

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SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15 22	C.E. Natco Co. Tulsa	Park View drainage			0.0005	#1 Oil &Grease	41	0.171		No Treatment. There are four discharging points. The total combined flow is 0.02 MGD.
						0.01	#2 Oil &Grease	4.	0.334		
						0.0015	#3COD	51.6	0.645		
							#3Zn	4.6	0.06		
							#4 Oil &Grease	15	1.0		

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SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15_{23}	Ozark Mahoning Tulsa	Berryhill Cr			0.0374	BOD	37	11.5		pH adjustment & precipitation of sludge in concrete settling basin. Installing 2 catch basins to control spills
							COD	31	9.67		
							F	4.67	1.46		
							NH_3	10	3.12		
							Oil & Grease	15	4.68		
							Total Solids	2500	780		
	15_{24}	Drum Service, Inc Tulsa	Cherry Cr Arkansas R								Pollution problem arises when drums are allowed to fall into Cherry Creek and the oil residue escapes. Some pollution from runoff. All other wastes go into underground collecting tank which is collected by Sun Oil Co.

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15_{25}	IBM Corp Tulsa	Arkansas R			0.00065	BOD	11	.6		No treatment. Discharges into storm sewer system.
							COD	59	.319		
							F	1	.005		
	15_{26}	Skelly Oil Co. Tulsa	Arkansas R			0.0003	#1 Oil &Grease	88	.22		No treatment There are 2 discharges #1 from boiler & #2 from cooling tower. The discharges are 0.0003 MGD & 0.0067 MGD respectively
							#1 P	11.1	.028		
							#1Totl Solids	1068	2.67		
						0.0067	#2 Cr	4	.224		
							#2 P	1.35	0.075		
							#2 Totl Solids	716	40		
							#2 Zn	6	135		

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SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15 27	McMichael Concrete Co. Tulsa	Arkansas R			0.04	BOD	8	2.67		Settling basin
							COD	32	10.68		
							P	2.38	.79		
	15 28	Flint Steel Corp Tulsa	No Name Cr Arkansas R			0.0288	COD	5	1.2		Boiler blowdown & cooling water is discharged into No Name Creek without any treatment. The discharge from the galvanizing process is pumped into an evaporation lagoon. Plans are to pump discharges down an injection well when completed. Galvanizing process discharge amounts to 0.0044 MGD.
							pH	7.4	7.4		
	15 29	Sun Chemical Co Tulsa	Cherry Creek Arkansas R			0.004	COD	1050	35		No treatment. Discharge consists of floor wash water & cooling water
							Oil & Grease	6.3	.21		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15_{30}	Texaco, Inc. Tulsa	Cherry Creek Arkansas R			0.0005	COD	228			No treatment Discharge originates from truck washing area. A gate has been placed in drainage ditch to control spills
							Oil & Grease	11.8			
	15_{31}	Public Service Co.-Tulsa Sta. Tulsa	Arkansas R			0.84	Cl	2350	16463		Treatment is attempted in a (0.04 MG capacity) Neutralization basin Cooling water discharge rate is 0.84 MGD
							Cr	9.8	68.6		
							TDS	3458	24225		
							NO_3	1.3	9.11		
							Total P	4.2	29.4		
	15_{32}	Dupont De Nemours Plastic Dept. Tulsa	Arkansas R			0.04	BOD	2	.667		No treatment. Surface runoff. Also directed to drainage ditch.
							COD	46	15.34		
							Oil & Grease	1	.334		
							P	1.45	.484		

D20

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15 33	Dover Corp. Tulsa	Cherry Creek Arkansas R			0.04	BOD	4	1.33		The only treatment consists of grease traps installed in discharge lines.
							COD	123.2	41.1		
							F	1.1	.367		
							NO_3-N	.63	.21		
							Oil & Grease	4	1.33		
							Zn	.4	.133		
	15 34	Best Car Wash Tulsa	Arkansas			0.0025	BOD	54	1.33		Treatment consists of recirculation and grease trap.
							COD	671	14		
							Oil & Grease	975	20.3		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15_{35}	Southwest United Industries, Inc. Tulsa	Arkansas R			0.2	CN	1.13			No treatment. plating wastes and rinse water are discharged into storm sewer at three points. Quarterly, old plating solutions are collected by US Pollution Control Inc. and injected into the Arbuckle limestone about 1000 gallons per batch.
							Cr	2			
							Ni	1.34			
							Oil & Grease	3.5			
							P	.88			
	15_{36}	Rainbow Baking Co. Tulsa	Arkansas R			0.004	BOD	485	16.2		No treatment. Boiler blowdown, cooling water, and truck wash water, storm runoff are discharged into storm sewer
							F	4.67	.5		
							Oil & Grease	15	.156		
	15_{37}	Midwest Marble & Tile Co. Tulsa	Arkansas R			0.0053	Total Solids	140	6.19		No treatment. Discharges into storm sewer

