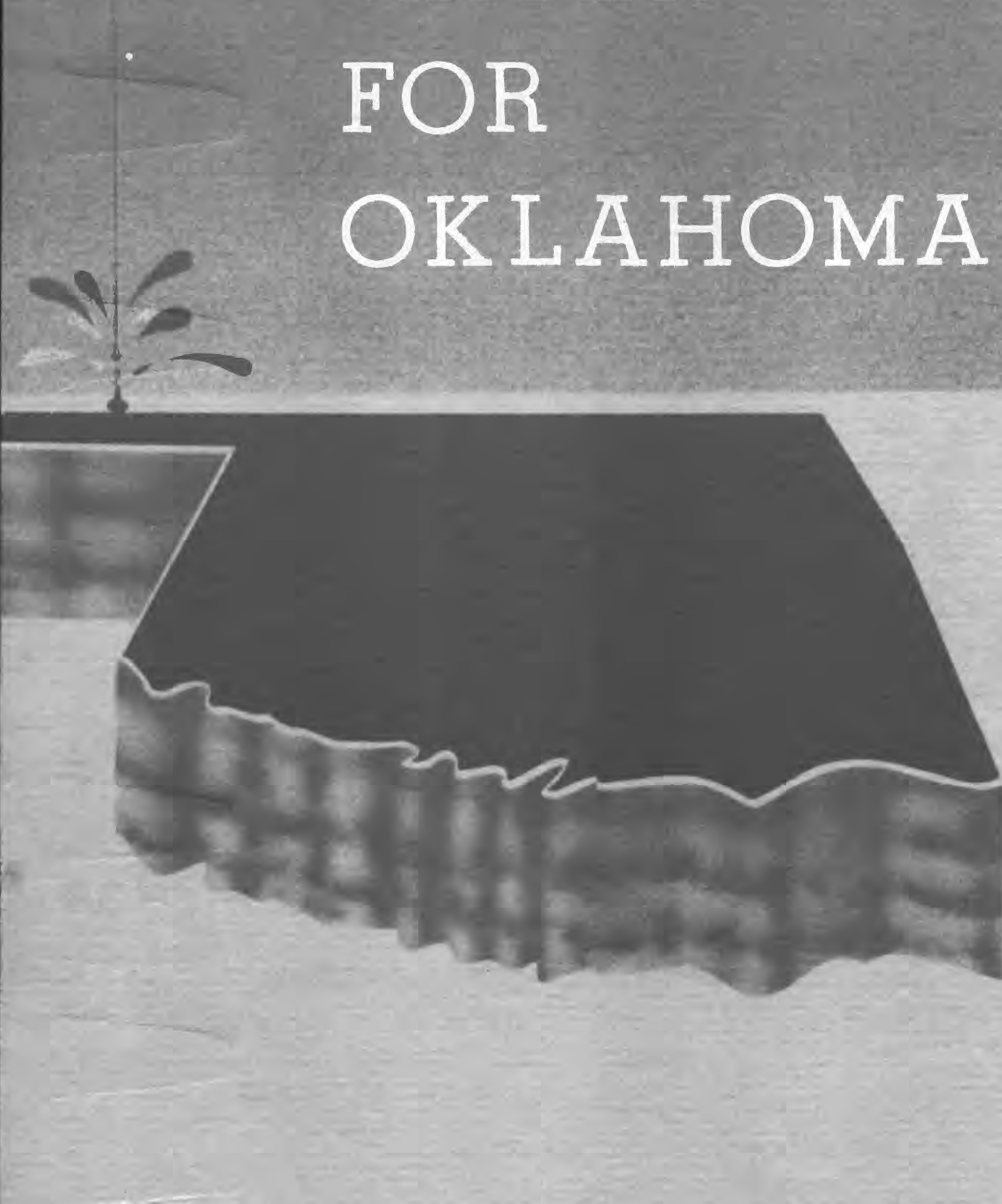
WATER FOR OKLAHOMA



GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1890

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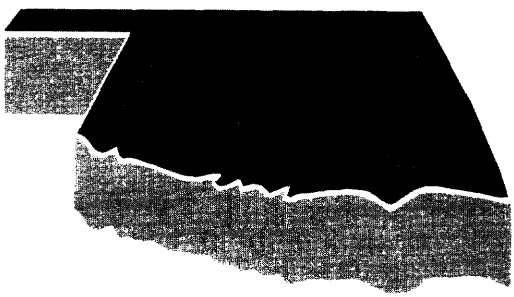
By T. B. DOVER, A. R. LEONARD, and L. L. LAINE



GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1890

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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WATER FOR OKLAHOMA

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INTRODUCTION

WE USE ONE PENNY OF THE WATER DOLLAR

Let's talk about water for Oklahoma as if it were dollars—dollars from two sources: precipitation in the State and inflow from adjoining States. Oklahomans use only about a penny of each of their water dollars. Some of the 99 cents evaporates and the rest flows out of the State toward the sea. Man can change nature's water distribution very little, but Oklahomans (with proper conservation and storage) might be able to use two pennies or more of each water dollar. Water income is unpredictable—sometimes it comes in floods and at other times it nearly ceases. Prudence dictates storage of this income so that all outgo—for agriculture, industry, or cities—may be covered.

The greater the distance water travels in streams or through the earth and the more it is reused, the more dissolved minerals it picks up. In other words, the chemical quality of water deteriorates with time, with distance, and with use. However, research, conservation, and good sense can help to protect the water currency from depreciation. With better understanding we may even improve its quality so that the water can be used again and again.

Water development has come a long way since Oklahoma attained statehood in 1907. Water then was little used by man except for the most essential purposes of daily living. Now, about 60 years later, we pump large amounts of water from underground reservoirs in the west for irrigation, we tap great surface supplies in the east for industrial expansion, and we compete so strongly for water in places that some cities reach out more than 100 miles for water. Our developing economy challenges us to use water still more efficiently, and our economic as well as our physical well-being depends on how wisely we plan for its use during the coming decades.

WATER HERITAGE FROM THE PAST

A long time ago water covered Oklahoma. Several times in the geologic past, long before man arrived on the scene, what is now Oklahoma and its neighbor States was under shallow seas; at times, parts of Oklahoma were deltaic and had a tropical climate and swamps and lush vegetation. Millions of years later the swamps dried up, the climate cooled, and modern vegetation took over. The events during the long periods of geologic time established conditions that still control the extent and character of our water supply.

The formation of modern ground-water basins and surface-water drainage boundaries began after internal forces of the earth had tilted and folded the outer layers. A slab of rock will bend when force is applied, if the confining pressure is great enough to prevent shattering. Such bending occurred when granite, limestone, and other rocks were uplifted, folded, and tilted to form the Arbuckle Mountains in south-central Oklahoma. Some beds of rock in that area and in the Ouachita and Wichita Mountains now stand almost vertically.

After the early mountains formed, streams flowing down their slopes carried off weathered rock material and deposited it as clay, sand, and other sediments in nearby shallow seas and lagoons. Much later the seas withdrew, but even after long periods of erosion some of the deposits remain at places. Porous layers in these beds contain water and are called aquifers or ground-water reservoirs (fig. 1). Dense, impervious rock layers underlie the aquifers, so the underground situation is analogous to a wet sponge on a tile floor. The red beds of central and western Oklahoma contain important aquifers, such as sand layers, which form the ground-water reservoirs in the Oklahoma City-Norman area, the Caddo County area, and the Elk City area. These beds consist of an assortment of layers of shale and of fine-grained

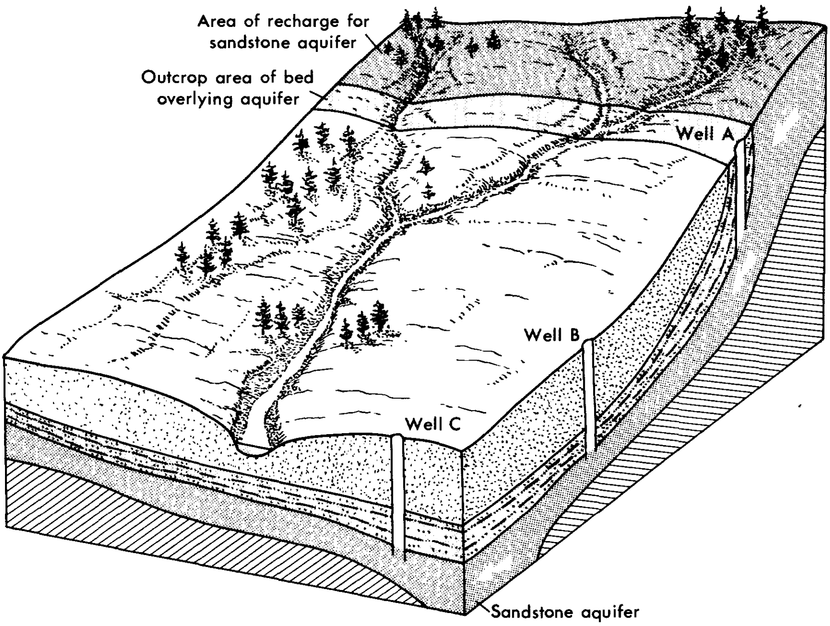

FIGURE 1.—Water-bearing layer or aquifer, underground and at earth's surface.

sandstone and a few layers of gypsum that are characteristically reddish.

The surface-stream patterns were changed several times during later periods of alternating uplift or depression below sea level. As a result more sediments which became locally important aquifers were deposited. Some of these are quite extensive, such as the sand beds that form a ground-water reservoir 20 miles wide, extending 150 miles from Love to McCurtain Counties in southeastern Oklahoma.

During the gradual uplift of the State from beneath the sea to its present midcontinent position, nature was being especially kind to future residents of the Oklahoma Panhandle. After the Rocky Mountains were raised, a series of southeastward-flowing streams carried large masses of sand and gravel from the mountain slopes—to be deposited in a broad blanket forming the present High Plains. This sand and gravel forms the highly productive ground-water reservoir that serves the panhandle and the northwestern part of Oklahoma today.

As a result of the continual uplift followed by deposition of weathered rock, water flowing over the earth's crust carved out the present-day drainage network—an intricate water-highway system providing direct and indirect routes of travel for water in its movement back toward the sea. As this drainage system developed, rivers shifted their courses and deepened their valleys, and some left behind great masses of sand and gravel to provide still another type of ground-water reservoir for Oklahoma. These masses of sand and gravel are the terrace deposits which occupy elevated positions along present-day stream valleys. They are the source of large supplies of irrigation water of excellent quality in places such as Tillman and Beckham Counties in southwestern Oklahoma, and they provide municipal water of good quality for cities such as Enid and Watonga in north- and west-central Oklahoma.

Not all the water heritage of the past is a blessing to modern water development. A modern problem of chemical pollution had its roots millions of years ago. Along the margins of the sea as it retreated, sea water was trapped in depressions, and evaporation caused salt and gypsum to be precipitated from it. Now, millions of years later, these deposits of salt and gypsum are near the surface in part of western Oklahoma. The water in surface streams which drain this area is too salty to use. A heavy salt load is picked up by the Cimarron and Salt Fork Arkansas Rivers as they flow through natural salt plains near Freedom and Cherokee. The salt water trapped in sands tapped by oil wells is brought to the surface at many places in the State. In several areas the salt water pumped from oil wells pollutes fresh-water streams and shallow ground-water reservoirs. In 1956 about 26 million barrels of oil-field brine that was dumped into Little River in the vicinity of Seminole County made the river at times more salty than the sea.

WATER OF THE PRESENT

Water often moves readily from a ground-water reservoir into a stream channel, and water flowing in streams often seeps into porous beds or banks. Water is exchanged in this manner especially along major stream valleys where flood plains are underlain by thick masses of loose sand, gravel, and silt (called "alluvium"). The ground water moves slowly, and during the long contact with rocks and soils it usually accumulates high concentrations of dissolved minerals. For instance, the water El Reno gets from the alluvium of the North Canadian River is about twice as hard as the river water which supplies Oklahoma City.

The character of the land determines what part of the rainfall will move underground, flow away in surface streams, or stand in lakes. If the surface is nearly flat and the soil is porous, most of the precipitation will quickly soak into the ground. Such movement occurs in the sand hills of north-central Woodward County where rainfall is absorbed so quickly that large areas have no well-developed system of surface drainage. On steeply sloping land with tight soil and dense bedrock, most of the rainfall flows away rapidly to the streams which become dry between rains. This pattern is illustrated by the Kiamichi River which drains the Ouachita Mountains in southeastern Oklahoma. The stream ceases flowing during many summers even though it drains part of the highest rainfall belt in the State. Some streams always flow because they are sustained in dry weather by ground water that seeps into the stream. The area from which the ground water comes may be larger than the area from which surface runoff comes to the stream. For example, in the Oklahoma City area, part of the precipitation falling on the Cimarron River drainage basin seeps underground, moves southward, and supplements the water in the North Canadian River basin (fig. 2, next page).

Oklahoma is a land of contrasts and its water features are equally varied. This area of 69,919 square miles extends about 500 miles from east to west and over several climatic zones. In the Ouachita Mountains of the southeast, annual rainfall averages more than 50 inches, and sharp ridges covered by pine and hardwood forests are separated by the deep narrow valleys of tumbling mountain streams. In contrast, the High Plains 500 miles to the northwest has little relief, no trees, and only about 16 inches of precipitation annually. In

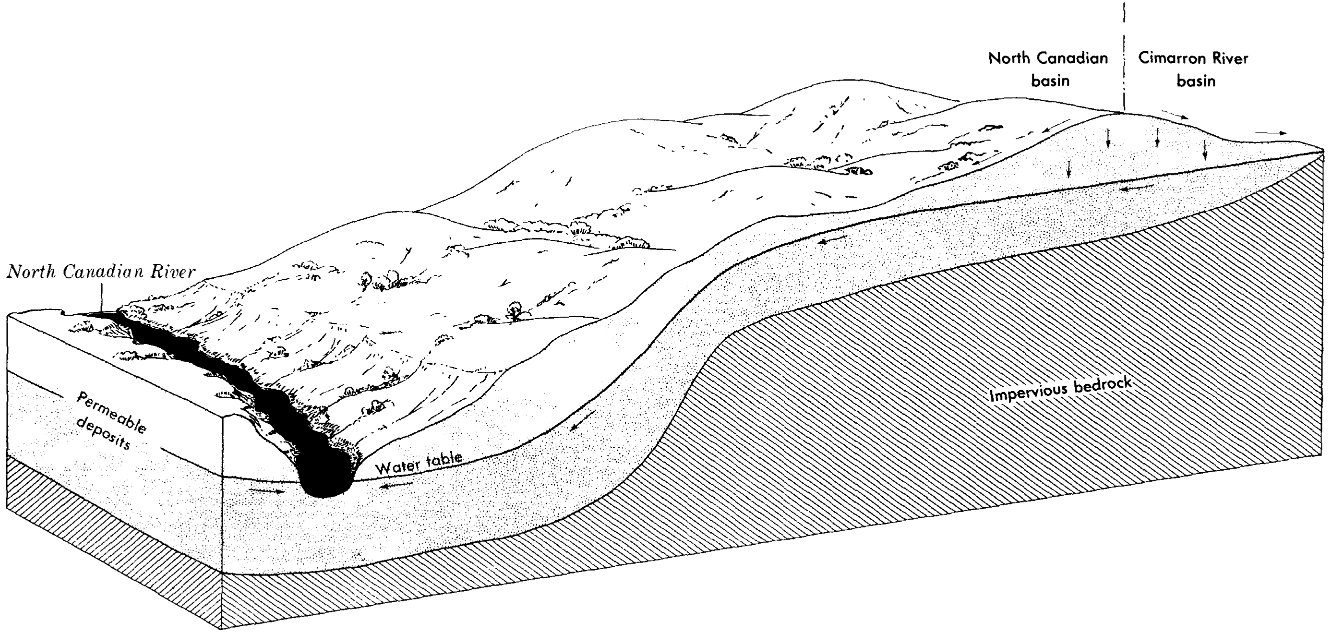

FIGURE 2.—Ground water sometimes moves across stream-basin divides. The boundaries of a ground-water basin do not always coincide with the boundaries of overlying surface-drainage basins. Surface runoff near Oklahoma City follows the slope of the land toward the North Canadian or the Cimarron River. Ground water, however, follows the slope of the water table, and south of Lake Hefner ground water in the Cimarron basin is moving toward the North Canadian River.

the broad, gently rolling region between these two extremes are the State's principal cities, most of the oil fields, and a large part of the wheat, cotton, and peanut land.

Will Rogers, who lived near Claremore in eastern Oklahoma, once observed, "If you don't like our weather, just wait a minute." At almost any time of the year the wind may shift suddenly from a gentle breeze to a gale. A drop in temperature of 50° in a few hours or a blinding dust storm followed by an equally blinding rainstorm are not unusual events. During a storm in Oklahoma City on July 16, 1955, 2.4 inches of rain fell in 20 minutes. When President Eisenhower visited the State early in 1957, blowing dust nearly prevented landing of the Presidential plane, the Columbine. On his return visit the following November, the same area was so soggy the farmer trying to harvest his cotton and corn was knee deep in mud. During the intervening months so much rain had fallen that Lakes Hefner and Overholser could have been filled four times from the swollen North Canadian River.

Most of Oklahoma's water supply is brought by air currents from the Gulf of Mexico. The sun's heat vaporizes the water of the gulf, and winds carry the vapors landward to Oklahoma. Sometimes the moisture-laden winds pass over Oklahoma without giving up any rainfall, but usually they meet cooler air masses over the State and rise above them. The moisture in the gulf air then is cooled and condensed; it forms a cloud as it rises, and as the air is cooled further, rain falls. Sometimes strong updrafts raise the raindrops repeatedly to the cold regions of the upper air where hail forms. In the winter, moisture may fall through a layer of cold air to arrive as snow and sleet or to re-form as ice on the trees and streets.

Annual precipitation varies with geographic location and with distance from the gulf (fig. 3, next page). Southeastern Oklahoma, closest to the gulf, has an annual rainfall averaging 50 inches. The western panhandle, several hundred miles to the northwest, receives, in addition to gulf moisture, some rainfall from Pacific air which has traveled across Arizona, New Mexico, and north Texas. Even so, this area is relatively high and dry, and rainfall at Kenton averages only

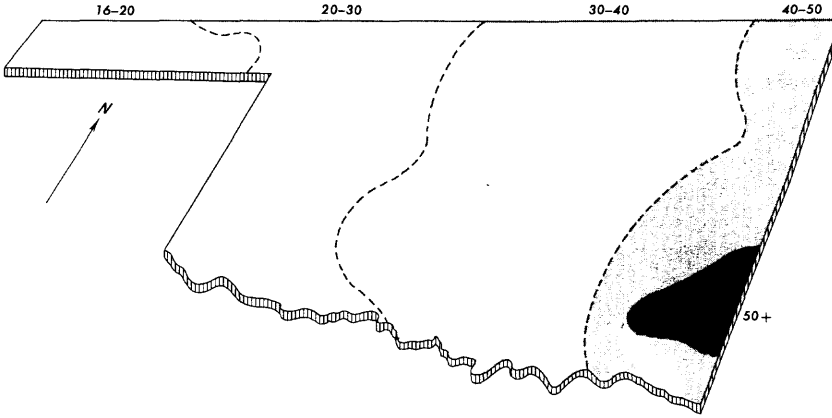

FIGURE 3.—Average annual rainfall in Oklahoma, which is a scanty 16 inches in the western panhandle, gradually increases across the State to about 30 inches in the central area and to 58 inches in parts of the well-watered southeastern area. If these variations were evened out, all parts of the State would receive an average of 33 inches annually.

16 inches annually. The weather conditions in Oklahoma are so variable that rainfall averages are misleading. The long-term annual average is 47 inches at Hugo in the southeast, but actual annual rainfall has ranged from 27 inches in 1956 to 75 inches in 1957; the annual rainfall at Kenton has ranged from 9 inches in 1935 to 37 inches in 1941; and the annual average of 33 inches for the State is based on a range from 20 inches in 1910 to 48 inches in 1908. Even the rainfall extremes are poor measures of water supply because a large percentage of the annual rainfall may come from torrential downpours, which produce very little usable water. In 1956, Vinson, in southwestern Oklahoma, had 18½ inches of rain, of which 65 percent fell during 8 days in May. Twenty inches of annual rainfall does not yield the same amount of usable water in different years or at different places.

The Federal income tax rate may seem high, but it is low compared to that levied on an Oklahoma water dollar by evaporation. The sun's heat that brings water to Oklahoma from the gulf also takes water away by evaporation. Any housewife who hangs laundry out to dry is aware of the wide variations in seasonal evaporation rates. Drying time for the family wash ranges from a few minutes on hot windy days to several hours on calm, cool and humid days. When clothes dry rapidly, other water also is lost rapidly. Many good clothes-drying days in Oklahoma show why the State's evaporation loss—about 85 percent of annual rainfall—is higher than the national average of 72 percent. The Oklahoma average annual rainfall of 33 inches provides 40 thousand billion gallons of water, of which about 34 thousand billion gallons evaporates. Thus, Oklahoma has an annual average of 6 thousand billion gallons, or roughly 17 bgd (billion gallons per day), of potentially manageable water, which represents 15 cents of the original water dollar.

WATER USE IS INCREASING

Withdrawals of water in Oklahoma in 1965 averaged about 1¼ bgd. About two-thirds of this was surface water and one-third ground water. The part of the State west of Oklahoma City is the principal user of ground water, and the eastern half of the State uses mostly surface water.

Some estimates indicate that the 1965 water use in Oklahoma may well double within 20 years. This estimate is plausible when the tremendous increase in water use during the previous 20 years is considered. Use of water for irrigation has increased from about 3 million to 450 million gallons a day in the 20 years prior to 1965. Municipal use has increased from about 100 to 230 mgd (million gallons a day), and industrial use has increased from less than 30 to about 550 mgd. An additional 50 mgd for rural use, not including irrigation, makes the present total water use more than a billion gallons a day, as compared to a fourth of this amount 20 years ago. Irrigation is increasing year by year, urban population continues to show an upward trend, and new industries continue to move into the State. A water requirement of 2 bgd within the next 20 years seems likely. The supply must meet this demand if the State is to continue to grow and prosper.

Concern about supplying water needs of 2 bgd from the potential supply of 17 bgd may seem foolish, but the problems involved will require carefully planned solutions if as much as 12 percent of the available supply, that is, 2 cents of our original water dollar, is to be used.

OKLAHOMA'S WATER IS NOT DISTRIBUTED EVENLY

Half the 17-bgd average precipitation falls on 17 percent of the State where only 12 percent of the people live. A look at the statewide surface-runoff pattern (fig. 4) shows the variations in the distribution of the runoff. Runoff in inches is the depth to which an area would be covered if all the water draining from it in a given period were uniformly spread over its surface. The average annual rainfall of 18 inches in the northwestern part of the State contributes an average annual runoff of 0.25 inch, whereas the average of 50 inches in the southeast contributes an average annual runoff of 20 inches—less than three times as much rainfall but 80 times as much runoff. We have many chances to use the 0.25 inch of runoff from the northwest as it flows across the entire width of Oklahoma, but only a momentary chance to use the 20 inches in the southeast before it flows out of the State.

Water use varies with time, and the demand is considerably greater in some seasons than in others. Industrial users of water are fairly consistent in their demands throughout the year, but municipal and irrigation users are not. Practically all the irrigation water is used during the summer growing season, a time when municipal demands for water also are at their peak. Oklahoma City uses more than 75 mgd at times during the summer, but less than one-third this amount during the winter. The billion gallons a day used in the State in 1965 is actually about 0.7 bgd during the winter and a maximum of about 2 bgd during the summer. If these amounts are doubled in 20 years, we must be prepared to utilize about 4 out of a possible 17 bgd for peak summer days.

The most important single factor affecting water-resources development is drought. The severity of recent droughts in 1952, 1954, 1956, and 1964 greatly affected public thinking about water. Some Oklahoma towns had to haul drinking water, and water rationing was more the rule than the exception. The Washita River east of Ardmore ceased to flow in 1956 for the first time in recorded history. Ground-water levels in the Caddo County area declined 7 feet between 1950

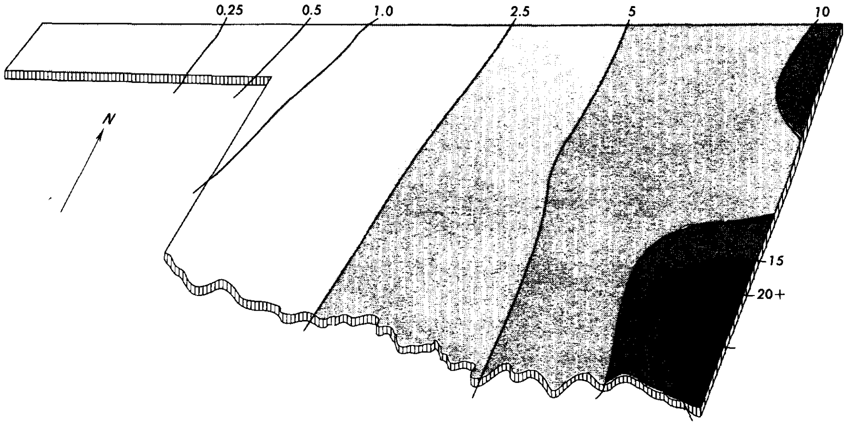

FIGURE 4.—Distribution of average annual surface runoff in Oklahoma. Surface runoff represents roughly that part of the total water budget available to Oklahoma for development and use. The average of 5 inches annually for the State as a whole produces an upper limit of 17 bgd, yet some areas of the State produce a very small part of this total. That part of Oklahoma lying in the 0.25-inch runoff belt contributes an average of only 40 mgd, but an equal-sized area in southeastern Oklahoma produces 3.2 bgd or 19 percent of the total.

and 1957. The lowest surface runoff during a 12-month period between 1951 and 1956 was less than 5 percent of the long-term averages at several places in the central and western parts of the State. Even in the relatively wet eastern parts of Oklahoma, runoff generally was less than 40 percent of average, and in the Bird Creek basin it was as low as 1 percent.

Drought is as inevitable as the night that follows the day, and science has not devised a means for predicting when it will occur. During 70 years of Oklahoma history, dry periods of about 11 years' duration alternated with wetter periods of about the same length. In each dry period we were caught with our water buckets empty. Water-resources planners might well adopt the Boy Scout motto: "Be Prepared."

PLANT LIFE DEMANDS ITS SHARE OF WATER

Before man begins control of water resources, he must recognize the water rights of other living organisms on this earth. The wheat and cotton, the pine and the pecan, all

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are worthy recipients of a fair share of the water dollar. However, the shallow underground water vaults sometimes are robbed by long-legged thieves such as the cottonwood, willow, and saltcedar. Roots of these trees reach down to the underground pools for moisture to be squandered into the atmosphere by their foliage (fig. 5). Many of Oklahoma's stream channels are lined with these thirsty plants. For example, cottonwood and willow trees lining the North Canadian River in Canadian County annually transpire more water than Oklahoma City uses from that stream.

The water demands of plant life vary widely. Requirements for the major money crops in Oklahoma range from 16 inches annually for grain and forage sorghums to 32 inches for irrigated alfalfa. Somewhat greater amounts of water probably are required for crops irrigated by the sprinkler systems in parts of western Oklahoma, because rates of evaporation from the spray and from the wetted surfaces of the plants are high.

Some plants, corn and grain sorghum, for instance, help to control and conserve water. The stalks and leaves absorb part of the impact of the falling raindrop, and the root systems help open the soil so that it will soak up more water and at the same time hold the soil together. The stalks and debris on the ground also help to slow down the runoff so that the soil will not be washed away and more water can soak into the ground. All these actions help to keep part of the water where it falls.

At times storm runoff exceeds the capacity of the stream channels, and then the lowlands are flooded. Water in this type of runoff cannot be effectively used. A flood flow commonly travels 25–50 miles in a day or less, and high flows may pass after a matter of hours in the smaller drainage basins. Storm water carries with it debris and sediment washed loose by rainfall impact and water erosion. In the streams these loose materials are carried along in suspension as fine particles or along the bottom as bouncing rocks and shifting sands. Sediment loads are greatest in western Oklahoma where the flood waters are colored red by clay from the red beds throughout the area. The washing of the fields and the caving of the streambanks combine to furnish tremendous

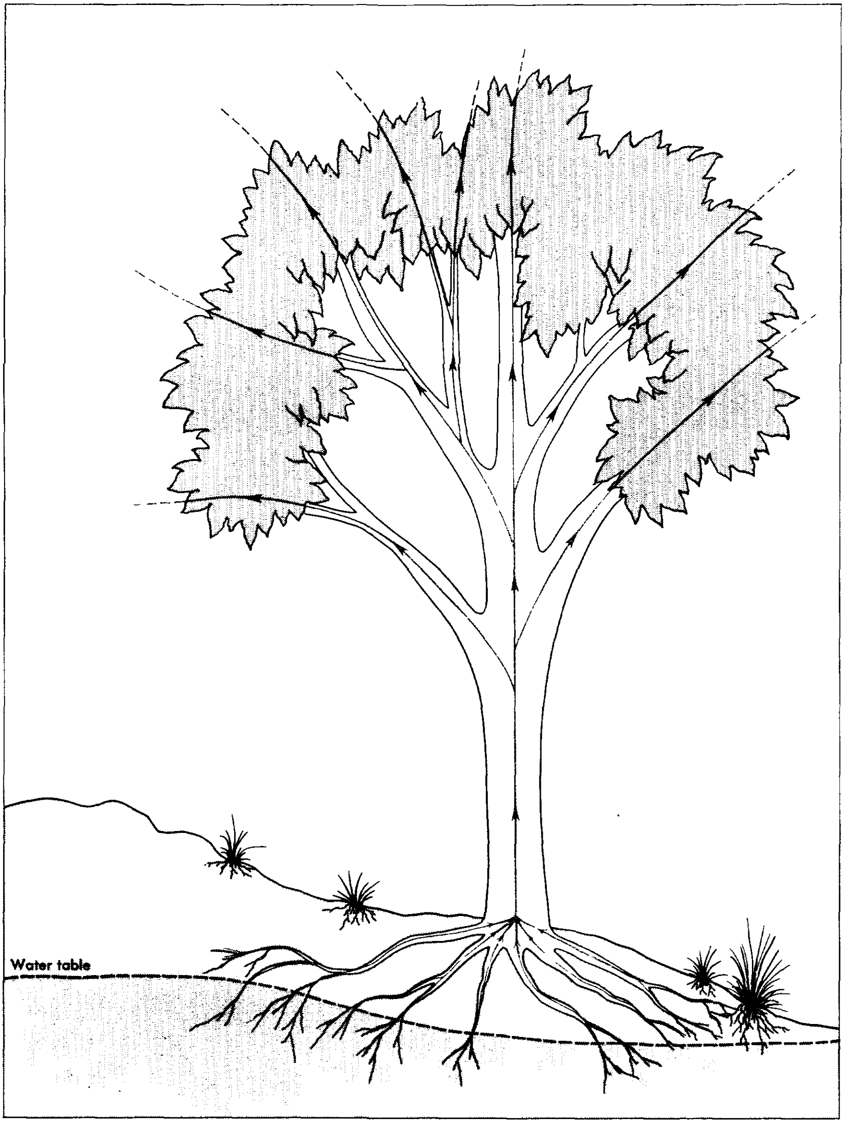


FIGURE 5.—Use of water by plant life. Certain trees and other plants habitually send their roots down to the water table and "pump" large quantities of water. This water moves upward through the trunks or stems and is dissipated into the atmosphere through the leaves as water vapor. More water in Oklahoma is consumed by such vegetation than by man for all his activities.

quantities of silt to the stream. The Washita River at Carnegie carried 257,000 tons of silt on May 18, 1949—enough to cover two lanes of U.S. Highway 66 with a foot of dirt from Oklahoma City to Weatherford, 70 miles away.

LAND FEATURES AFFECT WATER SUPPLY

The immediate surface runoff from a moderate storm usually is the smaller part of the total precipitation. A large part of the water is caught by the leaves of trees and plants, stored in minor depressions on the land surface, absorbed in the pores of the soil, and evaporated or filtered downward to natural reservoirs beneath the ground surface. Only the rainfall in excess of these amounts appears as storm runoff in the surface streams. Even in the mountainous basin of Mountain Fork in southeastern Oklahoma the runoff is only 48 percent of the annual precipitation. In areas of porous soils most favorable to infiltration there may be little runoff, and more than 20 percent of the rainfall may find its way downward to ground-water reservoirs. In areas where conditions are favorable, this natural process may be used to increase ground-water replenishment artificially. Ground-water reservoirs have been successfully replenished elsewhere by spreading water on porous sand and gravel beds, through specially constructed wells or pits and through small reservoirs specifically designed and properly located to increase infiltration.

Soils and rocks provide the honeycomb or framework to hold the ground water. All rocks are soluble in water to varying degrees. Limestone beds in some parts of eastern Oklahoma have been decayed by water corrosion, and they contain interconnected passageways for the free flow of underground water. Most of the springs that mark the Ozark region of northeastern Oklahoma come from such passageways. Less soluble rocks decompose very slowly but still provide some dissolved mineral content to water. Some minerals in water are desirable because "pure" distilled water has a flat taste and is highly corrosive to hot-water pipes, but sometimes the rocks provide too many minerals, and excess quantities result in a water that is undesirable or unacceptable. For instance, sulfurous ground water at the town of

Sulphur is suitable only for "medicinal purposes." Gypsum or calcium and magnesium sulfate waters, characteristic of ground water in Harmon County, have an objectionable bitter taste, although these same minerals are desirable in an irrigation water.

MAN MUST DO HIS PART TO CONTROL WATER

Water serves a complex role in modern life. Everybody and everything is affected to a degree by some of the many aspects of water use or control (fig. 6). If we are to obtain the few pennies of the potential water dollar needed for future growth, several conditions must be met at some point between the falling of the raindrop and its departure eastward from Oklahoma into Arkansas and Louisiana. The right kind of water must be caught where it will do the most good, and good water-banking practices must be followed to

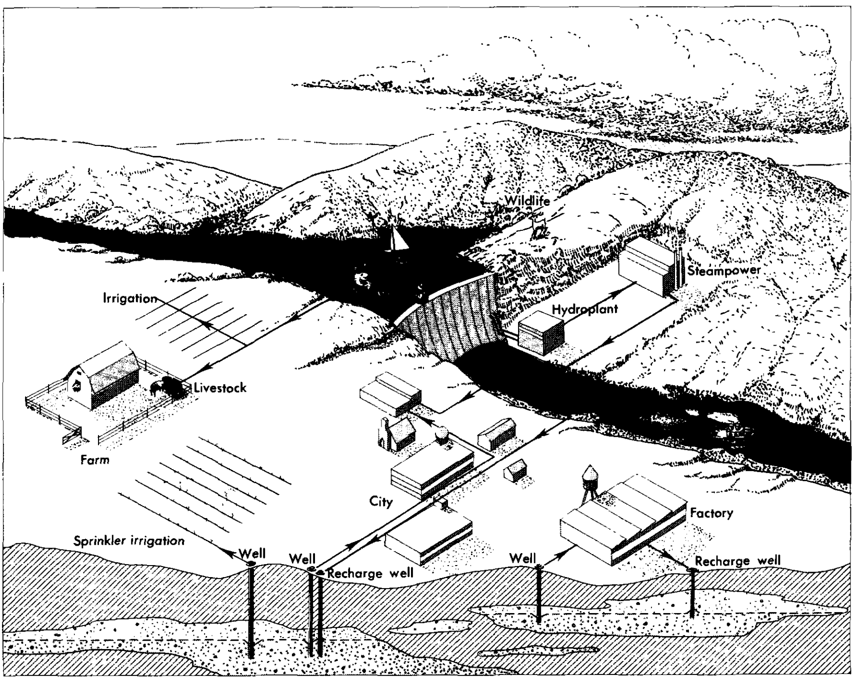


FIGURE 6.—Complex role of water. The falling raindrop will serve many water users as it flows underground or through lake impoundments and down river channels toward the sea. Many detours are made through the farm, city, and factory in an attempt to satisfy all of man's water needs.

save a proper share for the lean months and years of low water income. The industrial expansion centered around Pryor is a prime example of the rewards of meeting these complex water requirements.

To provide water for his own use, man must prevent flood damage and at the same time save the flow for future use. He can construct dams to hold back the excess surface flows, or he can devise methods for getting a larger part of the rainfall into ground-water reservoirs, or he can use a combination of these methods of storing water. Each method offers advantages and disadvantages as applied specifically to Oklahoma. We cannot catch the water at the right place by exclusive use of either method—we must use a combination of the two as determined by local geology and topography.

In planning reservoirs for water-resources development, which is most effective, a large or a small one? Oklahoma provides a natural setting for a clash of opinion in this matter. The people who live on the slopes of the valley or along the small creeks will derive most benefit from small upstream reservoirs, whereas those who live on the river flood plain must rely on large dams for flood protection. The topography of Oklahoma is such that structures of both types are necessary for the control and utilization of excess waters. Control of all floods in all areas by a comprehensive system of small reservoirs is physically impossible, and, even if possible, would not serve the best economic interests of the State. Such a system would not hold the water at the right place or in sufficient quantity for the beneficial uses—power development, navigation, large-scale recreational areas, supplies for larger cities, irrigation and industry. On the other hand, small reservoirs do store water in the upstream areas where man can use it for irrigation, recreation, and agriculture. A system of large reservoirs would not store the water where it is most needed for these purposes. To supply water of the right kind at all the right places, we need close cooperation between the upstream and downstream developers and users of Oklahoma's water resources.

To provide a continuously sufficient and dependable supply of water, major reservoirs must store enough to withstand the drain of 3–5 years' drought. Such large structures

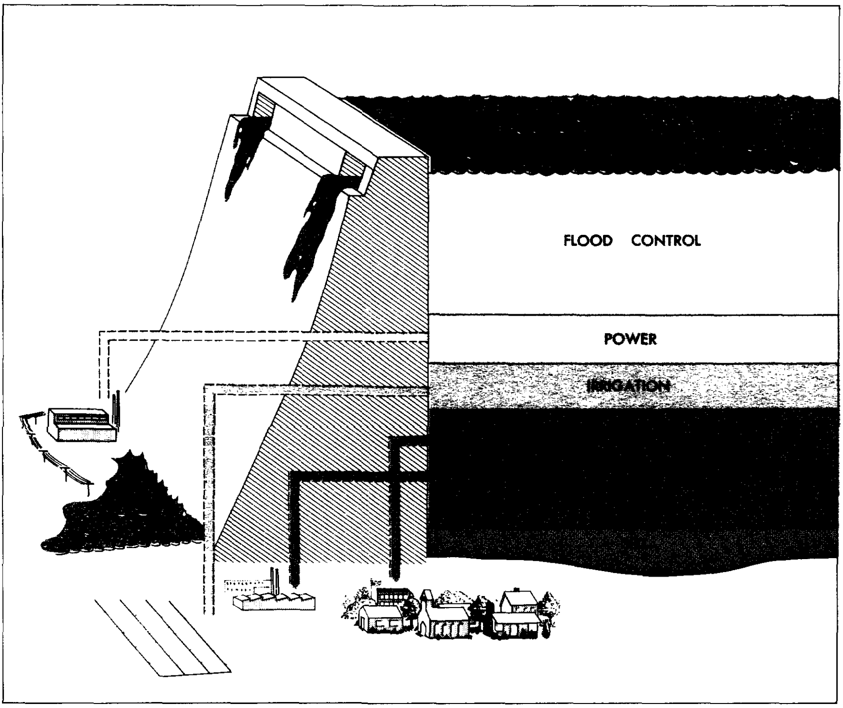


FIGURE 7.—Features and typical storage allocations considered in the design of multipurpose reservoirs in Oklahoma. Examples are Lake Fort Gibson, which includes all the features shown except irrigation, and Lake Altus, which includes all the features shown except power. All major reservoirs in the State include at least two of the features shown.

may be justified economically only by considering benefits of several kinds (fig. 7). Charges for allotments from the conservation pool of a reservoir for irrigation, municipal, and industrial water supply and for recreation can pay a part of the costs of a reservoir that would otherwise be used for flood control alone. Most large reservoirs in Oklahoma have been designed as multipurpose projects. Small upstream flood-control structures normally do not include a conservation pool. From a practical standpoint, however, the storage space set aside for trapping sediment provides a source of water for many years to the adjacent landowners.

Large evaporation losses are a price we must pay for the benefits derived from surface storage of water. For example, more water is lost through evaporation from Lake Hefner than is used from that source by Oklahoma City. Man is striving to develop methods to control to some extent the evaporation from reservoirs. A method tried experimentally during the summer of 1958 on Lake Hefner involved the application of hexadecanol, a colorless, odorless, and tasteless chemical which disperses to form an extremely thin film over the water surface and suppresses evaporation. Laboratory experiments with this material have shown reductions in evaporation of as much as 60 percent. If such savings are possible on a large scale, the usable water stored in a reservoir would almost double for a given investment.

Underground storage can solve part of the surface-water evaporation problem. If effective impoundments could be built over ground-water recharge areas so that lakes would drain out of the bottom, we would have a guaranteed savings plan for part of the water dollar. Damsites in such areas are scarce in Oklahoma, and the settling of fine sediments in a reservoir tends to seal off the bottom of the lake and prevent recharge to the underlying reservoir. Probably the most effective method of artificial recharge is through wells or pits using water from which the sediment has been removed (fig. 8).

Regardless of the type of storage used for saving part of the water dollar, the quality of the water must be guarded closely. Looks can be deceptive in selecting the kind of water to be saved because all that glitters is not necessarily good water! The unseen attributes are what count. Basically, water is a colorless, odorless liquid formed by the chemical union of hydrogen and oxygen, H_2O. When it falls to the earth as a raindrop, it contains some dust particles and some gases absorbed from the atmosphere, but for all practical purposes it is in its almost-pure basic form.

The almost-pure raindrop rapidly acquires additional minerals after it reaches the ground. Its powerful solvent action goes to work immediately to dissolve minerals from the soils and rocks. The amounts and kinds of these minerals depend on the types available and the duration of contact. The solvent power of water allows it to absorb readily the highly mineralized oil-field wastes, industrial-process wastes, municipal sewage, mine drainage, and return flow from irri-

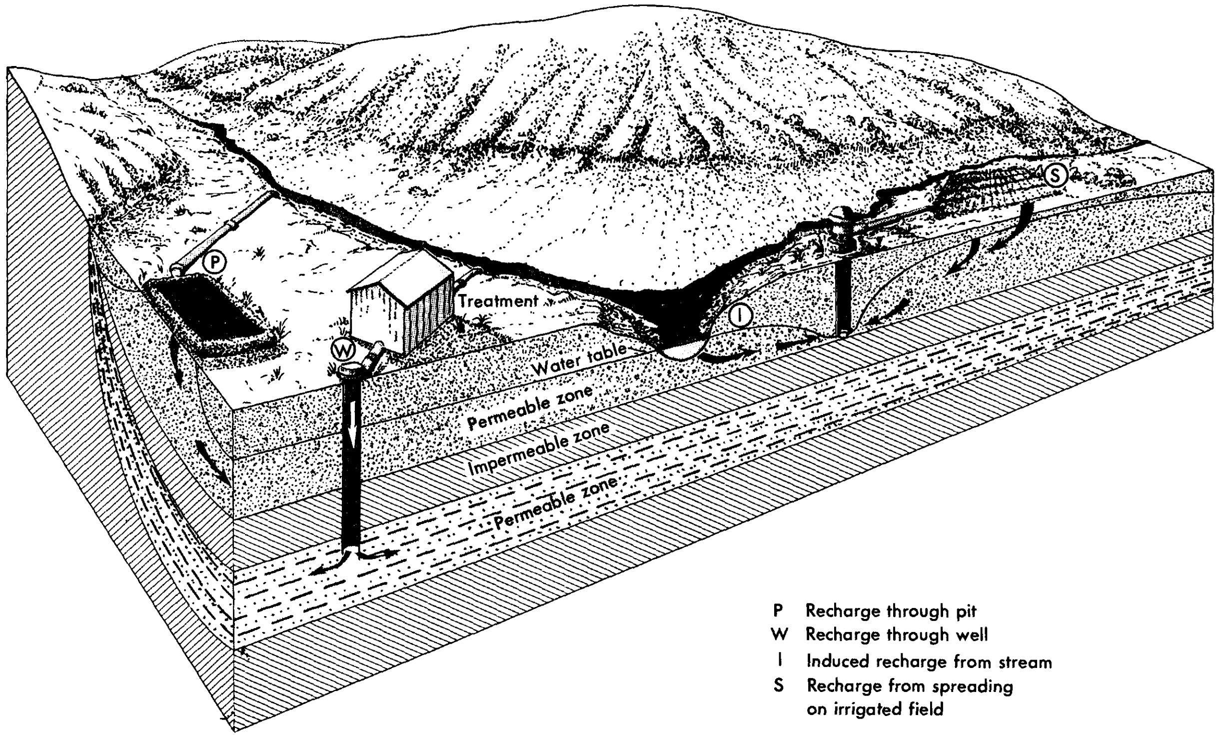


FIGURE 8.—Artificial recharge.

gation. After contact with this wide variety of conditions, water may look the same as the raindrop; that is, clear and colorless, but the resemblance ends there. It will have acquired unseen minerals that in part determine its usefulness to man. Every user of water has limitations with regard to the amount of minerals that can be permitted in the water he uses. Some minerals are beneficial to one user and detrimental to others, some are beneficial in limited amounts but harmful at higher concentrations. In cooperation with the State of Oklahoma, the U.S. Geological Survey keeps close watch on the quality of surface and ground water, and its records are available to industry and to the public.

WATER SERVES MANY MASTERS

Water requirements in Oklahoma would exceed the supply if each user "used up," or consumed, his share of the water. Because most of the use is nonconsumptive, the water is returned to the streams and is thus made available for re-use again and again. The development of any natural resource, including water, sometimes benefits only a few people if the user of that resource disregards consideration of others or of the future. As in other areas of the United States, some of Oklahoma's streams have been subject to pollution—by waste disposal from mine waters in the northeast and by oil-field brines, municipal sewage, industrial wastes, and irrigation return flow in many areas. The minerals from these wastes are added to those in the stream, and if the water is already at the borderline of suitability for certain uses, an otherwise insignificant new contribution may make the water unfit for downstream users. Each user, therefore, must protect and preserve the quality for the next man on the water line.

Water-treatment processes can change some of the acquired qualities of water by adding certain harmless chemicals to replace or kill the unwanted ones. Hardness of water may be reduced by treatment at the water plant or even in the home through use of individual softening units. This treatment is becoming increasingly less important to the individual user of water because of the widespread use of detergents in the laundry, kitchen, and even the bathroom.

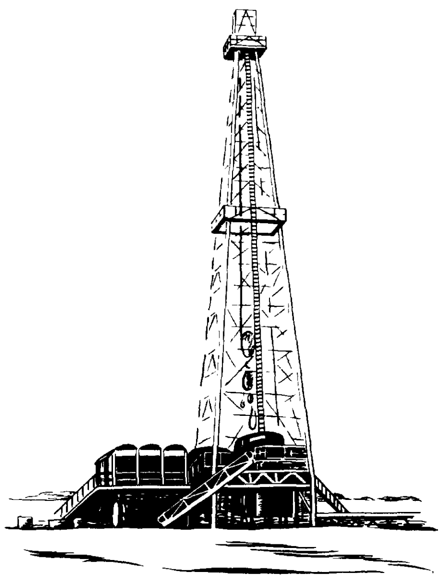
Muddiness can be eliminated at the treatment plant by use of agents such as alum to settle the suspended sediments. Just as we take antibiotics to kill certain germs in our bodies, a small amount of chlorine is administered to water at the treatment plant to kill any harmful bacteria present. We sometimes forget that this small precaution has all but eliminated the water-borne diseases of cholera and typhoid.

Considerable research is being done on the conversion of sea water and other highly mineralized waters for municipal, industrial, and irrigation uses. The cost of commercial treatment of large quantities of water should not be more than about 20 cents a thousand gallons to be economically feasible for municipal use in Oklahoma and not more than about 5 cents per thousand for irrigation use. No method has been devised thus far to produce large quantities of usable water from highly mineralized water at these prices. Successful results of this research would provide a means of utilizing much of Oklahoma's water that is naturally salty or contaminated by gypsum salts and oil-field brines.

One problem in the use and re-use of water is that too many users may be located at one site. The development of surface water by multipurpose reservoirs often leads to problems of distribution and conflicting interest. A reservoir designed primarily for flood control or power may become popular as a resort area. The level of water in a flood-control reservoir necessarily fluctuates. It must be low in those seasons of the year when floods are likely, in order to leave room for the extra water brought by a flood. It is difficult (though not impossible) to maintain boats and docks where the water level changes radically. People then agitate for stabilization of the pool elevation, a condition completely opposed to either power or flood-control uses. During recent years, recreation interests in the Grand Lake area (Lake O' the Cherokees; see p. 72) have recommended raising the minimum power-pool level. This action would benefit recreation but deprive power generation of water set aside for that use. Recreation developments sometimes encroach on the flood pool of the large reservoirs, and then the big flood comes along to cause extensive damage. Many cabins and recreational facilities in the Lake Texoma area were damaged when it was necessary to utilize the full extent of flood storage during the spring of 1957.

Even such simple things as deepening a stream channel to provide for storm runoff or the drainage of water-logged land may result in unexpected conflicts over water use. Such activities have been known to lower the underground water table and greatly reduce yields from wells on which individuals or cities depend for a water supply. The municipal water supply for Purcell in McClain County was formerly obtained from seven wells in the alluvium of Walnut Creek south of the city, but ditching by farmers in the valley to improve drainage of bottom lands lowered the water table, which in turn so reduced the yields of the wells that they could no longer supply the city's needs.