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15_{38}	Safeway Stores, Inc. Tulsa	Arkansas R			0.0029	BOD	410	9.92		No treatment. Discharge contains detergents and cold water from refrigerating units and goes into the storm drain.
							COD	580	14.03		
							Oil & Grease	12	.29		
							P	6.4	.155		
							pH	4.9	4.9		
	15_{39}	Texaco, Inc. Refinery Tulsa	Arkansas R			13.	BOD	50	542		Treatment consists of an API separator and aerated lagoon.
							COD	100	1084		
							Cr	1.1	1.1		
							NH_3-N	10	108		
							Oil & Grease	20	217		
							Phenols	.1	1.1		
							Sulfide	.18	2		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
		continued									
1-A	15_{39}	Texaco, Inc. Refinery Tulsa	Arkansas R			1.3	TOC	57.1	619		Data collected Sept., 1973. Temp. of effluent was 105^{0}F. Dissolved oxygen content of effluent is 0. The turbidity of sample was 55 JTU. Treatment consists of an API separator and air flotation device. Sun is currently installing an activated sludge treatment system.
							TSS	30	325		
	15_{40}	Sun Oil Co. Refinery Tulsa	Arkansas R			5.1	Cl	242	10293		
							COD	950	40407		
							NH_3-N	35	1489		
							pH	8.5	8.5		
							Phenol	4	170		
							SO_4	275	11697		
							TDS	1096	46617		
							TSS	116	4934		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED Mg/l	Lbs/day	Kg/day	REMARKS
1-A	15_{41}	AMOCO Production Co. Tulsa	Arkansas R			0.005	COD	4.2	.175		No treatment. Domestic and laboratory wastes go into Tulsa Municipal System. Storm runoff and cooling water discharged to storm drain. 50 gallons per month of solvent oils, etc are collected by Consolidated Cleaning Service Co.
							Total Solids	147	6.13		
			Hauled by Consolidated Cleaning Service Co.			0.00005	CN	.14	.00006		
							F	2.5	.001		
							Oil & Grease	10.4	.004		
							Zn	.12	.00005		
	15_{42}	Public Service Co. of Okla. Tulsa	Arkansas			12.96	Total Solids	700	75660		Treatment handled 5.98 MG capacity settling basin
	15_{43}	Public Service Co. of Okla. Riverside Tulsa	Arkansas R			2.514	Cr	18.5	388		All waste steams are combined in a neutralizing basin and directly discharged into the Arkansas River.
							P	2.6	54.5		
							Total Solids	4680	98124		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	15_{44}	Oral Roberts University Tulsa	Fred Creek Arkansas R			0.00576	COD	13.8	.66		No treatment of cooling water.
							NO_3	.7	.034		
							Total P	2.6	.12		
							Zn	.5	.024		
	15_{45}	Carnation Co. Tulsa	Arkansas R			0.0005	BOD	150	.0625		No treatment for discharge from floor wash water and boiler blowdown.
							COD	965	4.02		
							NO_3	1.2	.005		
	16	Sierra Coal Co. Porum	Arkansas R Dirty Creek			0.22	COD	150	275		The company discharges only when draining the mine floor. Therefore, the discharge rate varies from 0 to 0.22 MGD. The data shown reflects the maximum discharge.
							SO_4	300	550		
							TDS	800	1468		
							TSS	200	367		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	17	Jeffrey Sand Co Ft. Smith, Ark.	Arkansas R			0.35	TSS	450	1314		Jeffrey Sand Co. dredges the Arkansas River from river mile 303 to 359.3. There is no treatment.
	18	Commander Mills, Inc. Sand Springs	Arkansas R			0.193	BOD	375	604		At present there is no treatment. Plans are to tie into the Sand Springs municipal system when completed.
							COD	510	821		
	19	Southwestern Porcelain, Inc Sand Springs	Arkansas R			0.0173	Ni	3.3	.47		At present no treatment Plans are to tie into Sand Springs municipal system when completed.
							SO_4	240	34		
							pH	4.1	4.1		
	20	Pedrick Laboratories Sand Springs	Arkansas R			0.0015	BOD	165			Treatment presently is a settling basin. Plans are to tie into the Sand Springs municipal system when completed.
							COD	242			
							NH_3	27.7			
							P	66.2			

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	20	continued: Pedrick Labs Sand Springs	Arkansas R			0.0015	Oil & Grease	882			
	21	Fibercast Co. Sand Springs	Arkansas R			0.01	BOD	113	9.42		No treatment. Will tie into Sand Springs municipal system when completed
							COD	392	32.7		
							Total Solids	5865	489		
	22	Interstate Electric Co,Inc Sand Springs	Arkansas R			0.00023	BOD	140	.27		Grease trap with effluent tied into Sand Springs storm sewer.
							COD	1309	2.51		
							Oil & Grease	180	.34		
							P	42	.08		
							Total Solids	1723	3.3		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	23	Liberty Glass Co. Sapulpa	No Name Cr Polecat Cr Arkansas R			0.008	COD	128	8.54		Treatment consists of settling basins and oil & grease separator. At time that sample was taken there was a broken line to the separator. This has since been repaired.
							Oil & Grease	126	8.41		
	24	Bartlett-Collins Co. Sapulpa	Rock Creek Arkansas R			0.0072	Oil & Grease	1.2	0.072		Treatment consists of "Inflico Sedi-flotor" clarifier and settling vats.
							TDS	507	30.4		
	25	Bark Water Systems c/o Gulf Oil Corp. Sapulpa	Polecat Cr Arkansas R			0.045	BOD	4	1.5		Company is a batch treatment for water. Discharge is 0.63 MGD every 2 weeks or an average of 0.045 MGD.
							COD	10	3.75		
							N_k	1.2	.45		

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	26	Anchor/MULCO Concrete Co. Jenks	Arkansas R			0.768	Cl	622	3984		No treatment.
							Fe	7.6	48.7		
							SO_4	135	865		
							Total Solids	2760	17678		
	27	Arkhola Sand & Gravel Co. Muskogee	Arkansas R			2.34	pH	1.5	1.5		Treatment handled by 3 lagoons. pH neutralization.
							TSS	344			
	28	Arkhola Sand & Gravel Muskogee	Nameless Cr Arkansas R			2.898	pH	3-8.4			No treatment, only retention dikes at point of dredge discharge. pH varies between 3 to 8.4
							TSS	412	9958		
	29	Corning Glass Works Muskogee	No Name Creek Arkansas R			0.45	Oil & Grease	15.6	58.54		Oil is skimmed and hauled to landfill

TABLE NO. D
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED Mg/l	Lbs/day	Kg/day	REMARKS
1-A	30	Swift & Co. Dairy, Poultry, Muskogee	Arkansas R			0.001	BOD	79	.66		No treatment. Discharge is made up of wash down water.
							COD	275	2.29		
							NH_3	8.4	.07		
							NO_3	15.4	.13		
							P	11.7	.11		
							Total Solids	312	2.6		
	31	Fansteel Metals Muskogee	Arkansas R			0.4	BOD	274	914		Waste stabilization and neutralization is handled by onsite lagoons, discharge data shown as combined stream from both lagoons.
							COD	312	1041		
							F	30.9	103		
							NH_3	700	2335		
							Zn	.1	.334		