After the use and re-use of water in Oklahoma, it then is used in Arkansas and Louisiana. Just as the upstream States have a responsibility to furnish water of certain quantities and suitable qualities to Oklahoma, we have the same obligation to our eastern neighbors in adjoining States. Negotiations are underway to legalize these moral obligations into written compact agreements between the States.



WATER RESOURCES OF THE HIGH PLAINS

A BILLION-DOLLAR BANK ACCOUNT FOR THE HIGH PLAINS

Two million years ago, what is now the most arid part of Oklahoma was a broad plain marked with sluggish streams, dotted with marshes, and populated by herds of horses, zebras, camels, giant turtles, and rhinoceroses. The surface streams then flowing southeastward from the Rocky Mountains eventually buried the existing topography beneath a broad, thick layer of mud, sand, and gravel. The deeper valleys were covered with as much as 600 feet of this material. During the last million years the climate of the region has become progressively drier, an eastward-flowing stream system has developed, and erosion of adjacent areas has left the eastward-tilted plateau of the present (fig. 9, next page).

The change from conditions of two million years ago to a climate having the lowest rainfall in Oklahoma did not result in a lack of water. Nature provided a compensation through the tremendous underground water supply available to the area today. It is difficult to estimate the value of this underground water, but a conservative figure might be $30 a million gallons. At that rate, water available in the High Plains reservoir would be worth a billion dollars or more.

The Oklahoma part of this underground reservoir extends over all the panhandle except the northwest corner of Cimarron County, northeastern Beaver County, and a small area along the North Canadian River in southeastern Texas County and across Beaver County. It takes in most of Ellis County and parts of Woodward, Harper, and Roger Mills Counties. Most of the deposit ranges from about 100 to 300 feet in thickness, but in the northern part of Texas County it is as thick as 600 feet. This underground reservoir is only partly filled with water, and the saturated thickness generally averages about 150 feet. Where the deposits are thin,

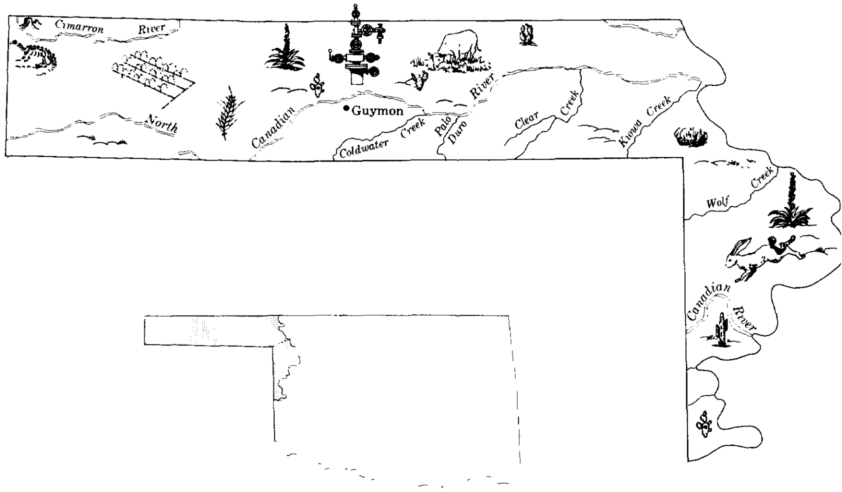


FIGURE 9.—Features of the High Plains.

the water-containing part may be less than 50 feet, but it reaches a maximum of 440 feet in the thick sections of north-central Texas County. The depth to water averages about 150 feet but ranges from less than 50 feet adjacent to the major streams to more than 250 feet in northwestern Texas County and northeastern Cimarron County. Water yields from wells in these deposits reach more than 1,000 gpm (gallons per minute) in the areas of thicker and more permeable material.

The High Plains is really a plateau with an eastward slope of about 14 feet to the mile. The altitude at the western edge of the panhandle is 4,800 feet, and it decreases to 2,000 feet in the western part of Woodward County. If the rest of Oklahoma sloped at the same rate, the southeastern corner in McCurtain County would be about 3,600 feet under the sea. In spite of its steep slope, the surface of the High Plains has many depressions, ranging in size from a few acres to several square miles, that trap the rainfall. Other parts of the region are marked with dunes and shifting sands which catch the falling raindrop and allow rapid infiltration. The loss of water to these ground-water recharge areas and to the surface depressions is partly responsible for the small flow in the surface streams.

Normal precipitation in the High Plains ranges from 16 inches annually at the western edge to about 22 inches at the eastern edge. A large part comes in the form of spring thunderstorms, and each year there may be extended periods of little or no rainfall. The near-featureless land surface presents little barrier to wind movement, and dust storms are common. The wind movement in combination with low humidity and high summer temperature results in a very high evaporation rate of about 65 inches a year, about four times the average annual rainfall. Because of the high evaporation rate, the rainfall accumulating in the depressions and farm ponds represents a relatively low beneficial return from the total water income. Any large, shallow surface reservoir in the area would have the same or higher evaporation loss.

AGRICULTURE IS THE PRIMARY INDUSTRY

The High Plains is predominantly an agricultural region and the use of water centers around the demand for irrigation, municipal, domestic, and stock purposes. Irrigation is widespread in Oklahoma, but the major development is concentrated in the Goodwell area of south-central Texas County and in the southern and central parts of Cimarron County. A small amount of water is used in the production of gas and related products, but this use is small compared to agricultural uses. The 138,000 acres of land under irrigation in 1965 in the panhandle counties represented more than 33 percent of the total irrigated acreage for the 77 counties of Oklahoma. Principal irrigated crops are wheat and sorghum, but alfalfa, corn, and pasture are also irrigated.

Because of the relatively small flow of the surface streams, ground water constitutes 98 percent of all water used in the Oklahoma High Plains. Surface water is used mainly for stock ponds and for irrigation from small, temporary dams across streams in Cimarron and Beaver Counties. The availability of irrigation water and of fertile land suitable for the application of water has contributed to this intensified development, and the availability of natural gas as a cheap fuel has made economically possible the lifting of irrigation water from depths of 150 to 400 feet, even for the relatively low-value crops such as wheat.

TWO MAIN RIVER SYSTEMS CROSS THE REGION

The raindrop falling on the High Plains in Oklahoma follows one of two main routes of surface travel —the North Canadian River or the Cimarron River. The principal secondary and farm-to-market water routes connecting with the two main highways are Coldwater, Palo Duro, Kiowa, Clear, and Wolf Creeks. The High Plains constitutes 11 percent of the land area of Oklahoma, but the surface runoff from the region amounts to less than 1 percent of the total leaving the State at its eastern boundary. The combined average flows of the North Canadian and Cimarron Rivers at the eastern edge of the High Plains is less than 300,000 acre-feet a year, a drop in the bucket compared to the average 35 million acre-feet a year flowing out of Oklahoma.

In 1965, surface water supplied less than 2 percent of the irrigation water used in the Panhandle, but it was in considerable use before ground-water development started in 1915. Sixty years ago there were many small diversion dams on the North Canadian River between Guymon and Fort Supply. The remains of a prehistoric irrigation canal in northeast Beaver County near Gate indicate that the good-quality surface waters were utilized there long before the white man came to Oklahoma. The nearly perennial flow of the Cimarron River, maintained by springs and seeps from the huge ground-water reservoir, has been recognized since the days of the Sante Fe Trail. Because of its dependability, this stream served as a watering point northeast of Boise City. During the severe drought of 1956 when many of the State's streams were dry, the lowest daily flow in the Cimarron River at the eastern edge of the High Plains was 20 acre-feet.

Low yields of streams in the Panhandle coupled with the potentially high evaporation losses discourage any wide-scale development of surface waters there. Winter irrigation near Boise City makes use of the small flows available in the Cimarron River at that time. The development of the proposed Spurgeon Dam on this stream would stabilize flows for that area and provide water to irrigate an additional 3,000 acres. Also provided would be a recreation pool 7 miles long and three-quarters of a mile wide. Farther downstream at the eastern edge of the High Plains, the proposed Englewood Dam would provide irrigation water for more than 6,500 acres along the Cimarron River. The other major impoundment under consideration for the High Plains is at a site on the North Canadian River just below its junction with Coldwater Creek, to be known as the Optima Reservoir. This project has been authorized by Congress as a flood-control measure.

HIGH PLAINS DEPOSIT IS THE PRINCIPAL AQUIFER

The principal aquifer supplying ground water to the High Plains is the thick, widespread layer of sand and gravel known as the High Plains deposit. This vast underground reservoir supplies nearly all the ground water for irrigation and municipal water for the principal cities of Guymon, Goodwell, Boise City, and Arnett. Quality of water from the High Plains aquifer is uniformly good throughout the area. The water is of the calcium, magnesium bicarbonate type, having a total mineral content of about 400 ppm (parts per million), a hardness of about 280 ppm, and a low sodium content of less than 25 ppm. The water is excellent in quality for irrigation and agricultural uses, and it meets all standards for drinking water. For drinking purposes the water offers a bonus—a natural fluoride concentration of about 1.5 ppm—an attribute that most health officials consider to be beneficial to children's teeth during their formative stages.

Several minor aquifers supply small quantities of ground water in certain areas of the High Plains. The alluvial deposits of the North Canadian River, Cimarron River, Wolf Creek, and smaller streams supply the municipal systems of several towns, such as Beaver City, and furnish small quantities of water for domestic and stock use and irrigation. The yields from wells tapping these aquifers are quite erratic as is the water quality. Some of the sources, such as the one being tapped for the water supply of Beaver, have water similar in quality to that of the High Plains aquifer. In contrast, other alluvial sources, such as the one along Palo Duro Creek, contain highly mineralized water. Water in this aquifer has sulfate concentrations as high as 2,000 ppm and total mineral concentrations exceeding 3,000 ppm. The water from these minor aquifers has a relatively low percentage of sodium and is acceptable for irrigation on the sandy soils, but is of poor quality for domestic supplies.

The red beds supply some water for local use from the southeastern corner of Texas County south of the North Canadian River across Beaver County. This water generally is highly mineralized with excessive chloride and sulfate concentrations and is suitable only for livestock use. Several formations exposed along the Cimarron Valley of northwestern Cimarron County supply meager to moderate quantities of water. The quality of these water supplies is similar to that from the High Plains deposit. This area is sparsely populated, and the water supply is tapped mostly for domestic and stock use on isolated ranches.

MEETING FUTURE NEEDS

Future increased demands for water in the High Plains probably will continue to center around agriculture, and these demands will continue to be supplied from the High Plains aquifer. About 140,000 acres in the High Plains was under irrigation in 1965, and it has been estimated that the aquifer can safely supply water for at least twice this acreage. Recharge of only 1 inch annually over the High Plains region would supply water for 300,000 acres indefinitely. The use of water for irrigation has grown sporadically since World War II. The area being irrigated increased rapidly during the drought of the 1950's, levelled off during the relatively wet years of 1958–62, and is now (1965) increasing rapidly again. The present irrigation development has not caused the lowering of water levels, even in areas of concentrated pumping such as the one around Goodwell. However, in parts of the High Plains in Kansas and Texas pumping for irrigation exceeds the rate of replenishment, and there is danger that similar overdevelopment may occur in Oklahoma.

The ultimate water "crop" in the High Plains might be increased by recharging the ground-water reservoir artificially.

The surface waters that collect in natural depressions during wet seasons and the flood flows that are lost as runoff in the streams are two potential sources of this recharge water. Yields from the minor aquifers, particularly the alluvium, might be increased considerably by eliminating the cottonwood, willow, and saltcedar trees that line the valleys of streams such as Coldwater and Kiowa Creeks and the Cimarron and North Canadian Rivers.

WATER RESOURCES OF WESTERN OKLAHOMA

FERTILE PLAIN OR BURNING DESERT?

The agricultural lands of western Oklahoma (fig. 10) were long dormant until the region was opened to white settlers about 20 years before statehood. Various explorers described western Oklahoma as a fertile plain or a burning desert, depending upon whether they visited the area during a wet or a dry cycle. These extreme cycles average out to produce a semiarid climatic zone with rainfall ranging from 22 inches a year along the western edge to about 30 inches annually along the eastern edge. This region, long the home of the Indian and the buffalo, became the domain of the cowboy and the longhorn during Territorial days, and gradually developed into the predominantly agricultural land of today. The present-day cotton, wheat, and peanut land contains nearly 60 percent of the irrigated acreage of Oklahoma.

Much of western Oklahoma is underlain by red beds, layers of red shale and sandstone which produce its characteristic red soils. These beds lie at the surface or are buried to varying depths by stream-deposited materials. The shale beds are so dense they neither absorb nor release water readily. Yet they are easily eroded by wind and water to form spectacular erosional gullies and other forms of surface relief. On the other hand the sandstone beds in the central area are very porous. They absorb water readily and provide abundant yields of excellent quality to wells tapping them. The sandstone is poorly cemented and easily pulverized, and deep gullies have been cut in it to form unusual features such as Red Rock Canyon in north Caddo County and the high bluffs along Sugar Creek east of Binger. In other areas, thick layers of massive gypsum deposits form resistant caprocks that produce the whitetopped mounds, such as Glass Mountains near Fairview, and the badlands and prominent escarpments in southwestern Beckham County.

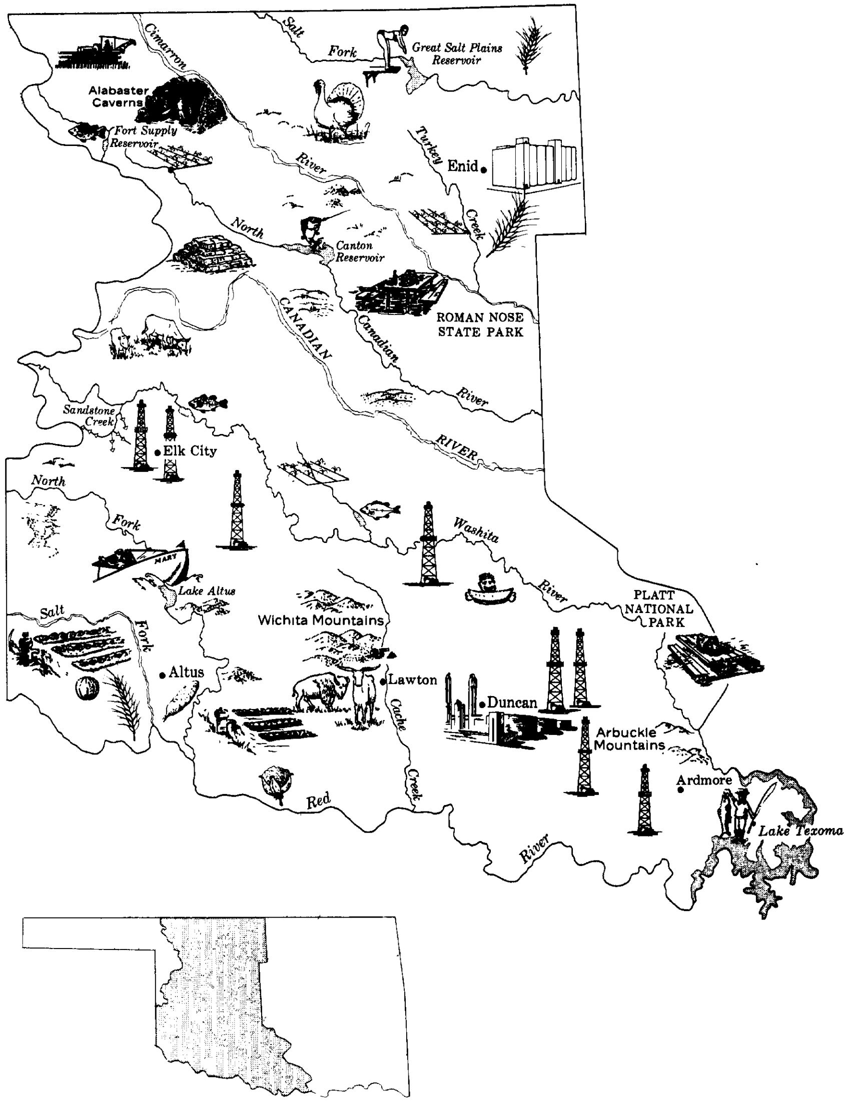


FIGURE 10.—Features of western Oklahoma.

The gypsum deposits form conspicuous features in some areas, although they are only a small part of the total red-bed sequence. The Alabaster Caverns near Freedom are caves or tunnels formed when water dissolved parts of these gypsum deposits long ago. In Roman Nose State Park near Watonga, water now issues as springs from similar solution openings in massive gypsum. Many other springs occur in southwestern Oklahoma, and tremendous quantities of irrigation water are pumped from caverns in the Hollis area.

The varied occurrences of ground water in western Oklahoma are matched by the variations in surface water. The principal streams commonly have southeastward courses, but here their similarity ends. Adjacent streams have entirely different runoff patterns and chemical characteristics. The Canadian River at Bridgeport drains an area of 25,229 square miles and yet is dry at times in most summers. Water in this stream is so highly mineralized, as a result of oil-field pollution in the Texas Panhandle and of gypsum deposits in the basin that more than 10 thousand tons of salt has been carried by the Bridgeport site in one day. Just over the hills to the southwest, Cobb Creek, with a drainage area of only 319 square miles, flows practically all the time. The quality of this water is excellent for all beneficial uses. Although western Oklahoma has many similarities in topography, climate, and soils, the occurrence and quality of water are so variable they cannot be described collectively.

LET'S TAKE A TRIP—TO THE RED RIVER AND OTHER STREAMS

To see what western Oklahoma looks like, let's take an imaginary conducted tour through the region. The tour might begin on a route from south to north, somewhere near the trail reputedly taken by the early Spanish explorer, Coronado, in 1541. He traversed the western side of Oklahoma in search of Quivera, a legendary city of gold. The starting point would be the Red River which forms the southern boundary of the State.

A crossing of the Red River (Prairie Dog Town Fork) at the southwestern corner of Oklahoma might be made on a dry sand bed at times, even though the river drains an area of 7,847 square miles in the Texas Panhandle. Rainfall is scanty, and areas of low runoff are so extensive that more than half the overall drainage area in the upper basin seldom contributes flow to the stream. The flows that occur are of very poor quality because of natural pollution from salt and gypsum deposits. At low flows of about 6 cfs (cubic feet per second), the chloride concentration of the water is about 6,000 ppm. In one day this flow of about 4 million gallons of water carries about 160 tons of salt. Even before the white man's arrival, the Indians had not explored much of the upstream area of the Red River because they could not drink the water.

Nearby Lebos, Gypsum, and Turkey Creeks offer little improvement in quality of the surface water. Water in these streams is similar in quality to that of the Red River, being highly mineralized with salt and gypsum. At low flows of about 6 cfs, chloride concentrations range from about 800 ppm in Turkey Creek to about 1,400 ppm in Lebos Creek.

Even though good surface water is scarce in Harmon and Jackson Counties, a thriving agricultural economy has resulted from the extensive development of ground water for irrigation near Hollis and Duke. The solution cavities in massive gypsum beds are filled with ground water which, as might be expected, has a high concentration of calcium and magnesium sulfate or gypsum. This combination of chemical constituents is particularly suitable for irrigation. In 1965, more than 500 wells supplied water to irrigate 31,500 acres in Harmon County. About 60 percent of the irrigated acreage was planted in cotton and most of the remaining 40 percent in grain and forage sorghum, alfalfa, and wheat.

In contrast to the major ground-water development in Harmon County, neighboring Jackson County had 55,000 acres under irrigation by surface water. This water is supplied by canal from the 140,000 acre-feet of storage at Lake Altus on North Fork Red River. It also is of the calcium sulfate variety and is excellent in quality for irrigation. Even though the water has a relatively high hardness of about 500 ppm, Lake Altus also supplies municipal water for

Altus, the principal city of southwestern Oklahoma. In addition to supplying water for irrigation and municipal use, Lake Altus provides 35,500 acre-feet of storage for flood control. It is the only major lake in the southwestern area and its setting among granite hills provides an important recreational center for such activities as fishing, swimming, boating, and water skiing.

Water of a quality similar to that in Lake Altus may some day be developed from Salt Fork Red River. The potential yield of this stream is about half that provided to Lake Altus by North Fork Red River. However, the water of Elm Fork, between Salt Fork and North Fork, is so salty a traveler might well think he was at the seashore instead of in western Oklahoma. Salt springs feeding this stream near the State line are so mineralized that salt has been produced commercially in the area since 1880. Elm Fork flows into North Fork immediately below Lake Altus Dam, and from this point downstream the water is too salty for any use. This stream contributes a sizable salt load to the already overloaded Red River. Under typical low-flow conditions the daily salt load of 160 tons in Red River at the starting point of our journey increases to 340 tons just below the mouth of North Fork.

ELK CREEK AND OTTER CREEK

To make our trip through western Oklahoma more interesting, we might deviate from Coronado's route and swing eastward through the Wichita Mountains to pick up the old Chisholm Trail cattle route in the eastern part of the region. East of the North Fork Red River we cross an area of excellent potential for surface-water development. The potential yield of water from Elk Creek would provide a supply about a third as large as Lake Altus. Full development of this stream would require storage to dilute the more concentrated low flows with the good-quality flood flows. Elk Creek drains an area predominantly of shale and sandstone, but a moderate amount of calcium sulfate is picked up from massive gypsum deposits in the central part of the basin. Low flows in this stream have a sulfate concentration of about 600 ppm and a hardness of about 900 ppm. However, flood flows reduce these concentrations so that an impounded supply on the creek would provide water of about 150 ppm sulfate and about 275 ppm hardness. These concentrations are only about half as high as those of water in Lake Altus. South of Elk Creek, Otter Creek drains a shale plain around the foothills of the only mountains in western Oklahoma, the Wichitas. This stream has water of extremely good quality with a total mineral content of about 150 ppm.

Just south of the mouth of Otter Creek, large terrace deposits supply ground water to irrigate about 30,000 acres in Tillman County. In this sandy, gently rolling area the average yearly replenishment to the ground-water reservoir is about 50 million gallons for each square mile, and total recharge is about equal to pumpage. The underground reservoir supplies municipal water to Frederick and several other towns in the area, and about 500 wells tap the aquifer to supply the irrigation water.

THE WICHITA MOUNTAINS

As we travel northeastward from Tillman County the skyline is dominated by the massive granite peaks which rise about 1,000 feet above the surrounding plain and form the core of the Wichita Mountains. The Wichitas are of historical interest as the scene of at least four fruitless gold rushes. The area is now the site of a wildlife refuge for such near-extinct animals as the longhorn and bison. The 26 lakes provide a natural setting for the principal recreational area serving Lawton. Mount Scott, rising to an altitude of 2,464 feet, is the sentinel of the Wichitas. Its summit commands a multitude of hard granite peaks, the northern flanks of which are buried by layers of limestone.

In the vicinity of Lawton the limestone, which is buried by younger rocks, contains fresh water to depths of more than 1,000 feet. In the early 1940's, Lawton had several municipal wells tapping these limestone beds, with each well producing about 500 gpm. This source of supply for municipal use was abondoned because the water contains excessive concentrations of fluoride, about 10 ppm, but it still is a potential source of industrial water. The principal water supply serving Lawton is the 63,000-acre-foot Lake Lawtonka, formed by an impoundment on Medicine Creek at the base of Mount Scott. The water is of excellent quality for municipal and industrial uses, having a total mineral content of about 175 ppm, a hardness of about 150 ppm, and a chloride concentration of only 10 ppm. A newly developed source for Lawton is the 48,000-acre-foot Lake Ellsworth on East Cache Creek northeast of the city, completed in 1961.

RAINFALL AND STREAMFLOW INCREASE EAST OF THE WICHITAS

The Wichitas are the eastern boundary of the semiarid part of western Oklahoma. East of the mountains, the average annual rainfall, which exceeds 30 inches, is reflected by increased yields of the surface streams. The average annual runoff in Cache Creek to the east is about $3\frac{1}{2}$ inches, or four times that of the Salt Fork Red River to the west. The mineral quality of streams east of the Wichitas also shows a decided improvement over streams to the west. The siltstone and shale drained by the eastern streams contain none of the prominent gypsum beds that are the source of high sulfates and chlorides in the streams to the west. The annual flow in Elk Creek to the west in 1951 was the same as that in Cache Creek in 1952, yet these identical flows produced 4,000 tons of gypsum in Cache Creek compared to six times this amount in Elk Creek.

The area between Lawton and Duncan south to the Red River is poorly supplied with ground water. Some of the small towns are supplied with water from numerous wells of low yields tapping the alluvium of small creeks, but most of the larger cities depend on surface supplies. The reservoir authorized for Beaver Creek near Waurika will provide water for Waurika and other cities in the area. It will furnish irrigation water for 2,000 acres of farmland and flood protection for the city of Waurika, which was flooded five times during the 7 years prior to 1958. Beaver Creek has some oil-field pollution, but the impounded water, diluted by flood flows, will be of excellent quality for municipal and irrigation use.

The old Chisholm Trail, established in 1868, crossed the Red River from Texas into Oklahoma at about Jefferson

County. Frequently the cattle had to swim across because the streamflow was, and is, continuous and often quite high. Inflows from springs in the upland areas and from the Wichita River in Texas combine to maintain a year-round flow. The lowest flow observed in the Red River at Terral since 1938 was 43 cfs, a flow that would provide 30 mgd. However, even with the inflow of water of good quality from such streams as Cache and Beaver Creeks, the Red River at Terral still is too salty for any use except as cooling water. In 1956, the Red River contributed more than a million tons of salt to Lake Texoma.

Most of Love and Marshall Counties, north of the Red River, are well supplied with ground water. A water-bearing sand deposit underlies the western part of the Coastal Plain and dips southeastward toward the river. The fresh-water zone extends generally to a depth of about 600 feet but in some areas to about 800 feet. The water is of a sodium bicarbonate type and has a hardness of about 50 ppm. Several towns near the Red River tap this aquifer for municipal supplies.

RIVER FLOW AND GROUND WATER ARE ABUNDANT NEAR LAKE TEXOMA

Lake Texoma, one of the largest manmade lakes in the world, is the recipient of the combined flows from the Red and Washita Rivers. It normally covers a surface area of 90,000 acres and has a total storage capacity of about 5.5 million acre-feet of water (1,800 billion gallons). It was formed by a rolled-fill earth dam across the Red River just below its junction with the Washita River near Durant. Lake Texoma represents the largest developed supply of surface water in Oklahoma. Since its initial filling in 1945, the lowest level reached in the lake was on March 1, 1957, at the end of a severe 5-year drought in the southwest. At that time the lake contained more than 1½ million acre-feet of water (about 500 billion gallons). Less than 2 months after reaching this low level, the lake was forced to utilize the full flood storage of 2.66 million acre-feet. So much water flowed into the lake that water flowed 3 feet deep through the emergency spillway, designed for 100-year floods.

Storage set aside in Lake Texoma for power development is 1.75 million acre-feet, and this amount can generate as much power as is used by New York City. Recreational activities in the lake area accommodated more than 8 million visitors during 1957. Almost completely overlooked and unused during the past 20 years has been the tremendous, relatively stable supply of surface water impounded in the lake and available for municipal, industrial, and agricultural uses. Water quality in the Red River arm of the lake is not very desirable for consumptive use because of the highly mineralized water from the river. However, water intakes properly located in the Washita arm of the lake, upstream from the Santa Fe railway bridge, could withdraw water of about 500 ppm total mineral content and having a hardness of about 200 ppm.

THE WASHITA RIVER AND ITS DEVELOPMENT

Turning northward, we cross the Washita River, the other large contributor of water to Lake Texoma. This stream drains an area only one-fourth the size of the Red River drainage above Lake Texoma, but it contributes more than one-third of the inflow to the lake. About half the total runoff of the Washita River originates below Pauls Valley, although two-thirds of its total drainage area lies above this point. In the lower part of the basin, the average annual rainfall varies from 34 to 40 inches, the runoff is highest, and the water quality is at its best.

Downstream from where the Washita River enters Oklahoma from the Texas Panhandle, an abrupt change in the geology brings about a corresponding change in the mineral quality of the stream. In Texas, the quality of the river water is very good, being characteristic of a water derived from the High Plains deposit; there it has a total mineral content of less than 400 ppm, hardness of less than 200 ppm, and no appreciable amount of sulfate. Just east of the State line the river flows through exposed beds of gypsum associated with the red beds, and the mineral concentration of the water immediately increases. In the 35 miles from the

State line to Cheyenne the mineral concentration and hardness increase about threefold, and the mineral content becomes progressively higher downstream as far as Clinton. A maximum hardness of 2,000 ppm, mostly sulfate or permanent type, has been observed during low-flow periods at Clinton.

In the western part of the Washita Basin near Elk City, the Sandstone Creek drainage basin offers the traveler an opportunity to observe the comprehensive development of a small watershed. The Flood Control Act of 1944 (H.D. 275, 78th Congress, 1st Session) authorized the Department of Agriculture to carry out works of improvement to retard runoff and prevent erosion on upstream watersheds of the Washita River basin. Sandstone Creek was the first watershed in the basin to receive a complete flood-preventive treatment under the Act. Sandstone Creek has a drainage area of 107 miles and contains 24 reservoirs which control runoff from 68 percent of the basin. Each structure is designed to catch the storm runoff from a specific area and allow it to flow through a small outlet at a fixed rate (fig. 11, next page). The reservoir designs also provide for sediment storage to be accumulated over a period of years. In effect, this design supplies each adjacent landowner with a small lake for irrigation, stock, and recreational uses.

Alluvial deposits along the upper Washita River do not offer much potential for extensive development of groundwater supplies. At several places, wells in the alluvium supply moderate quantities of water for local irrigation. In general the water from these deposits is extremely hard and not of desirable quality for municipal water.

Moderate quantities of water are pumped from a fine-grained sandstone in the red beds for municipal and irrigation use in the Burns Flat area east of Elk City. The aquifer has a maximum thickness of about 200 feet, and the wells have maximum yields of about 200 gpm. Wells in this small area supply water to Clinton-Sherman Air Force Base and to several irrigation installations and municipal water to several towns. Continued development of the aquifer to supply the several users within a small area may lead to overdevelopment and a conflict in water use.

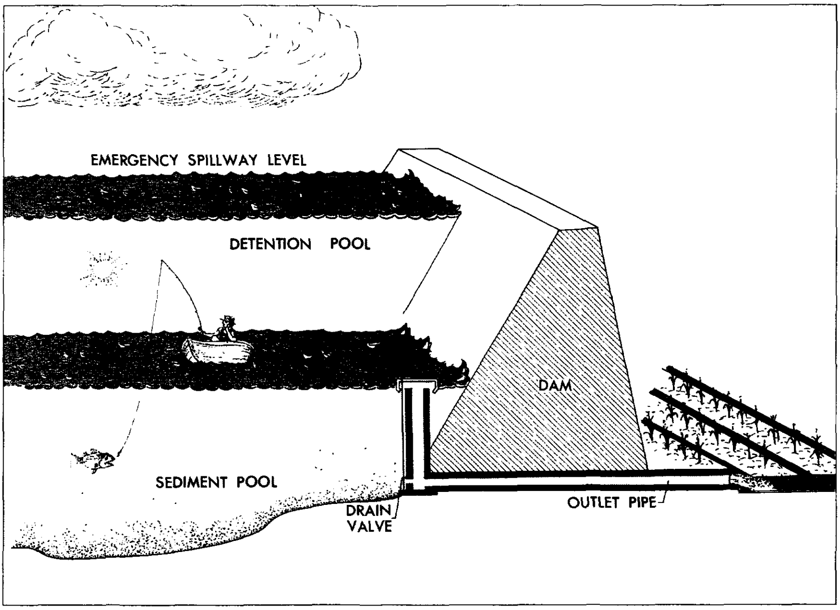


FIGURE 11.—Typical upstream floodwater-retarding structure. Flood flows are temporarily detained at the dam and released through the uncontrolled outlet pipe at a much lower rate of flow.

About 20 miles downstream from Clinton the Washita River leaves the gypsum hills and flows eastward through an area of red-bed sandstone and shale. Rainy Mountain and Stinking Creeks, which drain the northern flank of the Wichita Mountains, join the Washita River a few miles west of Carnegie. Neither stream is perennial, but the storm runoff which they carry contributes to the flow and improves the quality of water in the river.

In the stretch between Clinton and Anadarko the alluvium of the Washita River valley is too thin and fine grained in most places to support wells of large yield. However, about 10 percent of the valley is underlain by a gravel-filled channel which is more than 100 feet deep in places. Wells tapping the channel deposits will yield more than 250 gpm—enough to irrigate a moderate-sized field.

In contrast to the intermittent flows farther west, the Washita River and several of its tributaries flow most of the time from Clinton downstream to Lake Texoma. Two of these tributaries, Cobb and Sugar Creeks, flow southward into the Washita in Caddo County. They drain an area of sandstone and sandy soil, and their perennial flows of good-quality water help improve water in the river. Of the two, the larger base flow is in Cobb Creek, whose natural flow exceeds 10 cfs ($6\frac{1}{2}$ mgd) 90 percent of the time. A thick massive sandstone in the red beds is at or near the land surface throughout most of the Cobb Creek basin. Deep sandy soils developed on this sandstone allow the ready infiltration of water, and the nearly 300-foot thickness of the aquifer provides a tremendous reservoir for underground water storage. Cobb Creek in its lower reaches has cut into this reservoir and receives water from it to maintain flow during dry seasons. More than 500 irrigation wells, scattered throughout the basin, provide water to irrigate 20,000 acres of peanuts and 10,000 acres of other crops. The wells range in depth from 150 to 300 feet, and yields range from 100 to 700 gpm. This aquifer also provides water for towns as far southeastward as Marlow and Rush Springs, where the sandy hills are noted for abundant watermelon harvests.

In the main irrigation area, mostly in Caddo County, annual pumping is about equal to the replenishment rate. If additional irrigation wells continue to be drilled in the aquifer, problems of overdevelopment can be expected in a few years.

Between Clinton and Anadarko, several pumping plants withdraw water directly from the river for supplemental irrigation in the valley. A power plant at Anadarko withdraws cooling water from the Washita River, and the cities of Anadarko and Chickasha formerly withdrew municipal water from the stream. Hardness of this water exceeds 700 ppm at times, and sulfate concentrations exceed 500 ppm, too high for good drinking water. Chickasha has completed construction of a reservoir on Spring Creek, and Anadarko is supplied municipal water from Cobb Creek Reservoir.

Downstream from Chickasha the contributions from many small tributaries help to dilute and improve the quality of the Washita River. One of the largest, Little Washita River, flows into the Washita in southeastern Grady County and adds about 32,000 acre-feet of water per year to the system. The tributary streams of Rush, Wildhorse, and Caddo Creeks receive some oil-field pollution, but the overall effect on water quality of the Washita River is insignificant. In the extremely dry year of 1956 when mineral concentrations were very high, the average chloride concentration of Washita River water flowing into Lake Texoma was only 62 ppm. However, during this same period the average chloride concentration of the Red River inflow was 533 ppm.

In the lower part of the Washita River basin, an impoundment on Rock Creek near Dougherty is being constructed for development of additional surface water. This reservoir is designed to provide 58,000 acre-feet of storage for municipal water to supply several small towns of the area. It also will provide 36,000 acre-feet of storage for flood control. The impounded supply should have a total mineral concentration of about 265 ppm and a hardness of about 190 ppm, a water of excellent quality for both municipal and irrigation uses.

South of Dougherty we "shoot the rapids" where the Washita River has cut a canyon through the geologic complex known as the Arbuckle Mountains (fig. 12). This canyon separates the western part of the mountains from the main mountain area east of the river. The western part is an area of intensively folded and broken rocks, and springs maintain the flow of streams over rapids and cascades. Turner Falls on Honey Creek is the best known falls in Oklahoma.

The alluvium and terrace deposits along the lower Washita River supply water to several small towns. The wells are 50 to 80 feet deep with maximum yields of 200 gpm. In addition, a small amount of ground water has been developed for industrial and municipal use in the area roughly bounded by Pauls Valley, Ardmore, and southwestern Stephens County. Fine-grained sandstone in the bedrock supplies water for oil-field industrial use, for refineries, and for several small towns. Fresh water in this area extends to depths of about 800 feet in southwestern Carter County, and maximum well yields are from 200 to 300 gpm. The prin-

FIGURE 12.—Washita River canyon near Dougherty.

cipal supply for Ardmore comes from Mountain Lake, a 1,500-acre-foot impoundment on Hickory Creek in the Caddo Creek watershed. However, during the drought year of 1956, eight wells were constructed in central Carter County to supplement Ardmore's supply.

The Washita River is scheduled for one of the most extensive developments of surface-water resources in the State. In addition to the numerous farm ponds and upstream detention reservoirs completed, under construction, and planned, major reservoirs have been completed on Cobb Creek northwest of Anadarko and on the Washita River west of Clinton. Cobb Creek and Foss Reservoirs have a combined capacity exceeding a million acre-feet and will serve as irrigation and municipal water supplies and for recreation and flood control. Much of western Oklahoma's agricultural future is tied into proper use of the water resources of the Washita stream system.

THE CANADIAN RIVER BASIN

Leaving the Washita River valley and continuing north we find that crossing the Canadian River may be treacherous at almost any place. In contrast to the Washita River whose reddish-brown water flows in a narrow, meandering channel, the Canadian River flows through a broad, sandy flat. Stream channels a few feet wide shift their courses back and forth across this half-mile sandy waterway, changing their position with each flush of water (fig. 13). Numerous pockets of quicksand are found where swirls or slow-moving water have dropped fine sand after a rise. A lack of compaction of the sand grains and the presence of some water make the mixture soupy in spots and provide a sudden, unnerving collapse of footing—for feet or tires.

High flows from melting snow in the Rocky Mountains once was a barrier to crossing the river in the spring, but this source of water now is largely controlled by Conchas Dam on the Canadian River in New Mexico. Even so, an average of about 500,000 acre-feet of water annually comes into Oklahoma via this route. Even with the completion of Sanford Dam on the Canadian River north of Amarillo, Tex., Okla-

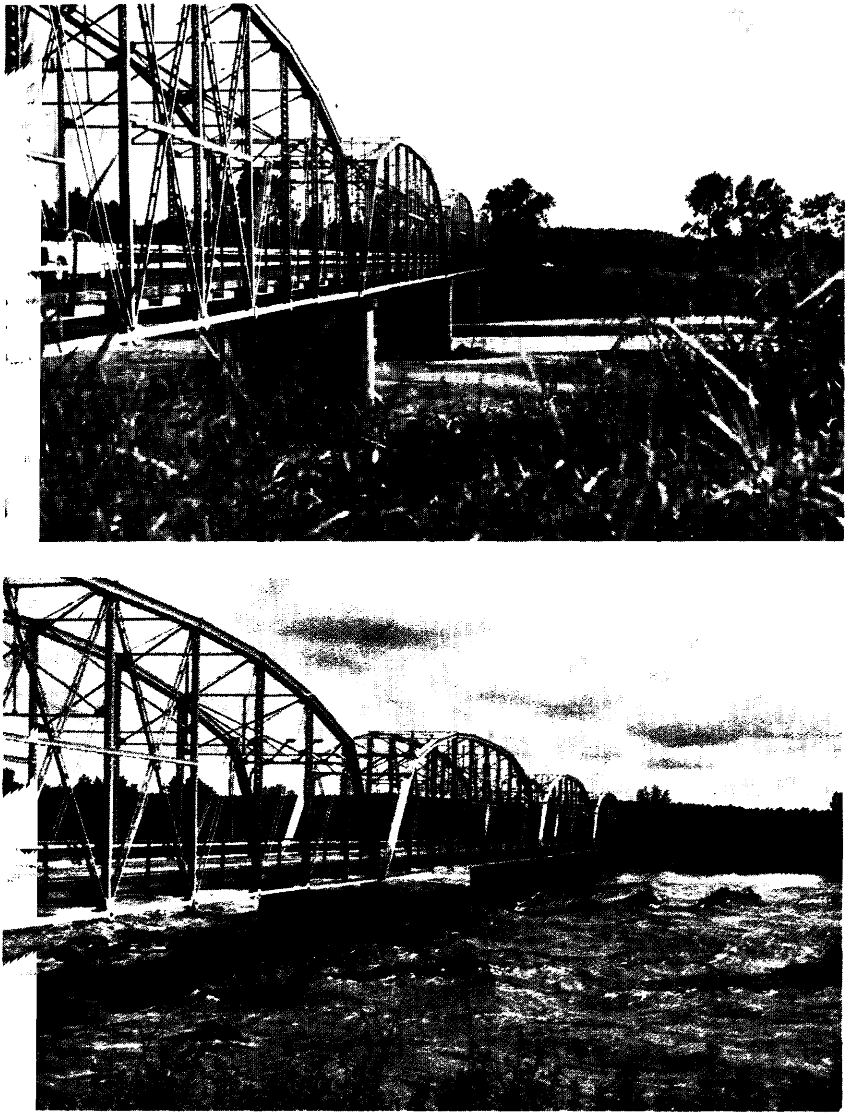


FIGURE 13.—Canadian River at low and high stages. A flow of 50 cfs in the Canadian River is hardly visible as it meanders among the sand bars. In sharp contrast, the sand-laden flow of 150,000 cfs challenges the ingenuity of man to provide controls for these infrequent whims of nature.

homa can depend on about 300,000 acre-feet of water coming into the State annually under present interstate-compact agreements. Although the Canadian River drains about 2,700 square miles in western Oklahoma, channel losses are such that annual flow of the stream south of Oklahoma City is about the same as at the Texas border.

The sandy valley of the Canadian River provides a high sediment load to the river. On May 18, 1949, when the Washita River at Carnegie was carrying 257,000 tons of sediment, the Canadian River at Bridgeport was carrying 4,-300,000 tons of sediment. This amount of dirt is equivalent to an inch of erosion from a 32,000-acre farm. Flushes of water down the Canadian River reach velocities of as much as 15 miles an hour, and a scouring of the sandy bottom is quite common at bridge crossings. In fact, the river bottom may go down more than the river surface comes up. Sand sections 80 feet thick have been found in the river channel at Camargo; near Norman, the sand in the channel is about 30 feet thick. Bridge supports must extend to the underlying red beds because of scour pockets that develop around the piers.

Ground water in the alluvium adjacent to the Canadian River also is undeveloped. Loose sandy soils which are characteristic of the valley allow ready recharge of the aquifer, and the coarse material underneath provides a ground-water reservoir that at any location contains a moderate amount of water. Properly constructed wells in more productive parts of the alluvium yield 500 gpm. A few towns adjacent to the river tap this aquifer for water supplies. Quality of the alluvial water is erratic because it is influenced by the bedrock bordering the valley, which in places contains gypsum and in other places is predominantly sandstone. Because of the resulting high sulfate concentrations, ground water along parts of the Canadian River valley offers little potential for wide-scale development except for local irrigation use.

Crossing the basin divide to the north, the traveler finds a geologic whim of nature. Although the North Canadian River originates 500 miles away in New Mexico, its basin width at El Reno is only 10 miles. Furthermore, the elevation of this narrow basin from this point upstream to the panhandle is higher than that of the adjacent basins on either side. At El Reno the North Canadian River is 50 feet higher than the Canadian River to the south, and more than 200 feet higher than the Cimarron River to the north. Most of the flow originates in the High Plains area. The principal tributary of the North Canadian River is Wolf Creek, which is controlled near its mouth by Fort Supply Reservoir. The capacity of this flood-control and recreation impoundment is 106,200 acre-feet.

The North Canadian River receives some natural pollution from gypsum deposits west of Woodward, but the impounded supply downstream at Canton Reservoir still is of suitable quality for both municipal and irrigation uses. Oklahoma City presently is renting temporarily 90,000 acre-feet of storage in this reservoir for release at opportune times to flow 110 miles downstream to Lakes Overholser and Hefner. Canton Reservoir provides 69,000 acre-feet of storage for irrigation use if or when facilities are installed at the request of an organized irrigation district.

The North Canadian River channel above Canton Reservoir is confined in low banks, and the flood plain in many places is more than a mile wide. A broad area of sand dunes and sandy soils borders the flood plain on the north. This area represents terrace deposits left behind by the North Canadian River during an earlier period. West of Fort Supply the terrace deposits are about 3 miles wide, but they widen to more than 10 miles just east of Woodward. These deposits have a maximum thickness of 120 feet, and their sandy character allows the ready infiltration of rainfall. The saturated material in the deposits is as much as 60 feet thick and depth to water ranges from 20 to 80 feet; wells in the thicker, more permeable sections yield as much as 1,000 gpm. The water from the aquifer is of the calcium, magnesium bicarbonate type and has a total mineral content of about 300 ppm—good quality for both municipal and irrigation use. Wells tapping the aquifer supply water to irrigate 2,400 acres near Mooreland and also supply irrigation water for smaller areas in Harper and eastern Woodward Counties. Woodward and several smaller towns of the area get municipal water from the terrace deposits.

Alluvial deposits upstream from Canton Reservoir supply municipal water to Seiling and a small amount of irrigation water in Woodward County. The depth to water in these deposits generally is less than 20 feet, but because the saturated thickness is less than that of the terrace deposits, wells generally yield no more than 800 gpm. Quality of the water from the alluvium is erratic because of its different sources of recharge. Where the flood plain is bordered by extensive dune areas, most of the recharge is from local precipitation and by movement of water from the adjoining terrace deposits. Quality of this water is very good and its total mineral content is only about 200 ppm. In the area around Seiling, gypsum in the Permian rocks adjacent to the valley probably is the source of much higher mineralization of the alluvium water, and the mineral content is about 800 ppm.

The channel bed of the North Canadian River generally is higher than the water table in the alluvium, and the river loses water during most periods of flow. These losses just about balance inflow to the river from tributary streams in the lower reaches, and the average annual flow of 200,000 acre-feet at El Reno is about the same as that 84 miles upstream at Canton. When 25,000 acre-feet of water is released from Canton Reservoir during a dry period, as much as 40 percent of the water will be lost before the flow reaches Lake Overholser at Oklahoma City (fig. 14). Because of this loss, reservoir releases of the Oklahoma City municipal water storage at Canton usually are made at times when the river has some natural flow.

Channel losses are common throughout the western part of the North Canadian basin. A release of 4,260 acre-feet of water from Fort Supply Reservoir in 1943 ended as a mere trickle of 54 acre-feet past Canton 100 miles downstream. However, these channel losses do not represent a total loss of water for beneficial use. Much of the loss is merely a transition from above to beneath the surface where some of the the water is pumped from the alluvium for municipal and irrigation use. In Blaine County some of the surface water probably finds its way downward into solution channels of the massive gypsum beds where it dissolves gypsum and

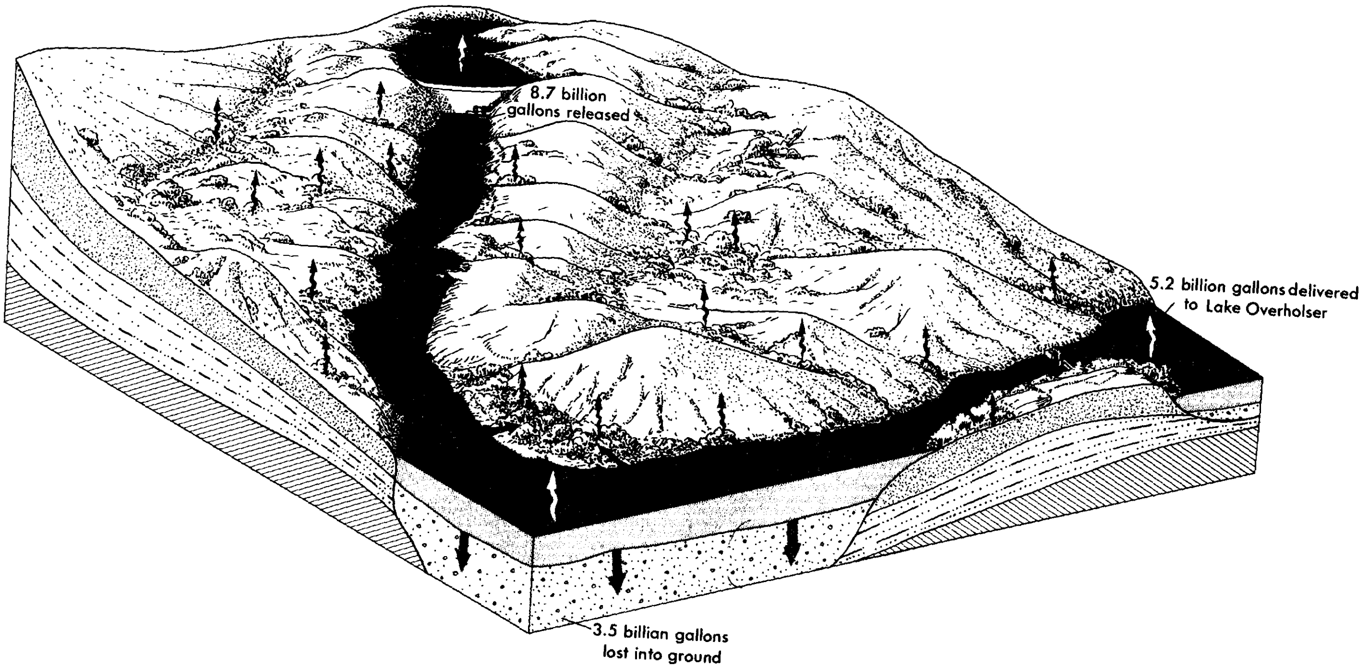


FIGURE 14.—Block diagram showing loss of water from the North Canadian River to the alluvium and the atmosphere.

mixes with a highly mineralized water to emerge from springs such as those in Roman Nose State Park. We tend to think that underground storage of water automatically eliminates the evaporation hazard of surface supplies. However, a large quantity of water from the North Canadian alluvium is wasted into the atmosphere by willow and cottonwood trees between Canton and Oklahoma City. Use of water by such vegetation across Canadian County alone, a distance of 40 miles, amounts to about 40,000 acre-feet annually—more water than Oklahoma City used in 1960.