TABLE NO.
INDUSTRIAL DISCHARGE INVENTORY

SEGMENT NO.	MAP IDENTIFICATION NO.	DISCHARGER	RECEIVING STREAM	STATE PERMIT NO.	S.I.C. CODE NO.	FLOW (mgd)	PARAMETER	QUANTITY OF DISCHARGED			REMARKS
								Mg/l	Lbs/day	Kg/day	
1-A	32	Brockway Glass Co. Muskogee	No Name Cr Arkansas R			0.22	Oil & Grease	5	9.17		Treatment by oil separator unit. Sludge hauled by contract.
	33	Oklahoma Gas & Electric Co. Muskogee	Arkansas R			108	BOD	4.6	4143		No treatment
							COD	12	10809		
							NO_3	.75	676		
	34	Arkhola Sand & Gravel Co. Muskogee	Grand Arkansas R			0.934	TSS	26	200		Two settling basins of 15 MG capacity each. Operating load is estimated load.
							TDS	4120	32093		

APPENDIX E

MUNICIPAL WASTE LOAD ALLOCATIONS

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-A	1	BIXBY Arkansas River	130/.329	30	82.32	34.34	30	82.52	37.34
	2	BOYNTON Cloud Creek	0.0/.041	20	6.84	3.10	30	10.25	4.66
	3	BRAGGS Sand Creek	0.0/.026	20	4.33	1.97	30	6.51	2.95
	4	BROKEN ARROW Broken Arrow Creek	0.0/1.131	20	188.48	85.49	30	282.98	128.36
	5	CHECOTAH Elk Creek	0.0/.307	20	51.21	23.77	30	76.81	34.91
	6	CONNER STATE COLLEGE Dirty Creek	0.0/.08	20	13.34	6.05	30	20.02	9.08
	7	COWETA Coweta Creek	0.0/.16	20	26.69	12.11	30	40.03	18.16
	9	GORE Unnamed tributary of Arkansas River one mile from confluence	0.0/.065	20	10.84	4.92	30	16.26	7.38

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-A	10	HASKELL Arkansas River	130/.217	30	54.29	24.63	30	54.29	24.63
	11	JENKS Arkansas River	130/.238	30	59.55	27.01	30	59.55	27.01
	12	KIEFER Childers	0.0/.084	20	14.01	6.36	30	21.02	9.53
	13	MOUNDS Snake Creek	0.0/.93	20	155.12	70.36	30	237.69	105.54
	14	MUSKOGEE Arkansas River	1300/6.2	30	1551.24	703.63	30	1551.24	703.63
	15	PORUM Dirty Creek(South)	0.0/.066	20	11.01	4.99	30	16.51	7.49
	16	SAND SPRINGS Arkansas River	130/.59	30	147.62	66.96	30	147.62	66.96
	17	SAPULPA Rock Creek	.29/58	20	96.74	43.88	30	145.12	65.82
	18	SAPULPA Polecat Creek	.77/1.16	20	193.49	87.76	30	290.23	131.65

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-A	19	TAFT Arkansas River	130/.053	30	13.26	6.01	30	13.26	6.01
	20	TAFT STATE SCHOOL Arkansas River	130/.09	30	20.02	9.09	30	22.52	10.21
	21	TULSA Arkansas River	130/15.288	30	3825.06	1735.02	30	3825.06	1735.02
	22	WARNER Dirty Creek	0.0/.122	20	20.35	9.23	30	30.52	13.85

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY / Stream	Duration Ratio Q_s/Q_e MGD	BOD mg/l	BOD lbs/day	BOD kg/day	Suspended Solids mg/l	Suspended Solids lbs/day	Suspended Solids kg/day
1-B	1	STILWELL Caney	.59/.343	20	57.21	25.95	30	85.82	38.93
	2	TAHLEQUAH Illinois	76.05/1.97	20	328.6	149.05	30	492.89	223.57
	3	WESTVILLE Shell	1.196/.3	20	50.04	22.7	30	75.06	34.05

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-C	1	ADAIR Bitter	0.0/.036	20	6.0	2.72	30	9.01	4.09
	2	AFTON Horse	.12/.087	20	14.51	6.58	30	21.77	9.87
	3	CARDIN Tar	.12/.007	20	1.75	.79	30	1.75	.79
	4	CHELSEA Pryor	0.0/.16	20	26.69	12.11	30	40.03	18.16
	5	CHOUTEAU Chouteau	0.0/.131	20	21.85	9.91	30	32.78	14.87
	6	COLCORD Tributary to Spavinaw	0.0/.05	10	4.17	1.89	30	12.51	5.67
	7	COMMERCE Tar	.12/.219	20	36.53	16.57	30	54.79	24.85
	8	EASTERN STATE HOSPITAL Bull	0.0/.197	20	32.86	14.90	30	49.29	22.36
	9	FAIRLAND Hudson	0.0/.057	20	9.51	4.312	30	14.26	6.47

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-C	10	FAIRLAND Ogeechee	0.0/.014	20	2.34	1.06	30	3.50	1.59
	11	FT. GIBSON Grand River	266.5/ .142	30	20.02	9.08	30	35.53	16.12
	12	GROVE Wolf Creek from Grand Lake	4.875/.179	20	29.86	13.54	30	44.79	20.31
	13	HULBERT Tributary to Fourteen Mile Creek	0.0/.059	10	4.92	2.23	30	12.51	5.67
	14	JAY Muskrat Creek	.68/.488	20	81.40	39.92	30	122.10	55.38
	15	LOCUST GROVE Grand Creek	0.0/.095	20	15.85	7.19	30	23.77	10.17
	16	MIAMI (1) Tar Creek	.12/.539	20	89.91	40.78	30	134.86	61.17
	17	MIAMI (2) Neosho River	266.5/.275	30	68.81	31.21	30	68.81	31.21

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD mg/l	BOD lbs/day	BOD kg/day	Suspended Solids mg/l	Suspended Solids lbs/day	Suspended Solids kg/day
I-C	18	MIAMI (3) Neosho River	266.5/.35	30	87.57	39.72	30	87.57	39.72
	19	PICHER Lyttle Creek Tributary of Tar Cr.	.187/.253	20	42.20	19.14	30	63.30	28.71
	20	PRYOR (TF) Pryor	0.0/.799	20	133.27	60.45	30	199.91	90.68
	21	PRYOR Pryor	0.0/.799	20	13.27	60.45	30	199.91	90.68
	22	QUAPAW Spring River	99.85/.069	30	17.26	7.83	30	17.26	7.83
	23	SALINA Salina		20	30.19	13.69	30	45.29	20.54
	24	SENECA (Mo) Lost Creek	0.0/.05	10	4.17	1.89	30	12.51	5.67
	25	SENECA SCHOOL Confluence with Grand Lake	90/.015	20	2.50	1.13	30	3.75	1.70

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-C	26	VINITA Big Cabin Creek	.65/1.01	20	168.47	76.42	30	252.70	144.62
	27	WELCH Little Cabin Creek	0.0/.068	20	11.34	3.14	30	17.01	7.72
	28	WESTERN HILLS LODGE Grand River	266.5/.59	20	98.41	44.64	30	144.62	66.96

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-D	1	AVANT Bird Creek	1.22/.042	30	10.51	4.77	30	10.51	4.77
	2	BARNSDALL Birch Creek	0.0/.15	20	25.02	11.36	30	37.53	17.02
	3	BARTLESVILLE Hillcrest	.78/.240	20	40.03	18.16	30	60.05	27.24
	4	BARTLESVILLE (1) Caney River	.78/2.6	20	433.68	196.71	30	650.52	297.07
	5	BARTLESVILLE (2) Caney River	.78/.33	20	55.04	24.97	30	82.57	37.45
	6	CATOOSA Spunky Creek	0.0/.10	20	33.36	15.13	30	14.01	6.36
	7	CLAREMORE Dog Creek	.75/1.34	20	223.51	101.38	30	335.27	152.08
	8	COLLINSVILLE Horsepen Creek	0.0/.10	20	16.68	7.57	30	25.02	11.35
	9	COPAN Little Caney River	0.0/.055	20	9.17	4.16	30	13.76	6.24

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-D	10	DELAWARE Captain Creek	0.0/.035	20	5.84	2.65	30	8.76	3.94
	11	DEWEY Coon Creek	0.0/.39	20	65.05	29.51	30	97.58	44.26
	12	HOMINY Claremore Creek	0.0/.22	20	36.70	16.65	30	55.04	24.97
	13	INOLA Pea Creek	0.0/.1	20	16.68	7.57	30	25.02	11.35
	14	NOWATA Western Branch Creek	0.0/.32	20	53.38	24.21	30	80.06	36.32
	15	OCHELATA Unnamed tributary to Caney River	0.0/.04	20	6.67	3.03	30	10.01	4.54
	16	OWASSO Bird Creek	/.28	20	46.70	21.18	30	70.06	31.78
	17	PAWHUSKA Bird Creek	1.3/.41	20	68.39	31.02	30	259.95	118.16
	18	ROLLING HILLS Spunky Creek	.149/.254	20	42.37	19.22	30	63.55	28.83

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-D	19	RAMONA Double Creek	0.0/.001	20	.17	.07	30	.25	.11
	20	SKIATOOK Bird Creek	1.3/.23	20	38.36	17.40	30	102.58	46.53
	21	SOUTH COFFEYVILLE Verdigris River	7.41/.056	30	14.01	6.36	30	14.01	6.36
	22	SPERRY Hominy Creek	.06/1.3	20	216.84	98.36	30	325.26	147.54
	23	TULSA FLAT ROCK Bird Creek	1.3/7.8	20	1301.04	590.14	30	1951.56	885.21
	24	TULSA NORTH SIDE Bird Creek	1.3/13.4	20	2235.12	1013.83	30	3352.65	1520.75
	25	TULSA ROSE DEW Spunky Creek	.149/.24	20	40.03	18.16	30	60.05	27.24
	26	TULSA COAL CREEK Bird Creek	1.3/4.1	20	683.88	310.20	30	1025.82	465.30
	27	WAGONER Coal Creek	0.0/.87	20	145.12	65.82	30	217.67	98.74

TABLE E

MUNICIPAL WASTE LOAD ALLOCATION

Segment Number	Map ID Number	MUNICIPALITY Stream	Duration Ratio Q_s/Q_e MGD	BOD			Suspended Solids		
				mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day
1-D	28	WYNONA Birch Creek	0.0/.052	20	8.67	3.93	30	13.01	5.90

APPENDIX F

INDUSTRIAL WASTE LOAD ALLOCATION

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD			Organic Suspended Solids			Conserva-tive Elements			
					mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day		mg/l	lbs/day	kg/day
1-C	3	Escoa Corp. Pryor	Pryor Creek	0.0/.0058	20	1	0.5	30	1.45	.66	Cr NO_3	0.1 3.6	.005 .02	.002 .01
	9	Eagle Picher Ind. Inc. Commerce	Tar Creek	.12/.0432	20	7	3	30	10.8	4.91	Zn	1.2	.43	.2
	7	Pryor Ind. Conservation Comm Pryor	Grand River	264/2.2	250	4583	2079	150	2750	1250				
	6	Milnot Co. Seneca, Mo.	Lost Creek	2.99/.108	20	18	8	30	27.0	12.3				
	8	B.F.Goodrich Miami	Grand River	88.4/.08	30	20	9	30	20.0	9.08				
	5	Midwest Carbide Corp. Pryor	Sulphur Creek	0.0/.017	-			-			NO_3	2.7	.383	.174
	4	Okla. Cement Co. Pryor	Sulphur Creek	0.0/-										

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD mg/l	BOD lbs/day	BOD kg/day	Organic Suspended Solids mg/l	Organic Suspended Solids lbs/day	Organic Suspended Solids kg/day	Conservative Elements	mg/l	lbs/day	kg/day
1-D	15_4	Byron Jackson, Div. of Borg-Warner Corp. Tulsa	Mingo Creek	0.0/.00124	20	1	0.5	30	.31	.14	-			
	15_6	Leland Equipment Co., Tulsa	Mingo Creek	0.0/.00024	20	1	0.5	30	.06	.03	-			
	15_{10}	Lake County Beverage Co.,Inc. Tulsa	Mingo Creek	0.0/.0008	20	1	0.5	30	.20	.09	-			
	15_{13}	Dowell, Div. of Dow Chem. Co. Tulsa	Flat Rock Creek	0.0/.00012	20	1	0.5	30	.03	.014	-			
	15_{16}	Yuba Heat Transfer Division Tulsa	No Name Creek to Bird Creek	0.0/.0074	20	1	0.5	30	1.85	.84	-			
	15_{12}	McDonnell-Douglas Corp. Tulsa	Mingo Creek #2 #3	0.0/.039 0.0/.078	20 20	7 13	3 6	30 30	9.76 19.5	4.43 8.85	NO_3 F NO_3	5.26 1.0 5.8	1.71 .65 3.77	.78 .30 1.71