THE CIMARRON RIVER

The traveler might next reach the Cimarron River valley by descending one of the numerous short tributary streams that drains northward along the exposed red beds and heads within a few miles of the North Canadian River. The red beds that border the Cimarron River in Harper, Woodward, and Major Counties have been severely eroded to form canyons more than 100 feet deep. The three massive layers that make up the gypsum within the red beds form a step-like bluff nearly 100 feet high. The bluff is the south bank of the Cimarron River in Harper and Woodward Counties, and it forms the framework of the Cimarron Valley on the south in Major County. Ground water moving along fractures and joints in these massive beds has dissolved the gypsum and left behind channels and huge caves such as the Alabaster Caverns in northern Woodward County. In places large springs of highly mineralized water such as those in Roman Nose State Park flow from these solution channels. Wells drilled into these openings supply a highly mineralized water that is used for livestock, but it is not suitable for human consumption.

Southeastward from Fairview in Major County to near El Reno, the gypsum bluff becomes progressively lower; it still faces the Cimarron River, but it retreats from the river bank to a distance of about 20 miles to the southwest. The area between the bluff and the river is a gently rolling plain developed on shale of the red beds. It is poorly supplied with ground water, although wells producing a highly mineralized water in meager quantities can be obtained at depths of less than 200 feet throughout most of the area. The water is of undesirable quality for human consumption, and is used mainly for livestock.

In contrast to the prominent bluffs and rolling redlands that mark the south side of the Cimarron River, the area immediately north of the stream is marked by sandy soils and drifting windblown sand. This sand overlies an area of terrace deposits that ranges in width from about 3 miles west of Waynoka to nearly 15 miles in southeastern Woods County and averages about 10 miles. These deposits, which were left behind by the Cimarron River during an earlier period, have a maximum thickness of 120 feet and average about 60 feet. Their average saturated thickness is about 40 feet. Wells yielding 100 gpm can be obtained in most parts of the area, and at favorable spots properly constructed wells yield more than 600 gpm. The relatively thick saturated section combined with a material of good permeability provides a sizable ground-water reservoir. About 770 million gallons of water is stored beneath each square mile of terrace, and because of the sandy soils and large areas of sand dunes, recharge or infiltration is constantly replenishing the supply. During average periods, rainfall percolating into the reservoir would support pumpage of about 200 thousand gallons a day from each square mile.

Water from the Cimarron terrace deposits is of the calcium, magnesium bicarbonate type, with a total mineral concentration of about 400 ppm and a hardness generally less than 200 ppm—suitable in all respects for a municipal or irrigation supply. A number of cities in the area, including Enid and Alva, tap this reservoir for their water, and it is used extensively for irrigation in Woods, Major, and Kingfisher Counties. Ground water in the terrace deposits generally is moving toward the alluvial valley adjacent to the Cimarron River, and it replenishes water in the alluvium and contributes flow to the streams. Where small creeks have cut through the terrace deposits to expose the underlying red beds, springs such as those near Cleo flow from the terrace deposits and help to maintain surface flows.

The alluvium of the Cimarron River underlies the flood plain of the stream and a low bench a few feet above the flood plain. It consists chiefly of sand and gravel ranging from 25 to 75 feet in thickness. Depth to water generally is less than 20 feet and in many areas is less than 10 feet. The quality of water from this aquifer is very erratic because of the different sources of recharge. The towns of Fairview and Kingfisher tap the alluvium for municipal water at places where it derives the major recharge from the good quality terrace deposits. At other places, where the principal recharge is from the adjacent rocks and by lateral seepage from the highly mineralized Cimarron River, water in the alluvium is too highly mineralized for drinking purposes.

Water of the Cimarron River, which is suitable for irrigation in the western part of the Oklahoma Panhandle, takes on entirely different characteristics as it flows through natural salt and gypsum deposits west of Freedom. At this point the stream at times is more highly mineralized than sea water. In Woods County, west of Freedom, the entire Cimarron River flood plain for several miles is a dazzling plain of salt crystals. On typical low-flow days the Cimarron River water south of Waynoka contains a pound of salt for each 3½ gallons of water. Annual flow of the Cimarron River in western Oklahoma increases from about 240,000 acre-feet a year at the Kansas border to about 600,000 acre-feet at Guthrie, but the high salt concentration of this 200 billion gallons of water makes it unsuitable for any use except power or recreation.

THE SALT FORK ARKANSAS RIVER

Northward from the lower Cimarron basin we reach the Salt Fork Arkansas River. This stream rises in the gypsum hills of southern Kansas and is highly mineralized with calcium sulfate as it enters Oklahoma near Alva. Sulfate concentrations occasionally exceed 1,000 ppm during periods of low flow. The gypsum characteristic of the water at Alva is completely overshadowed as the river takes on a sodium chloride or salt attribute when it flows through the natural salt plain just above Great Salt Plains Reservoir. This reservoir, which lies on a part of the salt plain, mainly is for flood control, but it also provides recreation, and the surrounding area serves as a wildlife refuge. Water released from this reservoir does not have so high a salt concentration as the Cimarron River, though it contains about a pound of salt for each 18 gallons of water. Because of this concentration of salt, water in the Salt Folk Arkansas River downstream to its mouth is not suitable for municipal, irrigation, or industrial uses except for power and cooling water.

Unconsolidated sand and gravel of the alluvium and terrace deposits serves as a local aquifer in a broad area around the Great Salt Plains and in the valleys of the Salt Fork Arkansas River, Medicine Lodge River, and several small creeks. The main area extends about 20 miles south from the Kansas border and about 20 miles west of the Alfalfa-Grant County line. Narrow areas of similar deposits from 1 to 3 miles wide extend up the Salt Fork to the Kansas border. Although much of the area north of Cherokee is a flat plain, other parts of the area have the rolling topography that is characteristic of stabilized dunes which mark terrace deposits. These deposits consist principally of sand and gravel and are at least 50 feet thick in the vicinity of Cherokee where the depth to water is about 120 feet. The Cherokee municipal wells have a yield of about 350 gpm, and similar yields could be obtained elsewhere. In a small area about 3 miles north of Great Salt Plains Reservoir, artesian conditions cause shallow wells in the terrace deposits to flow naturally. These wells supply water to the Oklahoma State Fish Hatchery and local farms.

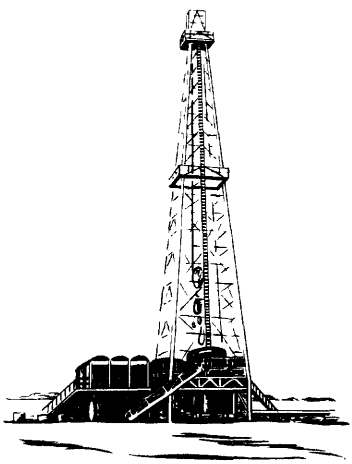
Deposits of alluvium along the Salt Fork formerly supplied water for Alva. This water is of the calcium sulfate or gypsum type with a hardness exceeding 500 ppm. In 1941, Alva abandoned the source for a water of better quality in the Cimarron terrace deposits 20 miles south of the city.

The main tributary to the Salt Fork downstream from Great Salt Plains Reservoir is the Chikaskia River. This stream has an average annual runoff of about 350,000 acre-feet at Blackwell, and it serves as the source of water for that city. The quality of this water usually is good, but during low flow, pollution from oil fields is responsible for momentary chloride concentrations exceeding 1,000 ppm that impart a noticeably salty taste.

Downstream from Great Salt Plains Reservoir, the alluvium along Salt Fork is from 2 to 3 miles wide. The quality of water in this stretch of the river is more erratic than upstream from the reservoir, and in places is affected by infiltration from the salty river water. The water supply for Pond Creek has a chloride concentration of 370 ppm as compared to concentrations of less than 50 ppm in the alluvium upstream from Great Salt Plains Reservoir.

THE TRAVELER TASTES A VARIETY OF WATER

On the rambling trip through western Oklahoma, the traveler does not suffer from thirst, but he is subjected to a variety of tastes. When Coronado explored the area, he reported that the water was plentiful, and the riders of the Chisholm Trail found more than they wanted to see at times. The water ranges from the pure mountainous flow of Otter Creek to the briny characteristics of the Elm Fork Red and Cimarron Rivers. The overall quantity and quality of the water more than maintains the rich agricultural lands of the region, which includes about 60 percent of the total irrigated acreage for the State. With current (1965) prices of cotton, wheat, and peanuts at approximately $150 a bale, $1.80 a bushel, and 10¢ a pound, it is quite evident that additional irrigation development in western Oklahoma will help convert more of the water dollar to cash in the bank.



WATER RESOURCES OF THE CENTRAL AND EASTERN PLAINS

SUPPLIES OF OIL AND WATER ARE BOUNTIFUL

The Indian Territory of the early days of exploration and settlement saw the beginning of commerce and industry which now thrive in eastern Oklahoma (fig. 15, next page). Steamboats from New Orleans came up the Arkansas River to Fort Gibson regularly during the boating season from December to July, beginning in 1824 when the small steamboat *Florence* brought military supplies to the fort. This river traffic continued for about 50 years until railroads were built in the region. Incoming commodities were largely supplies for military camps and Indian trading posts; outgoing commodities included pecans, salt, furs, and corn. Still untapped were the vast reserves of coal, oil, and other minerals of the central plains.

At the time of statehood in 1907, some groups advocated making separate states of Oklahoma Territory and Indian Territory. However, the advantages of combining predominantly agricultural Oklahoma Territory with the resources of Indian Territory, which even then showed promise of becoming an industrial area, were obvious, and a single State was established. More than any other area of the State, the central and eastern plains during the early days of statehood were dominated by the gushing oil industry. As might be expected in an industrial area, this section of the State includes the two largest cities: Oklahoma City, the State capital; and Tulsa, long called the "oil capital."

The central and eastern plains are a region of broad rolling prairies and waving fields of wheat and corn, made familiar by the musical comedy "Oklahoma!" The monotony of the plains is broken by numerous tree-covered bluffs and hills of sandstone and limestone which face the east and southeast through much of the region. In places these

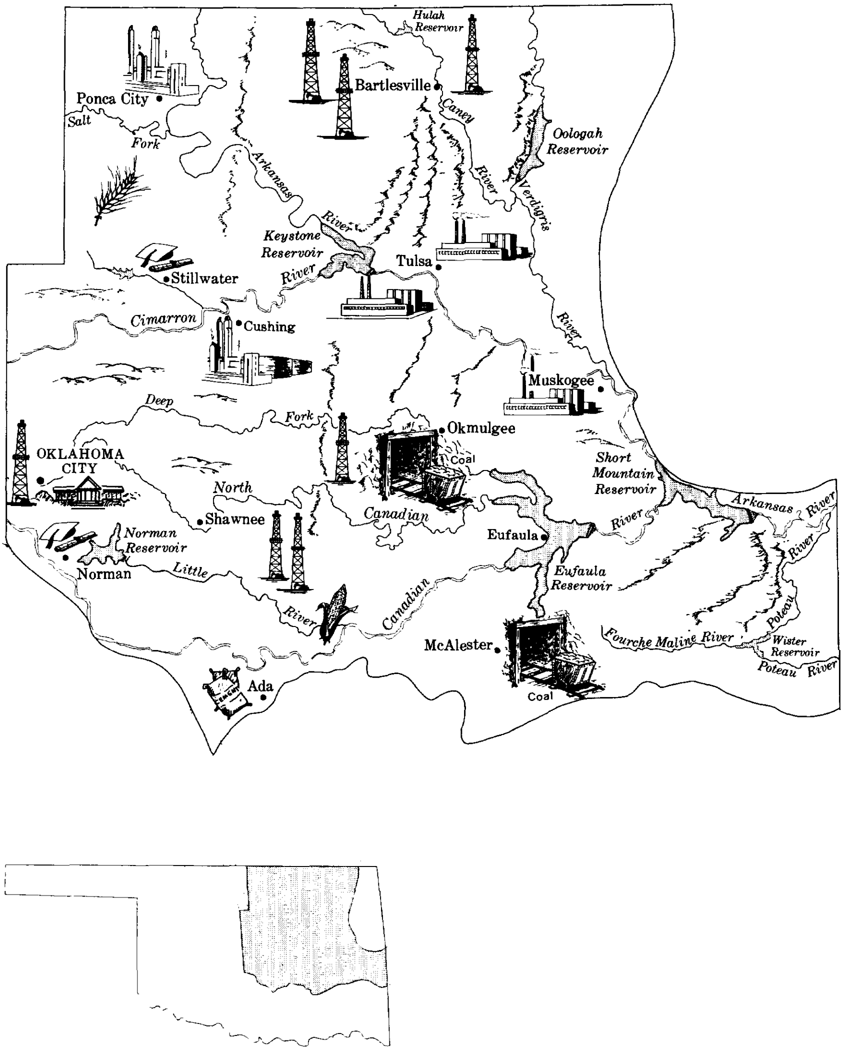


FIGURE 15.—Features of the central and eastern plains.

bluffs have been dissected into areas of jumbled hills such as the Osage Hills of Osage County. South of the Arkansas River below the mouth of the Canadian are elongated east-west ridges and large hills such as the Sans Bois Mountains near Wilburton. The southeastern part of this region in Le Flore and Latimer Counties is geologically a part of the Ouachita Mountains.

For the most part, the central and eastern plains lie in a subhumid climatic zone. The average annual rainfall ranges from 28 inches in the extreme northwestern corner to 45 inches in the extreme southeastern corner. Geologically this region is formed by alternating layers of soft shale which make up the plains and by hard sandstone and limestone which form the hills and bluffs. These layers dip slightly westward and overlap each other to the west. Soft coal, interbedded with the shale and sandstone, has been mined in a belt 30 miles wide extending from the Kansas border in Craig County south through the towns of Henryetta and McAlester to Coal County, and east from McAlester to the Arkansas State line.

GROUND WATER IS PLENTIFUL IN PART OF THE REGION

The many sandstone beds over much of the central and eastern plains provide ground water at moderate depths in quantities adequate for domestic and stock use or for small towns or industries. Larger quantities of underground water for cities or industries of moderate size are available only along some of the major streams and at two general areas. Sandstone layers in the red beds provide large supplies of ground water from southern Pottawatomie and Cleveland Counties north to Logan County. The sandstone beds, which are about 300 feet thick in the Oklahoma City area, are exposed in a band about 20 miles wide and dip westward, so the ground water has artesian pressure at Norman and Oklahoma City. In that area, wells as deep as 800 feet pump as much as 300 gpm, and wells producing more than 100 gpm are common. This aquifer supplies municipal water to Norman, Del City, Midwest City and a number of smaller towns in Cleveland and Oklahoma Counties. It also supplies a considerable quantity of water for industrial purposes in the Oklahoma City area. Oklahoma City has 21 wells for supplemental supply from which 300 million gallons of water was pumped in 1957.

The largest user of water in the Oklahoma City area is Tinker Air Force Base which uses about 1½ billion gallons a year, all from deep wells (see p. 90). Another billion gallons is used by cities in Oklahoma County. Water from this aquifer varies somewhat between the calcium, magnesium bicarbonate and the sodium bicarbonate types. Wells about 600 feet deep supply Norman with water of the sodium bicarbonate type which has almost no calcium or magnesium present. This water is one of the softest municipal supplies in Oklahoma, with a hardness of about 20 ppm. In other places, and especially at lesser depths, water from the sandstone aquifer has larger concentrations of calcium and magnesium, the hardness being about 200 ppm.

Ground water also is available from a narrow band of sandstone and gravel in the red beds extending from southern Seminole County to Osage County. The deepest wells tapping this aquifer are about 800 feet, and yields range from 50 to 150 gpm, being greatest near Seminole. The water is quite similar in quality to that of the red beds farther west—a calcium, magnesium bicarbonate water with a total mineral concentration of about 300 ppm and a hardness of about 200 ppm. The aquifer furnishes municipal water to Seminole, Stroud, Drumright, and Bristow, and water for numerous industries including an oil refinery at Cushing.

SURFACE WATER IS PLENTIFUL THROUGHOUT THE REGION

In contrast to the limited amounts of ground water available in the central and eastern plains, surface water is plentiful in most places. In its sweep through eastern Oklahoma the Arkansas River collects the inflows from several large tributary streams which are major rivers in their own right—the Salt Fork Arkansas, Cimarron, Verdigris, Neosho, Canadian, Illinois, and the Poteau. All these water highways originate in upland States, and the drainage area of the Arkansas basin above the eastern Oklahoma State line is 149,977 square miles, only 30 percent of which lies within Oklahoma. The combined flows of the Arkansas River system provide an average annual yield of 23 million acre-feet as it flows into Arkansas, about twice the flow of the Colorado River into Lake Mead at Hoover Dam.

The Arkansas River originates in the Rocky Mountains near Leadville, Colo., 870 river miles above the Oklahoma-Kansas State line. This reach of the river system drains an area of 46,000 square miles, and the average annual flow into Oklahoma is about 2 million acre-feet. Quality of the incoming water is rather poor, with high concentrations of calcium and magnesium sulfate and sodium chloride. The water is not suitable for municipal use or for industrial use other than cooling water.

The first major tributary to the Arkansas River in Oklahoma is the Salt Fork Arkansas River which makes its entrance at Ponca City. The stream provides an average annual flow into the Arkansas of 900,000 acre-feet, and combines with other tributary streams such as Beaver, Red Rock, and Salt Creeks to produce an average annual flow at Ralston of 3½ million acre-feet. Inflow from the highly mineralized Salt Fork does nothing to improve the already poor quality of the Arkansas River water, but local municipal and industrial surface supplies of good quality could be developed on Beaver, Red Rock, and Salt Creeks. For instance, Red Rock Creek drains a total area of 502 square miles and contributes an average of about 100,000 acre-feet of water a year to the Arkansas. Farther south, Black Bear Creek at Pawnee averages 130,000 acre-feet a year and also could be developed for municipal and industrial use. Under present conditions this stream is subject to pollution from oil-field activities and has chloride concentrations of several hundred parts per million at times. However, off-channel storage for taking water on a selective basis would provide a considerable quantity of good water for local use.

Ground water in the alluvium and terrace deposits along the Arkansas River above Tulsa is of better quality than the river water. In Kay County, the town of Kaw City obtains its supply from wells about 40 feet deep penetrating the Arkansas River alluvium. Water in the alluvium along this stream is derived from precipitation on the surface of the deposit and by infiltration from small streams that flow across the flood plain. Normally the water table in these deposits is higher than the level of water in the adjacent stream, and the resulting slow movement of ground water toward the stream prevents the contamination of alluvium water by seepage of the poor-quality water from the Arkansas River. At a few scattered spots in western Osage County, 20 wells supply irrigation water for about 800 acres.

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The next principal artery to the Arkansas River system is the Cimarron River which joins the Arkansas just above Tulsa. As might be expected in an oil-producing area, a considerable quantity of waste brine finds its way to the Cimarron River throughout the reach of this stream in the central plain. The salt from this brine, together with that already present as a result of flow through the natural salt plains near Freedom in western Oklahoma, makes the water in this reach of the Cimarron unsuitable for any consumptive use. Most of the streams tributary to the Cimarron in this region have sufficient yields and acceptable quality for local development. The cities of Guthrie, Stillwater, and Cushing obtain water from storage developments on Cottonwood Creek, Stillwater Creek, and Big Creek, respectively. Skeleton Creek supplies some water for irrigation southeast of Enid.

Water of good quality also occurs in the terrace deposits along the north side of the Cimarron River. The small town of Perkins in southern Payne County obtains its water from wells about 80 feet deep tapping these deposits. Wells in that area yield less than 100 gpm of water which has a total mineral concentration of about 475 ppm and a total hardness of about 250 ppm. However, the water contains nitrate in the excessive concentration of 94 ppm, which makes it undesirable as drinking water for infants.

THE ARKANSAS RIVER IS ERRATIC

The average annual flow of the Arkansas River at Tulsa is about 4½ million acre-feet. This volume of water of suitable quality would supply present-day demands for all municipal, irrigation, and farm use in Oklahoma, but the quality of the Arkansas River water at Tulsa is not suitable for any of these uses. Because of the large amounts of salt contributed by the Cimarron River, the Arkansas River is more highly mineralized at Tulsa than at any other point in Oklahoma. In 1950 the flow of the Arkansas River at Tulsa was 5.6 million acre-feet, somewhat above average. The Cimarron River contributed only 22 percent of the water, but it contributed 52 percent of the 4 million tons of salt moving past Tulsa.

Flows of the Arkansas River at Tulsa have been subject to the same large-scale flashy behavior that usually is associated with smaller streams. On May 21, 1957, during the biggest flood in history at Tulsa, a maximum peak flow of 235,000 cfs occurred. Less than a year earlier on October 12, 1956, the record low flow of 27 cfs occurred. Keystone Reservoir will do much to control and stabilize this wide variation of flows. The reservoir, completed in 1964 on the Arkansas River just below its junction with the Cimarron River, provides 1,216,000 acre-feet of storage for flood control and has a lake area of 25,580 acres. The lake is somewhat similar to Lake Texoma in that the Arkansas and Cimarron River arms show distinct differences in water quality. However, where water of one of the Lake Texoma arms is suitable for municipal use, water of neither arm of Keystone Reservoir is of such quality. The water of the upper Arkansas arm of the lake simply is less mineralized than that of the very highly mineralized Cimarron arm. Because of its quality deficiencies, potential use of this impounded supply will be confined to industrial cooling water, flood control, power, and recreation.

As a result of good-quality inflow from tributary streams, the Arkansas gradually improves in quality downstream from Tulsa. Because of this improvement, the river at Muskogee has about the same quality as where it enters Oklahoma at the Kansas line. It still is too highly mineralized for most uses, and the only withdrawal of water from the Arkansas in the Muskogee area is for industrial cooling water. With the completion of Keystone Reservoir the large variations in daily mineral concentrations at Tulsa have been decreased, and quality of the Arkansas River at Muskogee has greatly improved. Maximum chloride concentrations exceeding 5,000 ppm have been observed at times in the Arkansas River at Tulsa. These high concentrations normally occurred on days of low streamflow that would have had a comparatively small effect on the quality of water stored in Keystone Reservior. With the completion of the dam, the chloride concentrations of released water are not much higher or lower than 600 ppm, which when diluted by tributary inflow produces a water of less than half this concentration at Muskogee.

The first principal tributary stream entering the Arkansas River between Tulsa and Muskogee is Polecat Creek. Heyburn Reservoir in this basin provides a recreational lake of 10,200 acre-feet and additional flood-storage capacity of 49,500 acre-feet. The city of Sapulpa is supplied water from a 3,000-acre-foot lake on Rock Creek, a tributary to Polecat Creek below Heyburn Reservoir. Both of these reservoirs impound water of excellent quality for municipal and industrial use, total mineral concentrations being less than 200 ppm.

Between Tulsa and Muskogee the alluvium and terrace deposits along the Arkansas River average more than 5 miles in width, with a maximum of about 7 miles in southern Wagoner County. These deposits consist largely of sand and gravel, and individual wells yield as much as 600 gpm and average 350 gpm. In this stretch of the valley, ground water is used to irrigate 4,500 acres in Tulsa and Wagoner Counties—the largest irrigation development in the central and eastern plains region. The principal irrigated crop is alfalfa but some cotton, pasture, and truck produce are also grown. Because the water table is generally less than 20 feet deep, many wells consist of a battery of 2-inch sand points driven below the water table and pumped from centrifugal pumps on the land surface.

Three small towns a few miles north of the Arkansas River obtain their water supplies from springs that flow from sandstone in the bedrock. These springs are formed where small streams have cut valleys below the water-bearing section of the sandstone.

THE VERDIGRIS RIVER

The next principal artery to the Arkansas River system below Tulsa is the Verdigris River which joins the Arkansas at Muskogee. The Verdigris River originates in Kansas and receives about half its total flow from that State. Though it has a drainage area only a ninth the size of the Arkansas River at this junction, it contributes an average annual runoff of 3 million acre-feet, more than half as much as the adjacent Arkansas River. Surface waters in the Verdigris basin are used widely for municipal and industrial purposes, but the ultimate potential has barely been touched.

The Verdigris River basin contains water having wide variation in chemical quality although acceptable water for most uses can be found at places throughout the basin. In general, water of sufficiently good quality for municipal, irrigation, and many industrial uses can be found in the upper Caney River and Hulah Reservoir, upper Bird Creek, the main-stem Verdigris above Bird Creek, and some of the 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 of the smaller tributary streams 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 average annual flow of the Verdigris River as it enters Oklahoma is about 1.3 million acre-feet. Quality of this water is good—the total mineral concentration is usually less than 500 ppm. The city of Coffeyville, Kans., 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.

Flow in the Verdigris River increases to an average of about 1.7 million acre-feet a year just above its junction with Caney River near Claremore. This flow will be regulated by Oologah Reservoir recently built near the birthplace of Will Rogers. The reservoir is designed for a flood-control storage of 950,000 acre-feet, and a usable conservation storage of 510,000 acre-feet for navigation, municipal, and industrial water supplies. Water impounded in this reservoir meets all raw-water chemical-quality standards for municipal and many industrial uses. The water has a total mineral concentration of about 300 ppm, a hardness of about 170 ppm, sulfate of about 40 ppm, and chloride of about 60 ppm.