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD			Organic Suspended Solids			Conservative Elements			
					mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day		mg/l	lbs/day	kg/day
1-D	15_{12}	McDonnell-Douglas Corp., Tulsa	Mingo Creek #4	0.0/.344	20	57	26	30	86.0	39.0	F	1.0	2.87	1.30
	11	Peabody Coal Co. St. Louis, Mo.	Spencer Creek to Oologah Res.	0.0/.05	10	4	2	30	12.51	5.67	-			
	10	Peabody Coal Co.	Lightning Creek	0.0/.05	20	8	4	30	12.51	5.67	-			
	15_8	American Airlines Tulsa	Mingo Creek	0.0/.05	-			-			P	10	4.17	1.89
	15_1	Public Service Co N.E. Station Tulsa	Verdigris River	10.7/1.21	-			-			NH_3 P	0.26 1.6	2.67 16.0	1.21 7.3
	15_7	Hathaway Ind. Tulsa	Mingo Creek	0.0/.003	-			-			CN NH_3 Pb	2.2 13.0 0.1	.06 .33 .003	.03 .15 .015
	15_9	Fram Corp., Inc. Tulsa	Mingo Creek	0.0/.0394	20	6	3	30	9.86	4.48	Cr	0.1	.03	.015

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD			Organic Suspended Solids			Conserva-tive Elements			
					mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day		mg/l	lbs/day	kg/day
1-D	15_{14}	Bumper Service of Tulsa, Inc. Tulsa	Coal Creek	0.0/.09	-			-			CN Cr Ni	.07 .1 .2	.05 .08 .15	.025 .034 .07
	13	Phillips Pet. Co. Research Bartlesville	Eliza Creek	.8/.06	20	10	4.5	30	15	6.8	P	16	.08	.036
	15_{15}	Tulsa Chrome Plating Co. Tulsa	Spunky Creek	0.0/0.5	20	1	0.5	30	.5	.23	Cr	.1	.002	.001
	14	National Zinc Co. Bartlesville	Eliza Creek	.8/.5	20	83	38	30	125	56.9	Cd Cr Pb Zn	.01 .1 .1 2.0	.04 .42 .42 8.34	.02 .19 .19 3.78
	12	Tulsa Rendering Collinsville	Blackjack Creek	0.0/.05	20	8	4	30	12.5	5.69	NH_3	.47	.2	.09

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD			Organic Suspended Solids			Conserva-tive Elements			
					mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day		mg/l	lbs/day	kg/day
I-D	15_2	Chandler Material Tulsa	Bird Creek	1.3/.0002	-			-			NH_3	2.8	.2	.09
											Phenol	6.5	.01	.005
	15_5	Black Sivals & Bryson Tulsa	Mingo Creek	0.0/.018	20	3	1	30	4.5	2.05	NH_3	2.0	.3	.14
											P	5.0	.75	.34

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD			Organic Suspended Solids			Conservative Elements			
					mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day		mg/l	lbs/day	kg/day
1-A	15_{26}	Skelly Oil Co. Tulsa	Arkansas R. #1 #2	130/.0003 130/.0067	-			-			P Cr P Zn	10 4.0 1.35 6.0	.025 .224 .075 .335	.011 .101 .034 .152
	23	Liberty Glass Co. Sapulpa	No Name Creek to Polecat Creek to Arkansas River	0.0/.008	20	1	0.5	30	2.0	.91	-			
	24	Bartlett Collins Co. Sapulpa	Rock Creek	.44/.072	30	18	8	30	18.0	8.17	-			
	15_{43}	Public Service Co., Tulsa	Arkansas River	130/12.96	30	3242	1470	30	3242	1417	-			
	19	Southwestern Porcelain, Inc. Sand Springs	Arkansas River	130/.0173	-			-			Ni	3.3	.476	.216
	20	Pedrick Labs Sand Springs	Arkansas River	130/.0015	150	2	1	150	2.0	1.0	NH_3 P	27.7 66.2	.347 .828	.157 .376

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD mg/l	BOD lbs/day	BOD kg/day	Organic Suspended Solids mg/l	Organic Suspended Solids lbs/day	Organic Suspended Solids kg/day	Conserva-tive Elements	mg/l	lbs/day	kg/day
1-A	15_{44}	Oral Roberts Univ Tulsa	Fred Creek	.61/.0058	30	1	0.5	30	1.45	.67	NO_3 P Zn	.7 2.6 .5	.034 .126 .024	.015 .057 .011
	15_{33}	Dover Corp. Tulsa	Cherry Creek	.81/.04	30	10	5	30	10	4.54	F NO_3 Zn	1.1 .63 .4	.37 .21 .13	.17 .1 .06
	15_{43}	Public Service Co Riverside, Tulsa	Arkansas River	130/2.514							Cr P	2.59 2.6	54.2 54.2	24.6 24.7
	15_{41}	AMOCO Production Co., Tulsa	Arkansas River	130/.005	30			30			CN F Zn			
	15_{31}	Public Service Co Tulsa	Arkansas River	130/.84	-			-			Cr NO_3 P	7.74 1.3 4.0	54.2 9.11 28.0	24.6 4.13 12.7

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD			Organic Suspended Solids			Conservative Elements			
					mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day		mg/l	lbs/day	kg/day
1-A	30	Swift & Co. Dairy, Poultry Muskogee	Arkansas River	1300/.001	70	1	0.5	70	1.0	0.5	NH_3 NO_3 P	8.4 15.4 11.7	.07 .13 .098	.03 .058 .044
	15_{38}	Safeway Stores, Inc., Tulsa	Arkansas River	130/.0029	300	7	3	150	4.0	2.0	P	6.4	.16	.07
	33	O. G. & E Muskogee	Arkansas	1300/108	30	27022	12257	30	27022	12257	NO_3	.75	676	306
	16	Sierra Coal Co., Porum	Dirty Creek	0.0/.22	20	37	17	30	55.0	25.0	-			
	15_{28}	Flint Steel Corp., Tulsa	No Name Creek to Arkansas River	0.0/.029	20	5	2	30	7.26	3.29	-			
	15_{29}	Sun Chemical Corp. Tulsa	Cherry Creek	0.0/.004	20	1	0.5	30	1.0	.45	-			
	15_{30}	Texaco, Inc. Tulsa	Cherry Creek	0.0/0.1	20	1	0.5	30	.25	.11	-			

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD			Organic Suspended Solids			Conservative Elements			
					mg/l	lbs/day	kg/day	mg/l	lbs/day	kg/day		mg/l	lbs/day	kg/day
1-A	26	Anchor/Amulco Concrete Co. Jenks	Arkansas River	130/.768	30	192	87	30	192	87.2	-			
	28	Arkhola Sand and Gravel, Muskogee	No Name Creek to Arkansas River	0.0/2.898	20	483	219	30	725	329	-			
	15_{32}	Dupont Denemurs Plastic Dept., Tulsa	Arkansas River	130/.04	30	10	5	30	10	4.54	P	1.45	.484	.219
	15_{35}	Southwest United Ind., Inc. Tulsa	Arkansas River	130/.2	-			-			CN	1.13	1.89	.86
											Cr	2.0	3.34	1.51
											Ni	1.34	2.24	1.01
											P	.88	1.47	.67
	15_{39}	Texaco, Inc. Refinery, Tulsa	Arkansas River	130/1.3	50	542	246	50	542	246	Cr	1.1	11.9	5.41
											NH_3	3.0	32.5	14.8
											Phenol	.1	1.08	.49
											Sulfides	.2	2.17	.98

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INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD mg/l	BOD lbs/day	BOD kg/day	Organic Suspended Solids mg/l	Organic Suspended Solids lbs/day	Organic Suspended Solids kg/day	Conservative Elements	mg/l	lbs/day	kg/day
1-A	17	Jeffrey Sand Co. Ft. Smith, Ark.	Arkansas River	1300/.35	30	88	40	30	87.6	39.7	-			
	15_{40}	Sun Oil Co. Refinery Tulsa	Arkansas River	130/5.1	50	2127	965	50	2127	965	NH_3 Phenol	.77 .025	32.8 1.06	14.9 .48
	31	Fansteel Metals Inc., Muskogee	Arkansas River	1300/.4	250	833	378	150	500	228	F NH_3 Zn	30 97.5 .1	100 325 .334	45.4 148 .15
	15_{23}	Ozark Mahoning Co. Tulsa	Berryhill Creek to Arkansas R.	0.0/.0374	20	6	3	20	6	3	F NH_3	1. 10	.312 3.12	.142 1.42
	25	Barkwater Systems, Div. of Gulf Oil Sapulpa	Polecat Creek	.77/.045	30	11	5	30	11	5	-			
	15_{36}	Rainbow Baking Co. Tulsa	Arkansas River	130/.004	450	15	7	150	5	2.3	F	4.67	.156	.071
	15_{34}	Best Car Wash Tulsa	Arkansas River	130/.0025	50	1	0.5	50	1	0.5	-			

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD			Organic Suspended Solids			Conserva-tive Elements			
					mg/l	lbs/ day	kg/ day	mg/l	lbs/ day	kg/ day		mg/l	lbs/ day	kg/ day
1-A	15_{18}	Dover Corp. Norris O'Bannon Division Tulsa	Arkansas River	130/.2	-						Cd CN Cr Zn	.25 3.25 4.2 2.55	.417 5.42 7.0 4.25	.189 2.46 3.18 1.93
	15_{22}	C. E. Natco Co. Tulsa	Arkansas River	130/.0015	50	1.0	0.5	50	1.0	0.5	Zn	4.6	.058	.026
	15_{19}	Warren Petroleum Co., Tulsa	Arkansas River	130/.003	50	1	0.5	50	1.0	0.5	Cr Zn	.22 .52	.006 .013	.002 .006
	15_{25}	IBM Corp. Tulsa	Arkansas River	130/.00065	30	1.0	0.5	30	1.0	0.5	F	1.	.005	.002
	15_{17}	Coca-Cola Bottling Co., Tulsa	Arkansas River	130/.0003	30	1.0	0.5	30	1.0	0.5	NO_3	2.4	.01	.003
	18	Commander Mills Inc., Sand Springs	Arkansas River	130/.193	350	560	254	150	241	109	-			

TABLE F

INDUSTRIAL WASTE LOAD ALLOCATION

Segment No.	Map ID No.	Discharger	Stream	Q_s/Q_e mgd	BOD			Organic Suspended Solids			Conserva-tive Elements			
					mg/l	lbs/ day	kg/ day	mg/l	lbs/ day	kg/ day		mg/l	lbs/ day	kg/ day
1-A	21	Fibercast Co., Sand Springs	Arkansas River	130/.01	100	8	4	100	8	4	-			
	22	Interstate Electric Co., Inc., Sand Springs	Arkansas River	130/.00023	140	1.0	0.5	140	1.0	0.5	P	40	.007	.035
	15_{45}	Carnation Co., Tulsa	Arkansas River	130/.0005	150	1.0	0.5	150	1.0	0.5	NO_3	1.2	.005	.0023
	15_{20}	Thermal Systems, Tulsa	Arkansas River	130/.021	50	9	4	50	9	4	P	2.0	.35	.16
	15_{18}	St. Louis-San Francisco Railway Tulsa	Arkansas River	130/.0216	50	9	4	50	9	4	P	2.3	.41	.19
	15_{27}	McMichael Concrete Co., Tulsa	Arkansas River	130/.04	30	10	5	30	10	5	P	2.4	.80	.36

APPENDIX G

MATHEMATICAL MODELS FOR BOD ASSIMILATIVE CAPACITY

MATHEMATICAL MODELS FOR BOD ASSIMILATIVE CAPACITY

As stäted in the text of this paper, the original model for BOD assimilative capacity was proposed by Streeter and Phelps in 1925, and subsequently expounded upon by Phelps in 1944. This appendix will list various additions and improvements to the model which have been proposed by various investigators since the original work was published. While the material given below is not necessary to the use of the model presented in the text, the material in this appendix should give the interested reader a better understanding of the complex reactions represented by the model.