The Caney River, which joins the Verdigris River near Claremore, has its headwaters across the Kansas border, but its flow is caught 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. The chloride concentrations of low flows in the river at times exceed 250 ppm, a condition that imparts an unsatisfactory taste to the water.

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 runoff in this basin is excellent, and upstream from the source of pollution the Creek serves as the municipal supply for Pawhuska and several small towns.

Most of the alluvium along the Verdigris and Caney Rivers and Bird Creek is fine grained and is not a very productive aquifer. The only irrigation development in the Verdigris basin is about 1,000 acres supplied entirely by surface water.

Just downstream from its junction with the Verdigris River, the Arkansas receives another major contribution of water from the Neosho River system which is discussed in the section on the Ozark Plateaus (p. 72). The average annual runoff of 5.7 million acre-feet from the Neosho combines with the flow of other streams to produce an average annual runoff in the Arkansas River at Muskogee of 14.5 million acre-feet, about three times that of the Arkansas River at Tulsa. This yearly runoff is equivalent to an average flow of 13 bgd, although the flow has varied from a low of 49 mgd to a high of 420 bgd.

ARKANSAS RIVER ALLUVIUM NEAR MUSKOGEE IS A GOOD AQUIFER

Ground water in the alluvium of the Arkansas Valley between Muskogee and the mouth of the Canadian River is at a slightly higher elevation than water in the adjacent stream. This condition results from recharge of the aquifer by rainfall directly on the surface of these deposits, and it produces a water of better quality underground than that of the surface stream. Total mineral content of alluvial water in the Muskogee area is 300–400 ppm compared to concentrations as high as 3,500 ppm for Arkansas River water at Webbers Falls. Chloride concentrations of alluvial water usually are less than 30 ppm compared to concentrations of as much as 1,800 ppm in the river water.

The alluvium averages about 40 feet in thickness and consists largely of sand and gravel. Depth to water generally is 10–20 feet and yields of wells at favorable sites are 300–500 gpm. Because of shallow water levels and the recharge directly from precipitation on the flood plain, water levels in this aquifer are very sensitive to wet and dry periods. Levels will rise rapidly several feet following prolonged or heavy rainfall, such as occurred in the spring of 1957, and they will decline slowly during a drought, such as in 1956, to a level several feet below average. Water is pumped from these deposits for supplemental irrigation of about 400 acres in the Fort Gibson area and 300 acres in the Webbers Falls area. Considerable additional water can be developed for irrigation and industrial use from the Arkansas River alluvium in the Muskogee-Webbers Falls area.

THE CANADIAN RIVER CONTRIBUTES WATER OF POOR QUALITY TO THE ARKANSAS RIVER

Just downstream from Webbers Falls the Arkansas River is joined by the Illinois River, which drains from the Ozark Plateaus region. It contributes an average annual flow of 1.1 million acre-feet to the Arkansas system. Four miles farther downstream, the Arkansas is joined by the Canadian River, which contributes an average annual flow of 4.5 million acre-feet from a drainage of 47,700 square miles in Oklahoma, Texas, and New Mexico. In the reach of the Arkansas River from Tulsa to the Arkansas border, the Canadian River is the only stream which does not dilute or improve the quality of Arkansas River water. Much of the Canadian River water flowing into the central and eastern plains from western Oklahoma already is highly mineralized. Two principal tributaries in the central and eastern plains region, Little River and North Canadian River, add large quantities of brine as the result of oil-field pollution. However, pollution-abatement measures have improved the quality, and the

Eufaula Reservoir will stabilize the quality, perhaps to about 500 ppm dissolved solids in the reservoir.

EUFAULA RESERVOIR IMPOUNDS WATER OF THE CANADIAN RIVER SYSTEM

The water of the Canadian River system is impounded behind Eufaula Dam 27 miles upstream from the mouth of the river. Eufaula Reservoir has somewhat the shape of a ragged glove with the main stem forming the thumb and the four fingers extending up the Canadian River and its tributary Gaines Creek, and the North Canadian River and its tributary Deep Fork. This recently constructed reservoir has a flood-control capacity of almost 1.5 million acre-feet, and about 2.25 million acre-feet of storage is available for sediment control and hydroelectric power. The average annual flow of the Canadian River at the site is about 4.5 million acre-feet.

Terrace deposits occur in an area of about 60 square miles on the south side of the North Canadian River arm of Eufaula Reservoir. Little water has been developed from these deposits and not much is known about them. However, if the section of saturated deposits is comparable to similar areas upstream, this aquifer should be capable of considerable development for municipal and industrial water.

A somewhat smaller, more eroded area of deposits from which little water has been developed extends along the north side of the Canadian River southwest of Eufaula. The area averages 2 miles in width, and the deposits are about 100 feet thick. Wells yield as much as 250 gpm. The water in this aquifer is of the calcium bicarbonate type and is excellent in quality, its total mineral concentration is about 250 ppm, and it should be suitable for municipal or industrial use or for irrigation.

The Deep Fork originates in the city limits of Oklahoma City a few miles north of the North Canadian River. It flows in an easterly arc past Chandler and Okmulgee to enter the North Canadian River 6 miles north of Eufaula in McIntosh County. At present, no use is made of Deep Fork water, mainly because of its poor quality from oil-field pollution. At one time Okmulgee withdrew its water directly from it, but when the water became too salty, the city abandoned the supply and obtained a new surface source by an impoundment on a nearby tributary. That source is excellent in quality with a total mineral content of only 150 ppm.

QUALITY OF THE WATER OF THE NORTH CANADIAN RIVER AND ALLUVIUM IS POOR

The North Canadian River, which drains an area of 17,700 square miles, is a major stream system in its own right. It contributes an average annual runoff of 1.7 million acre-feet to Eufaula Reservoir and the Canadian River. About half this contribution is from runoff in Deep Fork. The North Canadian River in this region and the lower reaches of Deep Fork are both highly mineralized from oil-field brines, and their contributions do nothing to improve the quality of the Canadian River.

The North Canadian River is a principal source of water for Oklahoma City through storage in two off-channel reservoirs, Lakes Overholser and Hefner. At times, excessive flows above those needed to keep the lakes filled have caused flood damage as the stream flowed through Oklahoma City. In 1941 when the North Canadian had a flow of 17,000 cfs at the 23rd Street bridge, the river was out of its banks and caused extensive damage to the city. The 13½ mile floodway now passing through Oklahoma City will carry a flow of 45,000 cfs.

The quality of North Canadian River water begins to deteriorate almost immediately below the point of withdrawal for Oklahoma City's municipal supply. Before the river gets outside the city limits, the introduction of oil-field brines and industrial wastes sometimes increases chloride concentrations from 60 ppm at the storage lakes to more than 10,000 ppm. This degraded quality continues throughout the rest of the stream course, and in 1956 the North Canadian River at Wetumka carried more than 8,000 pounds of salt for each acre-foot of water. As a comparison, this stream at the Oklahoma City water-supply intakes carried only 340 pounds of salt for each acre-foot of water. Even though North Canadian River water is not suitable for municipal or irrigation use below Oklahoma City, it is used as a source of industrial cooling water by power plants near Harrah and Weleetka.

The natural runoff in most of the smaller streams tributary to the North Canadian River below Oklahoma City produces water of excellent quality. These surface sources provide municipal supplies for Shawnee and other towns along the river. All these supplies have total mineral concentrations of about 100 ppm. Pollution-abatement measures in recent years have brought about a gradual improvement of water quality in the North Canadian River. A continuation of this improvement, in combination with the excellent quality in flow from tributary streams in the lower reaches, may result in more effective uses of North Canadian River water below Oklahoma City.

The oil-field brines that degraded the North Canadian River water also caused extensive deterioration of water quality in the North Canadian alluvium below Oklahoma City. Because of this poor quality, the city of Shawnee found it necessary 30 years ago to abandon its well field in the aquifer and go to a surface source of supply. Recent improvement in brine-disposal methods of the Oklahoma City oil fields and the good water added to the formation from natural recharge by rainfall on the flood plain have brought about some improvement of water quality. The water is acceptable at places for irrigation, and more than 2,000 acres in Pottawatomie County are irrigated from 20 wells tapping the aquifer. The alluvium and adjoining terrace deposits average about 4 miles in width between Oklahoma City and Okfuskee County, and are 1–2 miles wide across southern Okfuskee County. The North Canadian alluvium in the western part of this region provides a ground-water reservoir that has a capacity and a potential for much greater development for uses where water-quality requirements are not too stringent. If brine-disposal methods continue to improve until this source of pollution is eliminated, water quality in both the stream and the alluvium will gradually improve until both sources will reach acceptable standards for irrigation, municipal and many industrial uses.

Little River originates in the southern part of Oklahoma County and flows about parallel to the Canadian River before flowing into it in western Hughes County. In the upper reaches of Little River near Norman, where this stream has an average annual runoff of 65,000 acre-feet, a reservoir for municipal-water supply was recently completed. The natural runoff in this part of the basin over the sandstone and shale of the red beds produces a calcium bicarbonate water of excellent quality. The impounded supply will have a total mineral concentration of about 250 ppm dissolved solids, a hardness of 175 ppm, and sulfate and chloride concentrations of 15 ppm and 30 ppm, respectively. In the lower reaches of Little River, oil-field brines discharged into the stream have made low flows more concentrated at times than sea water. During 1956 the Little River drainage basin contributed only 5 percent of the measured streamflow of the Canadian River near Whitefield, but contributed 43 percent of the chloride load. This load amounts to an equivalent of 26 million barrels of brine discharged into the Little River system between the reservoir site near Norman and the mouth of the stream, a distance of 96 river miles. Pollution-abatement measures in recent years have reduced these chloride concentrations; for instance, in 1962 they did not exceed 1,500 ppm, even at low flows.

The Canadian River in the central plains has the same broad sandy channel that characterizes it in western Oklahoma. It generally becomes perennial near Purcell and gradually picks up flow downstream from small tributaries. Because of its narrow drainage basin, the tributaries are short and drain small areas but, except for Little River, their flow improves the quality of water in the river.

The alluvial deposits of the Canadian River in this area are similar in width, character, and thickness to those upstream in western Oklahoma. The aquifer now supplies municipal water to a few small towns, and a considerable quantity of additional water could be developed from these deposits. However, the development would need to be carefully planned so that excessive pumping did not draw the poor-quality river water into the alluvium. An irregular band of sand and gravel that is nearly 200 feet above the

Canadian River and which reaches a width of about 4 miles in northeastern Garvin County probably represents deposits formed by the Canadian when it flowed at a much higher elevation many thousands of years ago. These deposits supply water for several irrigation wells and are the source of municipal water for the town of Stratford. Similar deposits on the north side of the river supply municipal water for the town of Konawa.

In contrast to the bad effects of Little River inflow to the Canadian River water, the next major downstream tributary, Gaines Creek, contributes an average annual runoff of about 800,000 acre-feet of water of excellent quality to Eufaula Reservoir. This stream heads in the northern edge of the Ouachita Mountains; its water usually has less than 200 ppm total mineral content. McAlester and the nearby Naval Ammunition Depot obtain their water supplies from impoundments of tributary streams in the Gaines Creek basin.

GOOD WATER IS PLENTIFUL NEAR THE ARKANSAS BORDER

Between the junction of the Canadian and Arkansas Rivers and the Oklahoma-Arkansas border, tributary streams contribute an average of 3 million acre-feet a year to the Arkansas River. These contributions make an average annual flow in the Arkansas River at the State line of about 23 million acre-feet. Development of surface storage in this reach of the river system consists of a low-water dam on Sallisaw Creek, to provide municipal water to Sallisaw, and Wister Reservoir, a flood-control and recreational lake on Poteau River about 10 miles southwest of Poteau. This reservoir has a flood-control storage of 400,000 acre-feet and a conservation pool of 30,000 acre-feet used for recreational purposes. Poteau River, Sallisaw Creek, and other tributaries to the Arkansas River in this area drain the northern slopes of the Ouachita Mountains on the south side and the south flanks of the Boston Mountains on the north side. Water in all these streams is excellent in quality, having total mineral concentrations most of the time of less than 100 ppm. These tributaries lie in a rainfall belt of about 45 inches annually and furnish abundant water of excellent quality suitable for irrigation, municipal, and industrial development. As a result of good-quality inflow from all tributary streams between Tulsa and the Arkansas border, with the exception of the Canadian River, the quality of water in the Arkansas River is better where it leaves the State than where it enters at the Kansas border.

The flood plain of the Arkansas River from the mouth of the Canadian to the Arkansas border averages about 3 miles in width. The deposits in this valley are about 40 feet thick and consist largely of sand and gravel. Several irrigation wells tapping these deposits are scattered along both sides of the river especially near the State border. The aquifer has considerable potential for additional development of municipal, irrigation, and industrial water supplies.

THE WATER FUTURE IS BRIGHT

One of the features of the central and eastern plains which contrasts markedly with western Oklahoma is the abundance of water available for future development. Plans for development of navigation on the Arkansas and Verdigris Rivers up to Catoosa near Tulsa include the construction of five major reservoirs: Oologah on the Verdigris River, Keystone, Webbers Falls, and Short Mountain on the Arkansas River, and Eufaula on the Canadian River. Three have been completed and Webbers Falls and Short Mountain are now (1965) under construction. In addition, the Oklahoma part of this system will have one lock and dam on the Arkansas River and two on the Verdigris River for maintaining navigation channels suitable for barge traffic.

WATER RESOURCES OF THE OZARK PLATEAUS OF OKLAHOMA

SCENERY AND MINES

The Ozark region of Oklahoma (fig. 16) is often referred to as the "Playground of the Ozarks." The combination of scenic wooded hills, deep valleys with clear spring-fed streams, and 130 square miles of lake surface in the man-made impoundments of Grand (Lake O' the Cherokees), Spavinaw, Fort Gibson, Greenleaf, Hudson and Tenkiller Lakes provides an attractive recreational area serving eastern Oklahoma and adjacent States.

This region was the first in Oklahoma to be occupied by white men, and the town of Salina, founded in 1802, the first permanent white settlement. For about 75 years preceding statehood, the region was part of the Cherokee Nation with its capital at Tahlequah. It also was the home of the famous Indian educator Sequoyah, who lived near the town of Sallisaw.

Rainfall throughout the Ozark Plateaus region is rather uniform; it varies from an average of 40 inches annually at the northeastern corner of Ottawa County to 44 inches along the Arkansas border. Average precipitation for the region is only a few inches less than that of the maximum-rainfall area of the State near the southeastern corner. Like the rest of Oklahoma, this region has considerable fluctuation in rainfall from year to year. At Tahlequah the annual rainfall averages 42 inches, but it has ranged from a low of 25 inches in 1954 to a high of 65 inches in 1945. This variation in rainfall is one reason why impounded storage is necessary, even for these well-watered eastern areas, to provide dependable supplies to last through the dry months and the drought years.

The Ozarks are not mountains in a geologic sense, but wooded flat-topped hills in which stream valleys 200 to 300 feet deep have been cut. Bordering the plateaus on the

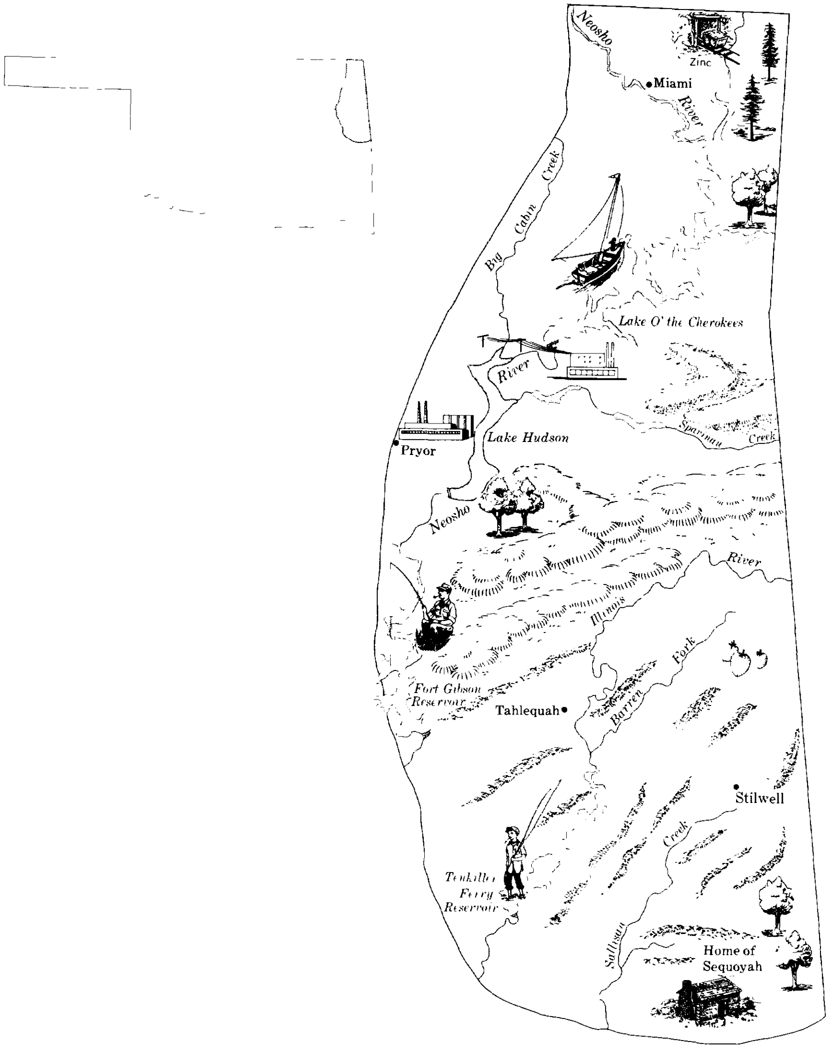

FIGURE 16.—Features of Ozark Plateaus region.

south and southeast are the Boston Mountains, an area about 50 miles wide. Huge blocks of resistant sandstone several miles long have been broken, raised, and tilted to form elongated ridges separated by streams flowing in valleys 300 to 500 feet deep. Parts of the Boston Mountains are known locally as the Cookson Hills and the Bushy Mountains.

In contrast, the northwestern half of Ottawa County is essentially a plain of little relief that is not marked by the timbered hills characteristic of the rest of the region. This part of Ottawa County is the site of the only metal-producing mines in Oklahoma, and it is part of the tristate mining district which includes parts of Kansas and Missouri. Lead was first mined in the area in 1891, and zinc in 1894. About 60 percent of the lead and zinc mined in this district has come from Oklahoma. More than a billion dollars worth of lead and zinc ores have been produced from the Oklahoma part of the district.

WATER DEVELOPMENT IN THE OZARKS

The Neosho River, in Oklahoma called the Grand River, drains an area of 5,800 square miles in Kansas. The Neosho River contributes an average annual inflow to Oklahoma of a little more than 2 million acre-feet. This inflow, together with that of such major tributary streams as Spring and Elk Rivers, is impounded by the largest multiple-arch dam in the world to form Lake O' the Cherokees, commonly referred to as Grand Lake. This reservoir, completed in 1940, was the first major manmade lake in Oklahoma. It was constructed primarily for the development of hydroelectric power by the Grand River Dam Authority, a State agency which operates the project. The power pool of the lake has a capacity of 1½ million acre-feet, and incidental flood-control features of the reservoir contain an additional storage facility for half a million acre-feet.

Quality of water in the Neosho, Spring, and Elk Rivers feeding Grand Lake is uniformly good. These rivers combine to produce an impounded supply that is a calcium bicarbonate water having a total mineral concentration of about 225 ppm, a hardness of about 160 ppm, and insignificant concentrations of chloride, sulfate, and sodium. Vinita and other cities in the adjacent area are supplied municipal water from Grand Lake, and Pryor withdraws municipal water from the Neosho River at a low-water dam 34 miles below Grand Lake. An extensive industrial development in the Pryor area consisting of two paper-product plants, a carbide chemical plant, a nitrogen-products plant, and a cement plant is one of the benefits shared by Oklahomans as a result of surface-water developments on the Neosho River. These industries are supplied processed steam, cooling water, and electric power from the Grand River Dam Authority project on Grand Lake.

In the lower reaches of the Neosho River, Fort Gibson Reservoir impounds 365,000 acre-feet of water for hydroelectric power, municipal and industrial water supply, and recreation; it has an additional 922,000 acre-feet of storage available for flood control. Muskogee and Wagoner are furnished municipal water from Lake Fort Gibson. Quality of water in Lake Fort Gibson is typical of water throughout the Neosho River basin of Oklahoma—it is excellent in quality for municipal use with a total mineral concentration of 200 ppm, hardness of 150 ppm, and chloride concentration less than 20 ppm.

The Illinois River drains an area of 755 square miles in Arkansas before flowing into Oklahoma at the east-central part of the Ozark region. The stream curves to the south in Oklahoma and flows into Tenkiller Reservoir southeast of Tahlequah, a few miles upstream from the junction of the Illinois River with the Arkansas River. This lake impounds 630,000 acre-feet of water for hydroelectric power and recreation, and an additional 600,000 acre-feet of storage is available for flood control. Quality of water impounded in this reservoir is typical of surface waters throughout the Ozark region—an excellent quality for just about any use with a total mineral concentration of about 100 ppm, a hardness of about 75 ppm, and less than 10 ppm each of chloride, sulfate, and sodium. This supply of surface water offers excellent potential for future development of municipal, industrial, and irrigation uses.

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GROUND WATER ALSO IS IMPORTANT TO THE REGION

Ground water, too, is an important factor in supplying municipal and industrial water, particularly to the northeastern part of the region. In the Miami area and the tristate mining district a few miles to the north, ground water has been extensively developed from deep sources. Sandy zones 100–200 feet thick at depths of 900 to more than 1,000 feet make up the major aquifer in this area. When wells were first developed to tap the underground supply in about 1900, artesian pressure was so great that the wells flowed freely at the land surface. However, because concentrated pumpage in a small area has decreased the artesian pressure, water levels are now about 400 feet below the land surface. Yields from the aquifer still are high—as much as 600 gpm for individual wells. The water is of the calcium bicarbonate variety and is excellent for municipal use, with a total mineral concentration of about 135 ppm and chloride and sulfate concentrations of 42 and 15 ppm respectively. This aquifer is the source of water supply for the city of Miami, for the principal industrial plants in the Miami area, for the mills in the lead-zinc mining district, and for several small towns in western Ottawa County and eastern Craig County. The daily pumpage from this aquifer is about 2½ million gallons, most of which is pumped from an area centered in north-central Ottawa County.

The lucrative mining activities of previous years may lead to problems of water pollution in future years. The rocks that contain the lead and zinc ore are badly shattered and fractured and contain many openings filled with water. As a result of contact with the ores, this water is strongly acid and contains high concentrations of iron and sulfate. During the period of heavy mining activity in the early 1940's, excess water was pumped from the mines at a rate of 13 million gallons a day. The decline in mining activity, accompanied by reduced pumping for mine dewatering, has resulted in the filling of many of the mines and mine shafts with water. As this highly mineralized water accumulates, some of it eventually may move downward along natural fractures or old wells to contaminate the deeper aquifer containing water of good quality.

The limestone and flinty limestone beds that make up the resistant rocks forming the hills of the Ozark Plateaus also are the rocks forming the principal aquifer of the region. Water moving through small cracks and fractures in these beds has gradually dissolved passageways that have developed into moderate-size caverns. These caverns are filled with water which flows out through the numerous springs of the region. Because of the fractured rock and flinty porous soils, precipitation readily soaks into the aquifer to provide a continual and plentiful replenishment to the reservoir. Limestone and other fractured rocks are not good filtering agents, and as a result bacteriological contamination of the supplies may readily occur. However, water may be easily treated for this type of pollution by the addition of chlorine or some other disinfecting agent. Chemical quality of the calcium bicarbonate water is excellent for municipal, irrigation, and most industrial uses.

The aquifer is about 300 feet thick throughout a large part of the area, so the ground-water reservoir contains a tremendous quantity of water. Springs issuing from the reservoir provide the headwater flow for most of the streams that start in the Ozark region. Spring flow in Ottawa County alone, which is a very small part of the region, is more than 14 million gallons a day, nearly half as much as the water requirement for Oklahoma City. Other springs are the source of municipal water for towns in Delaware, Mayes, and Adair Counties. Although this underground source of supply is tapped widely throughout the Ozarks for individual farm use, it is virtually undeveloped. It could supply large quantities of water for irrigation or industry.

One of the streams which derives much of its flow from springs issuing in the Ozarks is Spavinaw Creek, on which the city of Tulsa has developed two reservoirs for municipal supply. Tulsa is about 90 miles southwest of the Spavinaw lakes, but favorable topography allows water to be transported by gravity flow throughout this distance. Water from this source is one of the best municipal supplies in Oklahoma from a quality standpoint. It has a total mineral concentration of about 100 ppm, a hardness of about 90 ppm, and less than 10 ppm each of sodium, sulfate, and chloride.

Several small towns in the central and eastern plains also are furnished water from the Tulsa supply.

THIS REGION IS RICH IN WATER RESOURCES

Surface water in the Ozark Plateaus region is the most highly developed of any part of Oklahoma, yet the ultimate potential has barely been touched. This water probably is the best present and potential source of surface supplies in the State. Every major stream, tributary stream, and lake impoundment is of sufficiently good quality for municipal, irrigation, and many industrial uses.