An extensive search of the literature relative to mathematical modeling of BOD assimilative capacity has been made by the Washington office of the U.S. Environmental Protection Agency and circulated in draft form under the title, Analytical Techniques for Waste Load Allocation in Water Quality Limited Segments. This paper was intended to serve as guidance in selecting models appropriate to the data base available. Models were grouped into three types: A, B, and C, according to their level of sophistication. The part of the document dealing with flowing streams is exactly suited to the purpose of this study and is included below with only slight modifications.

Flowing Streams. Type A.

This technique might be used to study various parameters when there is a relatively small amount of instream of waste source data or when a rough analysis is required within a short time frame. The approach ignores or combines certain phenomena, but may be relatively accurate if the assumptions involved in the derivation are valid in reality. The primary assumptions are:

1) The flow is one-dimentional. This restriction means that all flow properties: velocity, cross-sectional area, depth, temperature, etc. vary only in the longitudinal direction (x), and not in the transverse or vertical direction.
2) Flow properties, flow velocity, area, etc. are assumed to be constant over each computational segment measured in the longitudinal (x) direction. However, different values of these properties can occur from segment to segment.
3) The flow is steady state. This restriction requires that all flow properties and concentrations are constant with time at any fixed position in the stream.
4) Dispersion is negligible. This restriction implies that advection is the only significant transport mechanism occurring and that "plug flow" without longitudinal mixing (dispersion) characterizes the model as the water flows downstream.
5) Carbonaceous and nitrogenous BOD are combined into one term and degraded by first-order time-tables.

Making use of the above five assumptions and assuming the first-order decay of a single, non-conservative substance, the first concentration of BOD as a function of longitudinal distance (x) can be described in a segment with a stream velocity, U, as a first order differential equation of the form:

$$\frac{dZ}{dx} = -k_1 \frac{x}{U}$$

The solution of which is:

$$Z(x) = Z_0 e^{-k_1 \frac{x}{U}} \qquad \text{(A-1)}$$

Where: Z_0 = Initial concentration ultimate combined BOD at an initial reference point, x_0

$Z(x)$ = BOD remaining at a distance x downstream of origin ($x = 0$)

k_1 = First order combined deoxygenation rate constant

e = Base of the natural logarithm

U = Constant stream velocity in region $0 \leq x \leq x$

It will be noted that in the form of the equation shown here and in Type B models the time does not appear explicitly, but only appears in the exponent in the form $\frac{x}{U}$. Since the velocity, U, is the assumed constant over the computational segment, the equation is often written as:

$$Z(t) = Z_0 e^{-k_1 t}$$

with time appearing explicitly, which is the form of the Streeter-Phelps model used in the text.

In the absence of instream data the rate constant, k_1, may be taken from the literature. Consideration should be given to the basic characteristics of different types of wastes.

The aeration rate constant, k_a, may be determined by means of several different relations. Many of the relations can be put in the following form:

$$k_a = B\frac{U^c}{H^c} \qquad \text{(A-2)}$$

Where: k_a = first order reaeration rate constant

U = stream velocity (mean)

H = Stream depth (mean)

The values of U and H may be estimated or computed from the measured flow with regression constants given in the literature. Coefficients B, c, and b can be obtained from O'Connor and Dobbins[1], Churchill, etal[2], or Langbein and Duram[3].

In modeling the dissolved oxygen in a stream, this approach considers only the replenishment of DO from atmospheric reaeration and the utilization of DO associated with the oxidation of the combined BOD. The applicable differential equation is essentially of the form proposed by Streeter and Phelps describing the oxygen deficit resulting from the interaction of two non-conservative substances, BOD and DO, as a function of distance downstream in a body of water flowing with velocity, U. The quation is an ordinary first order differential quation of the form:

$$U\frac{dD}{dx} = k_1 Z(x) - k_a D \qquad \text{(A-3)}$$

[1]O'Connor, O.J. and Dobbins, W.E. "Mechanism of Reaeration in Natural Streams" Trans. ASCE, Vol. 123, 1958

[2]Churchill, M.A. etal "Prediction of Stream Reaeration Rates" J. Sanitary Engineering Div. ASCE Vol. 88, No. SA 4, 1962

[3]Langbein, W.B. and Duram, W.H. "The Aeration Capacity of Streams" U.S.G.S. Circular No. 542, Washington, D.C., 1967

Where: D = dissolved oxygen deficit = $C_s - C$

C_s = saturation value of dissolved oxygen at a given temperature.

C = dissolved oxygen concentration at a given temperature

$$Z(x) = Z_o e^{-k_1 \frac{x}{U}} \quad \text{(Solution to previous Equation A-1)}$$

The elementary solution to equation A-3 (by means of an intergrating factor) is:

$$D = \frac{k_1}{k_a - k_1} \left(e^{-k_1 \frac{x}{U}} - e^{-k_a \frac{x}{U}}\right) + D_o e^{-k_a \frac{x}{U}}$$

Where: D_o = initial DO deficit at x = 0

D = deficit at distance x downstream

Equation A-4 with $\frac{x}{U} = t$ is the form of the classical Streeter-Phelps BOD-DO sag equation, with the rate constant determined from the natural logarithm.

Type B

This technique is a refinement over that presented as Type A and should be used where the following conditions prevail:

1) More data exists

2) More time is available for the analysis

3) A greater degree of confidence is desired in the predictive capability of the model

The greater degree of accuracy in the predictive capability can be obtained only by considering more phenomena. There should be good instream and waste source data preferably taken for the purpose of modeling. Good instream data should come from an intensive survey with a complete segment coverage within a relatively short time span closely approximating the steady state condition. Information about the stream cross-sections, velocity and reaeration rates would be extremely helpful. Since this technique considers more sources and sinks of DO than Type A, it will produce more accurate results only if those sources and sinks are relavant and the magnitudes and concentrations are known with reasonable accuracy.

This analysis, similar to the previous Type A, assumes one-dimentional, steady state conditions with only the advection transport process being condidered. Carbonaceous BOD can be represented most conveniently as decaying by first-order kinetics due to physical processes as well as biochemical oxidation. This can be described by a relation similar to that developed earlier for the combined CBOD-NBOD reaction:

$$L(x) = L_o e^{-k_r \frac{x}{U}} \qquad \text{(B-1)}$$

Where: $L(x)$ = carbonaceous BOD at a distance x downstream

L_o = ultimate carbonaceous BOD at x = 0

$k_r = k_d + k_3$

k_d = rate constant for decrease in carbonaceous BOD due to biochemical oxidation

k_3 = rate constant for decrease in carbonaceous BOD due to sedimentation and absorption

The value of k_3 is usually greater than k_d and the two may be isolated by analysis of instream data. At secondary treatment levels, k_3 may be insignificant.

The sequential oxidation of ammonia to nitrite and then nitrate may be represented as a first order reaction of ammonia directly to nitrate with a rate constant of k_n. This is usually a valid assumption because the reaction from nitrite to nitrate is significantly faster than the overall oxidation process of ammonia to nitrate. The concentration of ammonia is converted into an equivalent oxygen demand which represents the nitrogenous BOD. The equation describing this nitrification process is:

$$N(x) = N_o e^{-k_n \frac{x}{U}} \tag{B-2}$$

Where: $N(x)$ = nitrogenous BOD at a distance x downstream

N_o = ultimate nitrogenous BOD at x = 0

k_n = rate constant for the decrease in nitrogenous BOD due to biochemical oxidation

Furthermore, if we consider the following uniformly distributed sources or sinks of dissolved oxygen due to:

1) P - Distributed gross photosynthesis (source of DO)

2) R - Distributed algal respiration (sink of DO)

3) B - Distributed benthal demand (sink of DO)

These distributed sources (which become sinks of oxygen deficit, D) and sinks (which become sources of oxygen deficit) can be added to the basic differential equation of the form used previously (A-4) in the Type A analysis as follows:

$$U\frac{dD}{dx} = k_d L(x) - P + R + B + k_n N(x) \tag{B-3}$$

Substituting for functions L(x) and N(x) appearing in (B-3) above by the forms given in equations (B-1) and (B-2) respectively and integrating, the elementary solution can be written:

$$D = D_o e^{-k_a \frac{x}{U}} + \frac{k_d L_o}{k_a - k_r} \left(e^{-k_r \frac{x}{U}} - e^{-k_a \frac{x}{U}}\right) + \frac{k_n N_o}{k_a - k_n} \left(e^{-k_n \frac{x}{U}} - e^{-k_a \frac{x}{U}}\right)$$
$$+ \frac{B + R - P}{k_a} \left(1 - e^{-k_a \frac{x}{U}}\right)$$

The distributed source/sink parameters P, R, and B should be considered functions of downstream position, x, because their values can change at different locations. Throughout any computational element in x, however, the values of P, R, and B must be assumed constant. Judgement must be exercised in assigning particular values to those distributed source/sinks depending upon different waste treatment schemes.

Where thermal pollution exists the elevated stream temperature may be represented as returning to ambient temperature by first order kinetics.

Type C

An extensive data base must exist for this approach. This method is time-unsteady state and can consider both advective and dispersive transport. For flowing streams, the dispersive transport can be assumed negligible, and if photosynthetic oxygen is assumed to vary periodically and is the only time-dependent source, sink or input boundary condition, a dissolved oxygen balance yields the following partial differential equation[1] for the oxygen deficit:

$$\frac{\partial D}{\partial t} = -U\frac{\partial D}{\partial t} - k_a D - P(x_1 t) + k_d L(x) + k_n N(x) + R(x) + B(x) \qquad \text{(C-1)}$$

If the photosynthentic rate is assumed to vary as the sunlight intensity during the day and is zero at night, the relationship P(t) can be approximated by a periodic function of period, p:

$$P(t) = P_m \sin(\pi \frac{t}{p}) \qquad 0 \leq t \leq p$$

$$P(t) = o \qquad (1-p) \leq t \leq 1 \text{ day}$$

If the period assumed is equal to 13 hours, then the above function for P(t) may be described by a Fourier series which can be approxi-

[1]O'Connor, D.J. and Ditoro, D.M. "Photosynthesis and Oxygen Balance in streams", J. Sanitary Engineering Div., ASCE, Vol. 96, No. SA 2, 1970.

mated by including the first three terms as follows:

$$P(t) = P_m[\frac{1}{\pi} + \frac{1}{2}\sin(\pi\frac{t}{p}) - \frac{2}{3}\pi\cos 2\pi(\frac{t}{p})] \qquad \text{(C-2)}$$

Where P_m is the amplitude of the wave, i.e., the maximum rate over the period, p.

If the terms containing L(x) and N(x) appearing in (C-1) above are replaced by the forms appearing in equations (B-1) and (B-2) respectively, a closed form solution can be obtained describing the oxygen deficit variation both temporally and spatially due to a periodically varying source of photosynthetic oxygen. This solution can be found from O'Connor and Ditoro cited previously or from O'Connor[1].

When both advective and dispersive transport are considered, a mass balance equation can be derived under the assumptions of constant hydraulic conditions (flow velocity, stream cross-section, etc.) with distance and with periodically varying inputs to simulate for example durnal variations in the river. The partial differential equation for the time-unsteady oxygen deficit can be expressed in the general form:

$$\frac{\partial D}{\partial t} = E\frac{\partial^2 D}{\partial x^2} - U\frac{\partial D}{\partial x} \pm \sum S \qquad \text{(C-3)}$$

Where: E = longitudinal dispersion coefficient

The $\sum S$ term can include all pertinent sources or sinks of oxygen deficit having temporal and/or spatial variation. Examples would be the photosynthetic oxygen production term, P(x,t) as well as terms involving the spatial distribution of carbonaceous and

[1] O'Connor, D.J. "Reactions in Stream and Estuarian Analysis" Notes for Manhattan Summer Institute in Water Pollution Control, Manhattan College, Bronx, N.Y., 1967

and nitrogenous BOD described in the preceeding Type C analysis.

The complexity of equation (C-3) usually precludes closed form solutions using implicit, finite-difference methods can be employed usually to any required degree of complexity.