The system of surface reservoirs in this region offers an ideal opportunity to illustrate the advantages of the use and reuse of the same water by several users. The completion, in 1963, of Hudson Lake southeast of Pryor on the Neosho River between Grand Lake and Fort Gibson Lake further increases the opportunities for multiple use of the same water. This reservoir impounds 200,300 acre-feet of water for recreation and hydroelectric power and an additional 244,000 acre-feet of storage available for flood control. The same water that provides recreation in Grand Lake generates power as it flows through the turbines at the dam. As it flows out of Hudson Lake, it then generates more power at Kerr Dam, and is used in the Pryor area downstream as a source of industrial and municipal water. The water then flows into Lake Fort Gibson to provide more recreation and hydroelectric power as well as water for the municipal and industrial supplies of Wagoner and Muskogee. This same water then flows into the Arkansas River to become an integral part of the future navigation system for that stream.

The largely undeveloped ground-water reservoir in the central part of the region is capable of supplying several hundred gallons of water a minute to wells in a wide area. Only a small area is now under irrigation in the region, and the future may see a considerable increase in supplemental irrigation from ground water.

WATER RESOURCES OF SOUTHEASTERN OKLAHOMA

HISTORY IN THE ROCKS

Southeastern Oklahoma was the scene of some of the State's earliest developments of natural mineral resources. Coal was first mined in 1872 from a vein near McAlester, and a well drilled 12 miles west of Atoka in 1888 was the first attempt to find oil in Oklahoma. Today the region is best known for its vast timber and water resources. The lumber industry in McCurtain County has thrived for many years, but the economic development of the water has barely begun.

A person flying over the southeastern region (fig. 17) could easily wonder if he were actually over Oklahoma. Southeastern Oklahoma has none of the plains or red rocks, and little of the oil, wheat, and cotton so characteristic of the rest of the State. Red River, which forms the Oklahoma-Texas boundary to the south, is bounded by a sandy alluvial plain 1–6 miles wide. North of this alluvial plain is an area of gently rolling hills and low bluffs, formed on loose sand and beds of clay which make up the West Gulf Coastal Plain physiographic section. The plain has a maximum width of about 35 miles near Durant and averages 25 miles in width from Lake Texoma east to the Arkansas border.

Southeast from Sulphur and Ada, the main mass of the Arbuckle Mountains is made up of broken and jumbled limestone, sandstone, and granite in an area about 30 miles square. East and northeast from Atoka, there is a large area of sharp-crested elongated ridges and deep stream valleys which forms some of the most rugged and beautiful topography in Oklahoma. These ridges, the Oklahoma part of the Ouachita Mountains, include the Pine Mountains, Jackfork Mountain, Winding Stair Mountain, and the Kiamichi Mountains. The highest peak in this part of the State, Rich Mountain, which is about 25 miles south of Poteau, has an

FIGURE 17.—Features of southeastern Oklahoma.

elevation of about 2,700 feet. The lowest elevation in the State, only 73 miles south of Rich Mountain, is where the Red River leaves Oklahoma at an elevation of about 300 feet. The dense slaty shale and hard sandstone that largely make up the Ouachita Mountains coupled with the rugged topography result in a poor supply of ground water. However, small supplies adequate for farm and domestic use and small towns can be obtained at many places.

The lush vegetation and dense forests of the Ouachita Mountains and the eastern part of the Oklahoma Coastal Plain area contrast markedly with the grasslands and bare rocks of the Arbuckle Mountains. A record of one-fourth the earth's geologic history, nearly a billion years, can be read in the rocks that make up the small area known as the Arbuckles. Nowhere else in Oklahoma and probably not in

North America is such a large measure of geologic time evident in such a small, compact area. The granite and other crystalline rocks that form the core of the mountains in the vicinity of Reagan and Tishomingo are about 1.3 billion years old. Grouped around these crystalline rocks and overlying them to the north and west are younger sandstone, shale, and limestone that record a history of several hundred million years, ending with the period in which the red beds making up most of western Oklahoma were formed about 200 million years ago. Forces that dwarf the largest nuclear bomb into insignificance pushed these rocks to the surface and folded and fractured them, leaving great sandstone ridges and broad areas where massive limestone beds have been tilted and stood on edge. South of Davis on U.S. Highway 77, signboards and markers that identify the rock units and describe the geologic events and structures provide the layman with a brief course in geology.

WATER IS ABUNDANT IN LIMESTONE OF THE ARBUCKLE MOUNTAINS

In the northeastern part of the Arbuckle Mountains a thick sequence of massive limestone beds is exposed over a 200-square-mile area in southwestern Pontotoc and northwestern Johnston Counties. The limestone is bordered on the south by granite rock near Reagan, by younger sandstone near Connerville on the east, and by shale and sandstone on the west and north. The limestone is several thousand feet thick and contains fresh water to depths of 3,000 feet, which is about 2,000 feet below sea level. The forces that tilted and folded the main masses of the Arbuckle Mountains broke and fractured the limestone and provided easy access routes for water. Solution cavities and enlarged openings were produced over a period of several million years; a tremendous reservoir for underground storage was thus created, as well as openings from which springs issue to maintain surface flow of streams such as Mill, Rock, and Blue Creeks. One of the larger springs is Byrds Mill Spring, 12 miles south of Ada, which supplies water for that city. During the recent drought years the flow from this spring has ranged from 3½ to 22 million gallons a day.

Several irrigation wells were drilled in the limestone in 1956 and 1957, some yielding as much as 700 gpm. Because the surface of the 200-square-mile area is irregular, depth to water ranges from 50 to more than 100 feet but generally is less than 100 feet. Near the town of Sulphur the limestone is covered with younger rocks, and artesian wells that flow at the surface have been developed for industrial supply. The best of these wells yields about 2,000 gpm from a depth of 868 feet. In addition to Ada, municipal supplies for several smaller towns are derived from this limestone aquifer. Quality of water in the limestone is uniformly good throughout the area, with low sulfate and chloride concentrations. It is predominantly a calcium bicarbonate water with a total mineral concentration of about 500 ppm and a hardness of about 300 ppm. This hardness is mostly carbonate which could be removed easily at the treatment plant if desired.

SANDSTONE ALSO IS A GOOD SOURCE OF WATER

A series of sandstone beds totaling about 300 feet in thickness covers the limestone beds and forms the land surface in a 60-square-mile area of northeastern Johnston County. Smaller areas of the sandstone occur in central and in southeastern Pontotoc County, and in irregular areas east of Sulphur where they are much thicker. At Mill Creek a clean pure bed of this sandstone is mined for the manufacture of glass. The sandstone is fine grained and loosely cemented, so it yields water freely to wells. In the Pontotoc County area, the mountain-building events have created geologic structures suitable for artesian wells. Southwest of Ada a well drilled for industrial water taps the sandstone at a depth of 1,600 feet and produces 400 gpm. This aquifer supplies water for farm use in its outcrop area and domestic supplies for several small communities. Quality of water in the outcrop area is somewhat better than that issuing from the limestone, largely because of a lower hardness (about 150 ppm).

The sandstone is the source of many springs and wells flowing under artesian conditions in Platt National Park at Sulphur. The water contains high concentrations of sulfur, bromide, and iodide—constituents normally not found in natural water—and this has led to general acceptance by the public that the water has medicinal value. The municipal water supply for Sulphur is obtained from artesian wells 600 feet deep that tap a local conglomerate formation of small extent. This conglomerate is derived from limestone beds similar to those of the northeastern part of the mountain area, and the water quality is practically identical to that at Byrds Mill Spring. The aquifer also is the supply for Buffalo and Antelope Springs in Platt National Park. These springs respond rapidly to wet and dry cycles—a feature that suggests that the reservoir is of very small extent.

GROUND WATER MAINTAINS BLUE RIVER FLOW

The water-yielding capacity of the Arbuckle Mountains limestone aquifer is reflected by the rather high perennial flow in the uppermost reaches of Blue River, there known as Blue Creek. This stream has a drainage area of 122 square miles at a point near Connerville where the lowest flow observed during 1951–57 was 7.3 million gallons a day. A considerable amount of water is withdrawn from this stream for irrigation, and farther downstream, where it becomes known as Blue River, it supplies municipal water for Durant and water for a State fish hatchery. Quality of water in the Blue River also reflects its kinship to the limestone aquifer. The water is a calcium, magnesium bicarbonate type, with sodium, chloride, and sulfate concentrations of less than 25 ppm. The hardness generally is less than 250 ppm and is mostly of the carbonate variety which can be removed easily.

East and northeast of the Arbuckle Mountains the limestone beds are bounded by a gently rolling area of sandstone and shale layers. These rocks are relatively dense and do not contain large quantities of ground water. For this reason, streams of the Boggy Creek basin just east of Blue River are not perennial but go dry during rainless periods. The only significant base flow in the basin is that provided to Clear Boggy Creek in its upper reaches by flows from Byrds Mill Spring, a part of which is diverted for municipal requirements of Ada. Even this source fluctuates, and during the drought year of 1956 the yields from Byrds Mill Spring were barely sufficient for Ada's needs. During this same drought year there were 82 days of no flow on Clear Boggy Creek near Caney. However, the total yield for the year was 35,000 acre-feet, equivalent to the amount of water Oklahoma City used that year.

Clear Boggy Creek is the odd stream in southeastern Oklahoma so far as quality is concerned. It is the only surface-water source that does not have uniformly good quality suitable for just about any beneficial use. Oil-field pollution in southeastern Pontotoc County contributes sizable amounts of salt to this water. The main deleterious effect from the pollution is on the individual user who withdraws small amounts of water for irrigation during low-flow periods—a time when salt concentration is highest. On an annual basis these excessive amounts of salt do not materially affect the water quality. In the 1956 drought year, chloride concentrations of Clear Boggy Creek near Caney were as much as 800 ppm, although the average concentration for the entire year was only 104 ppm.

OTHER SURFACE WATER IS PLENTIFUL AND GOOD

The increase in precipitation eastward across Boggy Creek basin is reflected in the high flow of Muddy Boggy Creek, just below McGee Creek near Farris. The average annual flow at this site is almost 700,000 acre-feet, equivalent to the average annual flow in the Canadian River near Ada, which drains an area about 20 times as large as Muddy Boggy. Yields in this area are so high that substantial amounts of water can be developed from relatively small drainage areas. Oklahoma City has developed almost 100,000 acre-feet a year in Atoka Reservoir on North Boggy Creek from a drainage area of 179 square miles. A flood-control reservoir authorized on the lower reach of Muddy Boggy River near Boswell, where the average annual runoff is 1.5 million acre-feet, may include 1 to 2 million acre-feet of storage for water-supply purposes.

Major impoundments being considered for development of surface waters in southeastern Oklahoma include Hugo Reservoir and four others on the Kiamichi River and six reservoirs in the Little River drainage basin as part of an overall design for flood control and water supply in this stream system. The present (1965) authorized design for Hugo Reservoir on the Kiamichi River includes a conservation pool of 20,000 acre-feet and an additional 830,000 acre-feet of storage for flood control. Consideration is being given to an enlarged conservation pool of 643,000 acre-feet for this impoundment in order to provide municipal and industrial water to Hugo and more distant points. At the present time the only withdrawal use of water from the Kiamichi River is for the municipal supply of Antlers. The average annual runoff at this site of withdrawal is 1.6 million acre-feet, and, with the total mineral concentration seldom exceeding 100 ppm, the water is suitable for any use.

Glover Creek, Mountain Fork River, and Little River yield tremendous quantities of water, equal in quality to that of the Kiamichi River, with total mineral concentrations usually about 50 ppm. Runoff increases eastward across the Little River drainage basin and reaches a maximum of 25 inches annually at its junction with Mountain Fork. An average of 2½ million acre-feet of water a year goes into Arkansas via the Little River route. Including this flow, the Red River system has an annual discharge of 12 million acre-feet of water at the southeast corner of Oklahoma.

GROUND WATER FROM COASTAL PLAIN DEPOSITS IS VARIABLE

The Coastal Plain area east of Lake Texoma is bounded by the Red River on the south and by the towns of Tishomingo, Atoka, Antlers, and Broken Bow on the north. The rocks forming this plain are about 100 million years old—much younger than the rocks making up the Arbuckle and Ouachita Mountains. The beds forming the Coastal Plain overlap each other from north to south like shingles on a roof. Thus, all beds dip toward the south, and those that are exposed at the northern edge of the plain are buried deepest at the southern border of the State.

Beds of loose fine-grained sand in a 10-mile-wide belt at the northern edge of the Coastal Plain readily absorb rainfall and transmit water to the underground reservoir. Farther to the south where these beds are overlain by denser rocks, artesian conditions exist, and in favorable spots wells flow at the land surface fig. 18. A well in McCurtain County has flowed 3 mgd continuously since it was drilled in 1937. Water from this aquifer is the source of municipal supply for Hugo and several smaller towns in the area. During the last few years the reservoir also has been tapped by some irrigation wells, and in McCurtain County it is used as a source of industrial supply for small lumber mills and other small industries. Wells produce as much as 400 gpm, but because the sands are very loose, particular care is required in construction to prevent the pumping of sand.

The conditions under which water enters and moves through the rocks in the Coastal Plain aquifer are very diverse, and resulting water quality is extremely variable. The mineral concentration of water in the outcrop area to the north, where it has moved but a short distance through the formation, differs greatly from that several miles downdip under cover of younger formations where wells may be 600–800 feet deep. Total mineral concentration ranges from 130 to 1,240 ppm, hardness from 8 to 530 ppm, sodium from 1 to 350 ppm, and bicarbonate from 10 to 580 ppm. The extensive reservoir, broad recharge area, and ample rainfall available for recharge combine to produce a water supply of great potential for future development. However, the problems of well construction and variable water quality require careful exploration and planning before any large developments are carried out.

SOUTHEASTERN OKLAHOMA HAS A SURPLUS FOR EXPORT

Additional development of both ground and surface waters in southeastern Oklahoma for supplemental irrigation and for industrial use are expected, but this area is likely to have a surplus of water available for export to the less water-fortunate areas.

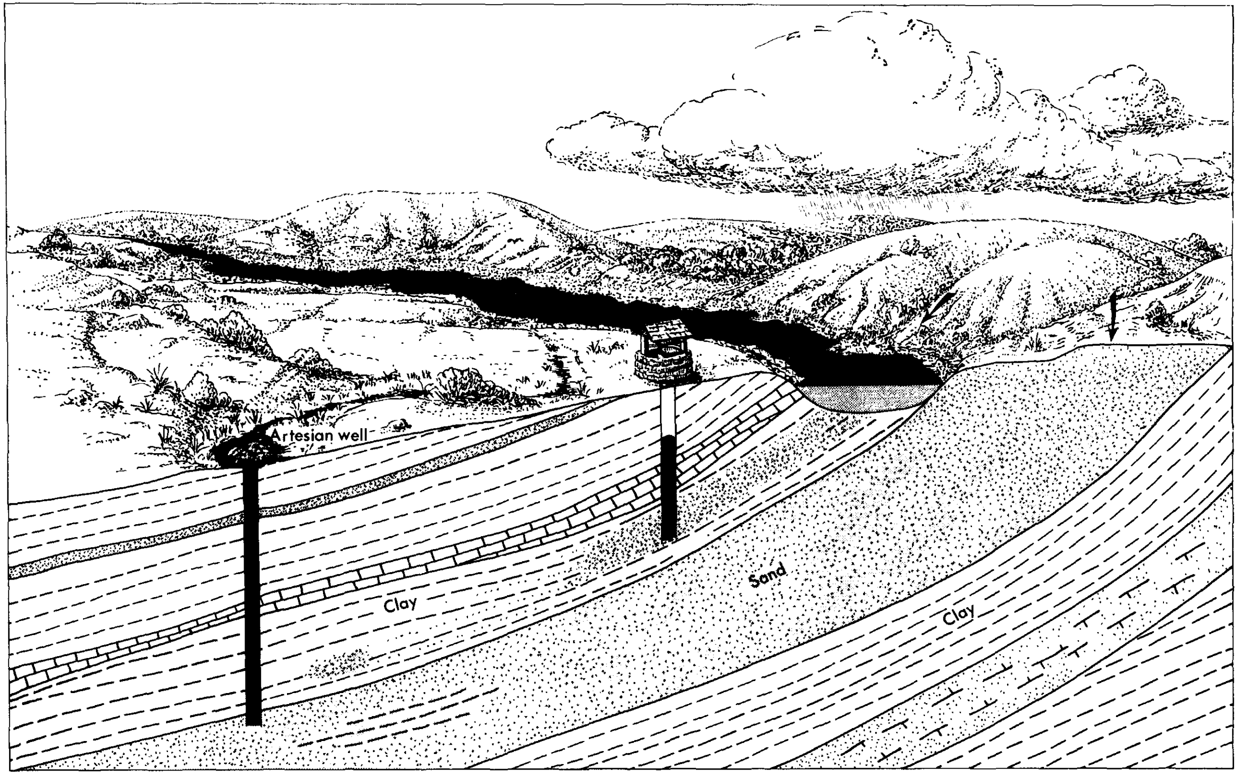

FIGURE 18.—Overlapping beds and artesian-well conditions. Individual layers of rock that form the Coastal Plain dip southward and overlap each other like shingles on a roof. Rainfall entering sand where it comes to the surface seeps slowly southward along the dip of the beds. In favorable places, as at the left of this diagram, the pressure of water in the aquifer causes wells to flow at land surface, and such wells are termed "artesian."

WATER SUPPLIES FOR PRINCIPAL URBAN CENTERS

CITIES AND INDUSTRIES GROW

The first 60 years of Oklahoma statehood have seen a gradual and continuing shift in population from rural to urban. In 1910, 3 years after statehood, more than 80 percent of the population lived in rural areas. By 1965 this relation had been reversed, and the urban population now exceeds the rural. The trend toward urbanization and industrial growth to supplement the agricultural economy likely will continue. This type of growth will change trends in agriculture and will increase demands for suitable water supplies. The ability of urban and trade centers and of rural areas to meet these water demands will require a careful and continuing audit of Oklahoma's water bank, which in places already is under considerable strain to keep deposits on a par with the withdrawals.

OKLAHOMA CITY'S WATER SUPPLY

In 1940 Oklahoma City, the largest city and the State capital, had a population of 204,424 and used an average of 13.4 mgd of water. By 1960 the city had expanded to about 650 square miles and into four counties. Population had grown to 324,253, and an additional 120,000 people lived in the urban area of Oklahoma County and northern Cleveland County. Average water use in the urban area in 1964 was about 60 mgd. Of this amount, 38.0 mgd, including 5.5 mgd furnished to commercial and industrial users, was supplied by the Oklahoma City municipal system. On the peak day, July 21, 77.8 million gallons was used. Ground-water use in the urban area was about 21 mgd, including about 10 mgd by self-supplied industries, 7.3 mgd by smaller cities, and 4 mgd by Tinker Air Force Base.

Oklahoma City's municipal water is obtained principally from the North Canadian River. This water is stored in two off-channel reservoirs, Lakes Overholser and Hefner, which have a combined storage capacity of 97,000 acre-feet or 31 billion gallons. This amount of water should last the city about 2 years. However, flows from the North Canadian River do not assure the filling of the lakes even once every 2 years. During the 2-year period from 1953 to 1954, flow in the river was only 70,000 acre-feet.

Oklahoma City looked elsewhere for additional water, and the immediate needs were supplied by developing ground water from the two principal aquifers in the area. In 1955 about 220 million gallons of water was pumped from 82 shallow wells in the North Canadian alluvium west and southwest of the city. During this period about 300 million gallons was pumped from 22 deep wells in the bedrock aquifer in the northern and northeastern parts of the city. An additional 90,000 acre-feet of storage has been rented in Canton Reservoir since 1955. Releases from this storage are planned for times when riverbed conditions allow a maximum part of the water to reach the lakes 110 river miles below the dam. Because the North Canadian River loses water to the alluvium in this reach, losses of released water are large. Of the 26,600 acre-feet of water released from Canton Reservoir in July 1956, about 39 percent or 10,400 acre-feet was lost in transit. (See fig. 14.) In March 1957, when river conditions were somewhat more favorable, only 28 percent of a similar release was lost.

Because of erratic flows, the North Canadian River is not an adequate source of municipal supply. The ground-water aquifers in the area are already being pumped extensively and cannot supply large additional quantities of water. Although the capital city is within 30 miles of two other major rivers, the Cimarron and the Canadian, these streams cannot supply much additional water of suitable quality for municipal use. The Cimarron River to the north is too highly mineralized at virtually all stages of flow for consideration as a source of water, and under present conditions, impoundment on the Canadian River to the south would not provide suitable water. Even off-channel storage would not provide quantities needed for a city the size of Oklahoma City.

Some additional water could be developed from the North

Canadian River by providing additional storage to catch the flood and wet-weather flows, such as the 362,000 acre-feet of water that passed Oklahoma City in 1957 when both Lakes Overholser and Hefner were brimful. However, such flows are infrequent, and a tremendous amount of storage would be required to utilize and develop the water in quantities to last through droughts.

Several areas in eastern Oklahoma are capable of supplying water of good quality in amounts adequate for future needs in the Oklahoma City area. Oklahoma City has chosen to develop a series of reservoirs in the southeastern mountains. Construction has been completed on the first of these reservoirs, a 125,000-acre-foot impoundment on North Boggy Creek northeast of Atoka. Water from this lake is pumped through a 100-mile 60-mgd-capacity pipeline that lifts the water 600 feet to Stanley Draper Lake, a 100,000-acre-foot terminal lake on Elm Creek southeast of the city. Between July 1964 and June 1965 about 46 percent of the water used by the city, nearly 6½ billion gallons, was from this source.

Other reservoirs under consideration in the master plan of development include impoundments of McGee Creek, Buck Creek, Tenmile Creek, and the Kiamichi River. Midwest City and Del City east of Oklahoma City get their water from underground sources and will obtain additional supplies from the Little River Reservoir, which was completed in 1965.

The largest user of water in the area is Tinker Air Force Base, with an average of nearly 4 million gallons used a day, and a peak summer use of about 6 mgd. This supply is furnished from 28 deep wells tapping the sandstone of the red beds. Additional water for the Air Force Base might be obtained from the Oklahoma City system.

SPAVINAW CREEK SUPPLIES WATER TO TULSA

Tulsa, the second largest city, supplies commercial services to the northeastern part of Oklahoma and parts of three other states. Its population grew from 142,157 in 1940 to 258,271 in 1960. Much of Tulsa's industry centers around oil, aviation, and space activities. Major industries include two oil refineries, two aircraft plants, an aviationmaintenance center, a cement plant, a university, and many metal-fabrication, oil-field equipment, and electronic firms. In addition, the city serves as national and regional headquarters for several oil companies, is the oil service center for a broad region, and has a diverse multitude of small industries. These industries used about 21 of the 51 mgd of water used in 1964. Another 1.2 mgd is supplied to small farms and local water districts that are connected to the Tulsa system. Maximum daily use during 1964 was on August 5 when 89.7 million gallons was pumped. Present water use is about three times the 1940 rate which averaged 16.7 mgd.

Tulsa's water is obtained from two lakes on Spavinaw Creek which impound 112,000 acre-feet of water in the central part of the Oklahoma Ozarks. For additional needs in the future, Keystone Reservoir on the Arkansas River near Tulsa will not impound water of suitable quality for municipal use, but this source can be used for industrial cooling water. Tulsa is within pipeline distance of several sources of water of excellent quality in almost unlimited amounts. Oologah Reservoir on the Verdigris River 25 miles to the northeast impounds water meeting all standards for a municipal supply. The Neosho River system to the east could be tapped at several places to supply water of excellent quality, either by diversion from the river immediately below Grand Lake into an enlarged Spavinaw Lake, or by pumping from Hudson Lake, or from Lake Fort Gibson directly east of Tulsa. The city has a 103-mgd-capacity booster station on the bank of Hudson Lake; this station is so designed that water can be pumped into the pipeline directly from the lake if it is needed for an emergency supply.

The Illinois River system southeast of Tulsa offers an excellent potential to supply large quantities of water of good quality. This stream could be tapped at either Tenkiller Ferry Reservoir or at new impoundments constructed in the upper reaches of the river. At the present time this stream is little used as a source of water for irrigation or municipal or industrial uses. Any combination of the several sources offers excellent opportunities to provide unlimited additional water for use in the Tulsa area.

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SMALLER CITIES SERVE AS INDUSTRIAL AND TRADE CENTERS

Oklahoma City and Tulsa are the two major centers of urban population in Oklahoma. However, other cities serve as important marketing centers and have moderate concentrations of industries. Several of these cities have remained at about the same population level the past 20 years, while others have shown extensive growth and increased water demands. Lawton, the third largest city in the State, has experienced a threefold increase in population since 1940. Midwest City did not even exist in 1940, and it now has more than 36,000 people expecting all the advantages of a dependable source of water. Water could well be a major factor in determining which of the moderately populated urban centers will make significant contributions to the State's future economy.

Ada

The principal activities at Ada are a cement-manufacturing plant and East Central State College. The city also has several small diversified manufacturing and agricultural processing plants. Between 1940 and 1960 the population declined slightly, from 15,143 to 14,347. Water use, however, increased from an average of 2.1 mgd in 1950 to 3.2 mgd in 1964. On the maximum day in 1964, 5.8 million gallons was used. Ada is supplied municipal water from Byrds Mill Spring which issues from a limestone aquifer in the northern part of the Arbuckle Mountains, 12 miles south of the city. Part of the water for the cement plant is supplied by a well 1,850 feet deep that taps the sandstone aquifer 5 miles southwest, but most comes from the city supply. The spring supply is adequate for present needs except during years of severe drought, such as in 1956 when water rationing was necessary. A supplemental supply totaling 9 million gallons a day recently has been developed from three wells that tap the same limestone within a few miles of Byrds Mill Spring. Although these wells were constructed in 1960, it had not been necessary to use them as of 1965. Other potential sources of water supply for Ada include additional limestone wells in the same area and impoundments on one of several small streams in the area, such as Spring Creek, a tributary to the Canadian River, and Blue and Clear Boggy Creeks, tributaries to the Red River. This water is all of excellent quality suitable for municipal use, and any of these sources or combinations would provide adequate water for any future needs of Ada.

Altus

One of the fastest growing cities in the State is Altus, whose population increased from 8,593 in 1940 to 21,225 in 1960. This city serves as a marketing and agricultural center for the important irrigation area in southwestern Oklahoma. Nearly one-third of the State's irrigated land is within 40 miles of this city. Industries not related to agriculture include several small manufacturing plants and a major Air Force installation. Altus obtains its water supply from an annual allocation of 4,800 acre-feet of water from Lake Altus, the 140,000-acre-foot reservoir constructed by the Bureau of Reclamation on North Fork Red River. Average daily water use increased from 0.88 mgd in 1940 to 4.3 mgd in 1964. During the same period, maximum daily use grew from about 1.6 to 10.7 million gallons on Aug. 6, 1964. The present source will barely supply the needs of the city, including the Altus Air Force Base, which used more than 1 mgd in 1964. The hardness of about 500 ppm makes the water of poor quality for municipal uses.

For several years Altus has been searching ardently for additional water sources. The only ground water available for development in the area is in the terrace deposits east of North Fork Red River in Tillman County and south of Red River in the north edge of Texas. Supplies in the Tillman County area already have been substantially developed for irrigation, and it is doubtful that several additional million gallons of water a day could be developed from these deposits. The additional water needed by the city could be developed from the deposits south of Red River in Texas, which the city explored extensively in 1964. However, a 1965 Texas law forbidding the exportation of water to another State probably will prevent development of this source.

Surface water of a quality similar to that in Lake Altus might be developed from Salt Fork Red River. Water of a much better quality will be available from the proposed Mountain Park project which will divert flows of Elk Creek into a reservoir located on Otter Creek. Mineral concentrations of water in this impoundment will be less than those of Lake Altus.

Ardmore

Ardmore serves as a commercial and service center for part of south-central Oklahoma and as local headquarters for parts of the petroleum industry, and has diverse small industries. In 1940, when the population was 16,886, water use averaged 0.94 mgd. The population has grown steadily, and was 20,184 in 1960. Water use has increased at a much greater rate and reached an average of 3.4 mgd in 1963. During August 1963, the month of greatest use, an average of 5.3 mgd was pumped and 6.5 million gallons was used on one day. Because of restrictions imposed during the drought, water use averaged only 2.9 mgd in 1964. Ardmore is supplied water from two small impoundments totaling 2,300 acre-feet in the Caddo Creek watershed. The largest is Mountain Lake on Hickory Creek 15 miles north of town. These impoundments store slightly more than a 1-year supply and are inadequate for even short periods of drought under present demands. A small amount of water, for use at the industrial park at the airport northeast of the city, is obtained from an infiltration gallery laid beneath the bed of the Washita River. In 1956, Ardmore drilled seven wells about 15 miles northwest of town for supplemental water during the drought period. These wells supply about 1 mgd. They were used extensively for the first time during the 1963–64 drought when 436 million gallons was pumped from them in 16 months. The aquifer yields water rather slowly although it contains a great volume in storage. Additional wells with similar yields could be obtained by expanding the well field to the west. Other possibilities are the limestone beds of the Arbuckle Mountains.

Potential sources of additional surface supply in this area include the authorized reservoir under construction on Rock

Creek near Dougherty, impoundments in the Caddo Creek basin a few miles north of town, and direct withdrawals from the Washita arm of Lake Texoma 15 miles east of town. Plans are in progress to purchase storage for the city in floodwater-retarding reservoirs that are being built as a part of the upstream watershed-treatment program in the Washita River basin (Flood Control Act of 1944). These reservoirs, which will be on tributaries of Caddo Creek north of the city, will supply about 5 mgd of additional water for Ardmore. An emergency source of water for Ardmore would be Lake Murray, a 153,000-acre-feet impoundment on Anadarche Creek 6 miles southeast of town. This is a State-owned lake used primarily for recreation and is the main attraction of Lake Murray State Park. Water from any combination of these various sources would provide an abundant supply of suitable quality for Ardmore.

Bartlesville

Bartlesville is the home office for two of Oklahoma's major oil companies, one of which also has a large refinery there. Other industries include a zinc smelter, oil-field service, and equipment plants. In 1940, Bartlesville had a population of 16,267 and used an average of 0.96 mgd of water. By 1960 the population had increased to 27,878. Water use in 1964 averaged 4.5 mgd, and on the maximum day was 9.3 million gallons, more than twice the average for the year. The principal water supply for Bartlesville is obtained from Lake Hudson, a 5,300-acre-foot impoundment on Butler Creek. A supplemental supply for this city has been provided by the rental of 15,400 acre-feet of storage in Hulah Reservoir on Caney River, 14 miles northwest of town. Both of these sources are excellent in quality for municipal use, and the combination of the two provides a supply adequate for several years to come.

Chickasha

The economy of Chickasha revolves around the processing of agricultural products, notably cotton and cotton oil. The 1960 population of Chickasha (14,866) was only slightly more than the 1940 population of 14,111.

Water use, however, increased from 1.37 mgd in 1945 to 2.0 mgd in 1964. Pumpage during the period of maximum use increased at an even greater rate, from an average of 1.65 mgd in August 1945 to 5.1 mgd in August 1964. The water supply for Chickasha is obtained by direct withdrawals from the Washita River. The quality of this water, especially during periods of low streamflow, is extremely hard, with sulfate concentrations exceeding 500 ppm and total mineral concentations exceeding 1,000 ppm. A supplemental source of supply has been developed through a 50,000-acre-foot impoundment northwest of town on Spring Creek. That supply was used for the first time during the drought in the summer of 1964. An additional surface-water supply could be provided by impoundment on Bitter Creek, 6 miles east of Chickasha. Two other possibilities are an off-channel reservoir to take water from the Washita River at high flows, thereby eliminating the poor-quality low-flow water, and the purchase of water from the Cobb Creek Reservoir about 35 miles to the northwest in Caddo County.

Duncan

The economy of Duncan centers around oil refineries and oil-field services to adjacent areas. Duncan's population more than doubled between 1940 and 1960, increasing from 9,207 to 20,009. It was the first city in Oklahoma to join hands with the Washita River basin upstream-watershed-treatment program (Flood Control Act of 1944) to get 10,700 acre-feet of water-supply storage set aside in Lake Humphrey, a flood-water-retarding structure on Wildhorse Creek. That source and the 9,600-acre-foot Clear Creek Lake, on a tributary of Wildhorse Creek, supplied an average of 1.8 mgd in 1964. The maximum daily use was on Aug. 24, 1964, when 5.1 mgd was pumped. In addition to these two reservoirs, the city owns Lake Duncan, a 5,000-acre-foot reservoir on another tributary of Wildhorse Creek. Lake Duncan formerly was used as the principal source for the city, but now furnishes water for operation of an oil refinery. For additional future water needs Duncan is included in the plan of a proposed reservoir on Beaver Creek at Waurika. These several sources of supply should provide adequate water for any future expanded needs in the Duncan area.

Enid

The city of Enid is an agricultural marketing center for northwestern Oklahoma. Its population has grown rather steadily from 28,081 in 1940 to 38,859 in 1960. Activities include an oil refinery, several small manufacturing plants, an Air Force installation, and Phillips University. Enid is supplied from 80 wells tapping terrace deposits north of the Cimarron River about 20 miles southwest of the city. Water use in 1964 averaged 5.4 mgd, compared to 1.3 mgd in 1940. Maximum daily use, on Aug. 3, 1964, was 10.6 mgd. Recent expansion of ground-water irrigation tapping this same aquifer has brought about competition for water that has created problems for Enid in expanding its water development from this source. However, the city has acquired property suitable for development of 30 additional wells. Other possible sources of water supply include surface supplies from the North Canadian River at Canton Reservoir, which would require construction of a surface-water treatment plant and the extension of the pipeline more than 20 miles from the well field. Additional sources of surface water for development in the Enid area include Eagle Chief Creek near Cleo, 40 miles to the west of Enid, where low flow varies from 0.3 to more than 10 mgd. A proposed reservoir on Turkey Creek about 20 miles south of Enid also could include storage of municipal water for the city's use. However, Turkey Creek water is of rather poor quality because of oil-field pollution; under present conditions its high-salt concentrations would make it unacceptable for drinking water.

Lawton

The chief activity for Lawton, at the foot of the Wichita Mountains, is supplying services to the Army Artillery Center at Fort Sill. The rapid growth of this facility during and following World War II has been paralleled by Lawton's population that increased from 18,055 in 1940 to 61,697 in 1960. Lawton also serves as a shopping center for much of the surrounding agricultural area. Small manufacturing plants in the area are mostly of the fabrication and agricultural-processing type.

Water use has increased even faster than population has grown, from an average of about 3.6 mgd in 1940 to 14.4 mgd in 1964, including 4.0 mgd used at Fort Sill. During July 1964, use averaged 21 mgd and on the peak day, July 9, was nearly 25.6 million gallons. One reason that per capita use of water by Lawton is greater than for other cities in Oklahoma is the practice of furnishing it to residential customers on a "flat-rate" rather than a "metered" basis. The principal water supply for Lawton is Lake Lawtonka, a 63,000-acre-foot impoundment on Medicine Creek at the base of Mount Scott, 10 miles northwest of the city.

Population growth and subsequent increased demand for water, coupled with the low flows of Medicine Creek during the drought of the early fifties, brought about a severe shortage of water in 1956 and made water rationing necessary for Lawton. Additional water supplies have since been developed at Lake Ellsworth, a 48,000-acre-foot impoundment on East Cache Creek, 14 miles northeast of Lawton near the town of Elgin. Somewhat less than half of Lawton's water is obtained from this source although it furnished more than 3 billion gallons in 1964.

Because of the high fluoride content, ground water from the deep aquifer at Lawton is not a suitable source for municipal water. However, if it could be conveniently blended with the surface supply to produce a naturally fluoridated supply at the concentration of about 1 ppm, the mixed water would be beneficial in the prevention of dental cavities in young children.

The ground-water source currently is being used by some of the small manufacturers in the area, and additional water for these users could be developed if wells were adequately spaced.

McAlester

McAlester's municipal water supply is from Lake McAlester, a 13,800-acre-foot impoundment on three small creeks in the Gaines Creek watershed. This municipal system also supplies water to the nearby Oklahoma State Penitentiary.

The 1950 population of 17,878 changed only slightly to 17,419 in 1960, but water use, which was 1.8 mgd in 1950, had increased to 2.4 mgd by 1964, and 4 million gallons was used on one day in July. Additional sources of good-quality water for any expanded need in this area could be obtained at several other sites in the Gaines Creek watershed, and the Gaines Creek arm of Eufaula Reservoir, which extends near McAlester, will provide water of excellent quality for municipal use.

Muskogee

Widely diverse large and small manufacturers, including chemical industries, make Muskogee an important industrial center of Oklahoma. An almost unlimited supply of water of excellent quality from Lake Fort Gibson on the Neosho River places Muskogee in a most favorable position with respect to availability of water. The 1964 water use for this city of 32,332 averaged 6.0 mgd compared to only 4.4 mgd in 1940 when the city had a population of 38,000. Because of its large source of supply, about the only problem Muskogee will face for future water needs will be those of treatment and distribution.

Norman

The economy of Norman is centered around the State institutions located there. These include the University of Oklahoma, the Cerebral Palsy Institute, and the Central State Hospital. Students enrolled at the University constitute about one-fourth of the city's population. Population growth and future expansion of Norman are likely to be related to the growth of these institutions and to the establishment of small industries. The city's proximity to Tinker Field and to the Oklahoma City industrial area also contribute to its growth. The present water supply for Norman consists of 27 wells about 600 feet deep in the sandstone aquifer. This water is of excellent quality for municipal use, being one of the softest supplies in the State with a hardness of about 20 ppm. The only undesirable feature about this water is the relatively high sodium concentration of 200 ppm, which limits its use for irrigation and for drinking purposes by persons with heart ailments who are on limited sodium diets.

In 1940, Norman had a population of 11,429 and used an average of 0.75 mgd. By 1960 the population (including students at the university) had grown to 33,412. Water use in 1964 averaged 3.0 mgd and the State institutions used an additional 1.7 mgd, all from ground water. During July 1964, peak use from the municipal system was 4.8 mgd, and 6.25 mgd was used on the maximum day. A large number of city and university wells concentrated in the northwestern part of the city has resulted in local overdevelopment of the aquifer and in lowering of water levels. In the northeastern part of the city, municipal wells compete for water with wells supplying the Central State Hospital. To reduce the concentration of wells and ease the problem of overdevelopment, the city recently constructed several new wells northeast of the city. A large quantity of additional water could be developed safely from wells in that area by using a similar spacing pattern. Still another several million gallons a day could be developed from wells tapping the terrace deposits and alluvium along the Canadian River near the city. This water would be harder and somewhat poorer in quality than the present supply, but with softening would be suitable for municipal use.

Norman, along with Del City and Midwest City, has elected to obtain water from the reservoir completed in 1965 on Little River, 12 miles east of Norman. Water from this source is expected to be available by the summer of 1966. This supply will be excellent in quality for municipal use, with a total mineral concentration of about 250 ppm, a hardness of 175 ppm, and concentrations of sodium, chloride, and sulfate that are insignificant for drinking water purposes.

Another possible surface-water supply for Norman would be an off-channel reservoir to take water from the Canadian River on a selective basis. With adequate storage facilities, an average of 25,000 acre-feet of water of a quality equal to Oklahoma City's supply could be obtained each year. The water available for development from these ground and surface sources provides Norman with a potential water supply adequate for considerable growth and expansion.

Okmulgee

Okmulgee's 1960 population of 15,961 was nearly identical to the 1940 population of 16,051. However, water use by the city increased from an average 1.4 mgd in 1940 to more than 2.5 mgd in 1964, and on the peak day in 1964, 4.33 mgd was used. Municipal water is supplied from Lake Okmulgee, a 13,560-acre-foot impoundment on Salt Creek, which is tributary to Deep Fork. The original supply for this city, obtained by direct withdrawal from Deep Fork, was abandoned because of high salt concentrations. However, during the drought of 1964 the city was forced to use more than 116 million gallons directly from Deep Fork. Although somewhat salty in taste, this water was usable under such emergency conditions. Water of good quality for municipal use could be obtained from this stream by diverting the best quality flows into off-channel storage. The city also is considering plans for a second reservoir on Salt Creek upstream from Lake Okmulgee. Another potential source of supply is storage in the proposed Welty Reservoir on Deep Fork about 25 miles west of Okmulgee. The impounded supply from Welty Reservoir should be suitable for municipal use because it is upstream from most of the oil-field pollution.

Ponca City

The economy of Ponca City is built around two major oil refineries and associated industries. Population has grown steadily from 16,794 in 1940 to 24,441 in 1960. Water use, however, nearly doubled, from 3.4 mgd in 1940 to 6.75 mgd in 1964, including 2.75 mgd supplied to the refineries. Maximum daily use reaches about 10 mgd. This city is within a stone's throw of three major rivers—the Arkansas, Salt Fork Arkansas, and Chikaskia—all of which present problems in supplying municipal water because of quality deficiencies.

The present water supply for Ponca City comes principally from 70 wells in the alluvium of the Arkansas River which is combined with Lake Ponca, a 15,000-acre-foot impoundment on Turkey Creek. The common practice is to pump 15–25 wells steadily to keep the lake as full as possible. The ground water, together with storm runoff caught in the lake, provides a dependable source of good-quality water adequate for expanded use. The quality of water from some wells is rather poor, being extremely hard and high in total mineral concentrations. Several former wells in the municipal system had to be abandoned because of high salt concentration from oil-field pollution, but the overall quality of treated water is good for both municipal and industrial purposes. The small impoundment on Turkey Creek would not alone provide a dependable source of supply through extended periods of deficient rainfall.

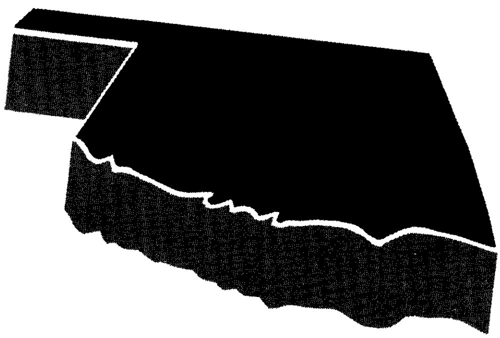
Potential sources of surface water suitable for development as municipal supplies in the Ponca City area include Beaver Creek and Salt Creek east of Ponca City across the Arkansas River, Red Rock Creek to the south, and Chikaskia River at the proposed Corbin Reservoir site just across the Kansas border. Consideration has been given to including storage for municipal water supply for Ponca City in the proposed Kaw Reservoir on the Arkansas River. Considerable improvement in quality of this water will be necessary if it is to be of suitable quality for a municipal supply. (See p. 59.)

Shawnee

Shawnee is a typical agricultural trade center, the site of Oklahoma Baptist University, and the home of several small diversified manufacturing plants. The population has been relatively stable since 1930, but increased slightly from 22,948 in 1950 to 24,326 in 1960. Average daily water use increased from 1.65 mgd in 1949 to 2.0 mgd in 1964. On the day of greatest use in July 1964 the 3.9 million gallons used was nearly twice the average for the year. The water supply for Shawnee is a 22,700-acre-foot impoundment on South Deer Creek, a tributary to the North Canadian River. This storage is more than adequate for present water use by Shawnee, and, with additional water available from an impoundment on North Deer Creek, the supply for the city should be adequate for years to come.

Stillwater

Stillwater has a unique water-supply arrangement in that the system is owned and operated by Oklahoma State University, the principal water user of this city. Students enrolled at the university constitute nearly one-third of the city's population, which increased from about 15,000 in 1940 to 23,965 in 1960. The water supply is derived from Lake Carl Blackwell, a 55,000-acre-foot impoundment on Stillwater Creek about 12 miles west of Stillwater. This source of supply is adequate for considerable expanded needs above present use, but because of limited treatment facilities, some restrictions on water use were imposed during the summers of 1964 and 1965. Average daily use by the city increased from 0.95 in 1940 to 2.2 mgd in 1964–65. The university uses an additional 1.3 mgd. During the day of maximum use in July 1964 nearly 5.6 mgd were used by the city and the university together.



OUTLOOK FOR THE FUTURE

The first 60 years of Oklahoma's statehood was marked by the fantastic development of petroleum resources; the next 60 years could well be marked by a similar effort to develop the water resources. Some parts of the State have an abundance of water in excess of their needs, whereas other areas have developed the full potential of readily accessible supplies. Just as the medieval village which once was a self-sufficient unit found it necessary to combine its economy with other villages, some areas of Oklahoma will need to join forces to develop a common water source if they are to grow and prosper.

Several cities have demonstrated this ability by their efforts to develop water from Foss, Norman, and Arbuckle Reservoirs. Other supplies have been developed by the construction of large and small reservoirs and wells. The steady progress in the control of oil-field pollution is improving the quality of water in many small streams, particularly in the central and eastern parts of the State. On the other hand, the rapid urban growth has strained the capacity of many municipal sewage plants, and the threat of stream pollution from this source has increased. Plans now being made to expand old facilities and construct new ones will help to remove this pollution threat.

Reservoirs constructed in some parts of the State have greatly improved some flow conditions and some water quality. In contrast, great numbers of recently built, small stockponds, which are essential for livestock and other purposes, provide large increases in shallow-water bodies from which there is increased evaporation. They may also withhold the best quality flood flows, thereby reducing both the quantity and quality in some of the rivers.

Saltcedar and other phreatophytes are spreading into thousands of acres along western streams and will consume large volumes of water that otherwise might move down valleys and be used by man.

Ground-water reservoirs in the Ozarks, the coastal plain, and the Arbuckle Mountains are little used. In contrast, the pumping from aquifers in Harmon, Caddo, and western Tillman Counties probably has reached or exceeded the available "water crop," and problems of overdevelopment can be expected. Additional wells can be developed in the Panhandle, but the High Plains aquifer is being overpumped on both sides, in Kansas and Texas. Some form of control will be necessary to prevent overpumping it in Oklahoma.

Thus, the outlook for Oklahoma's water supply is neither all bright nor all dark, but is full of contrasts.

The High Plains has adequate water for future municipal and industrial use and for sizable expansion in irrigation, but the supply is not sufficient for exportation to water-short areas.

Water is so abundant in the eastern third of the State that only development of the supply and of methods to transport it are needed to share this abundance with other areas.

In the remainder of the State, ingenuity and imagination will be needed to develop and conserve both the quantity and quality of water. One method is to construct off-channel reservoirs to store good water during times when streams are less highly mineralized or to mix water of varying quality; another is to recharge ground-water aquifers artificially; a third is to suppress evaporation. Improvement or perfection of methods for desalting mineralized water and control or abatement of man-made pollution will increase the amount of usable water for man.

As it is for any civilization, water is Oklahoma's lifeblood. It sustains health and growth; it is essential for agriculture; it nourishes industries and carries away their wastes; it provides recreational sites, avenues of transport, and power for modern living. Good water is one of the world's most precious resources. To ensure the future welfare and provide for the health and growth of Oklahoma's people, this essential resource must be wisely developed, carefully conserved, fully protected, and reverently cherished.

FOR MORE INFORMATION ABOUT . . .

. . . BASIC WATER FACTS, PRINCIPLES, AND PROBLEMS:

A primer on water, by L. B. Leopold and W. B. Langbein: U.S. Geological Survey special report, 50 pages, 1960.

A primer on ground water, by H. L. Baldwin and C. L. McGuinness: U.S. Geological Survey special report, 26 pages, 1963.

A primer on water quality, by H. A. Swenson and H. L. Baldwin: U.S. Geological Survey special report, 27 pages, 1965.

General introduction and hydrologic definitions, by W. B. Langbein and K. T. Iseri: U.S. Geological Survey manual of hydrology, part 1, General surface water techniques: U.S. Geological Survey Water-Supply Paper 1541–A, 29 pages, 1960.

Outline of ground-water hydrology, by O. E. Meinzer: U.S. Geological Survey Water-Supply Paper 494, 71 pages, 1923. [Reprinted 1960.]

The role of ground water in the national water situation, by C. L. McGuinness: U.S. Geological Survey Water Supply Paper 1800, 1,121 pages, 1963.

Study and interpretation of the chemical characteristics of natural water, by John D. Hem: U.S. Geological Survey Water-Supply Paper 1473, 269 pages, 1959.

Urban growth and the water regimen, by J. Savini and J. C. Kammerer: U.S. Geological Survey Water-Supply Paper 1591–A, 43 pages, 1961.

Phreatophytes, by T. W. Robinson: U.S. Geological Survey Water-Supply Paper 1423, 84 pages, 1958.

Hydraulic aspects of flood-plain planning, by S. W. Wiitala and others: U.S. Geological Survey Water-Supply Paper 1526, 69 pages, 1961.

Physiographic and hydraulic studies of rivers, by L. B. Leopold and others: U.S. Geological Survey Professional Paper 282, 210 pages, 1961.

National water resources and problems, by R. E. Oltman and others: U.S. 86th Congress, 2d session, Senate Select Committee on National Water Resources, Committee Print 3, 42 pages, 1960.

... OKLAHOMA'S RESOURCES:

A U.S. Geological Survey folder, "Water Resources Investigations in Oklahoma, 1965," notes many Survey Bulletins, Professional Papers, Circulars, Water-Supply Papers, open-file releases or other special reports on availability and occurrence of surface and ground water. These folders are available on request to the U.S. Geological Survey offices in Oklahoma City.

Details of water development and control are given in the numerous reports of other water agencies in the State. Specific inquiries may be directed to:

Oklahoma Water Resources Board, Oklahoma City

Oklahoma Geological Survey, Norman

Corps of Engineers, U.S. Army, Tulsa

Bureau of Reclamation, U.S. Department of the Interior, Oklahoma City

Soil Conservation Service, U.S. Department of Agriculture, Oklahoma City

Federal Water Pollution Control Administration, U.S. Department of the Interior, Ada

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