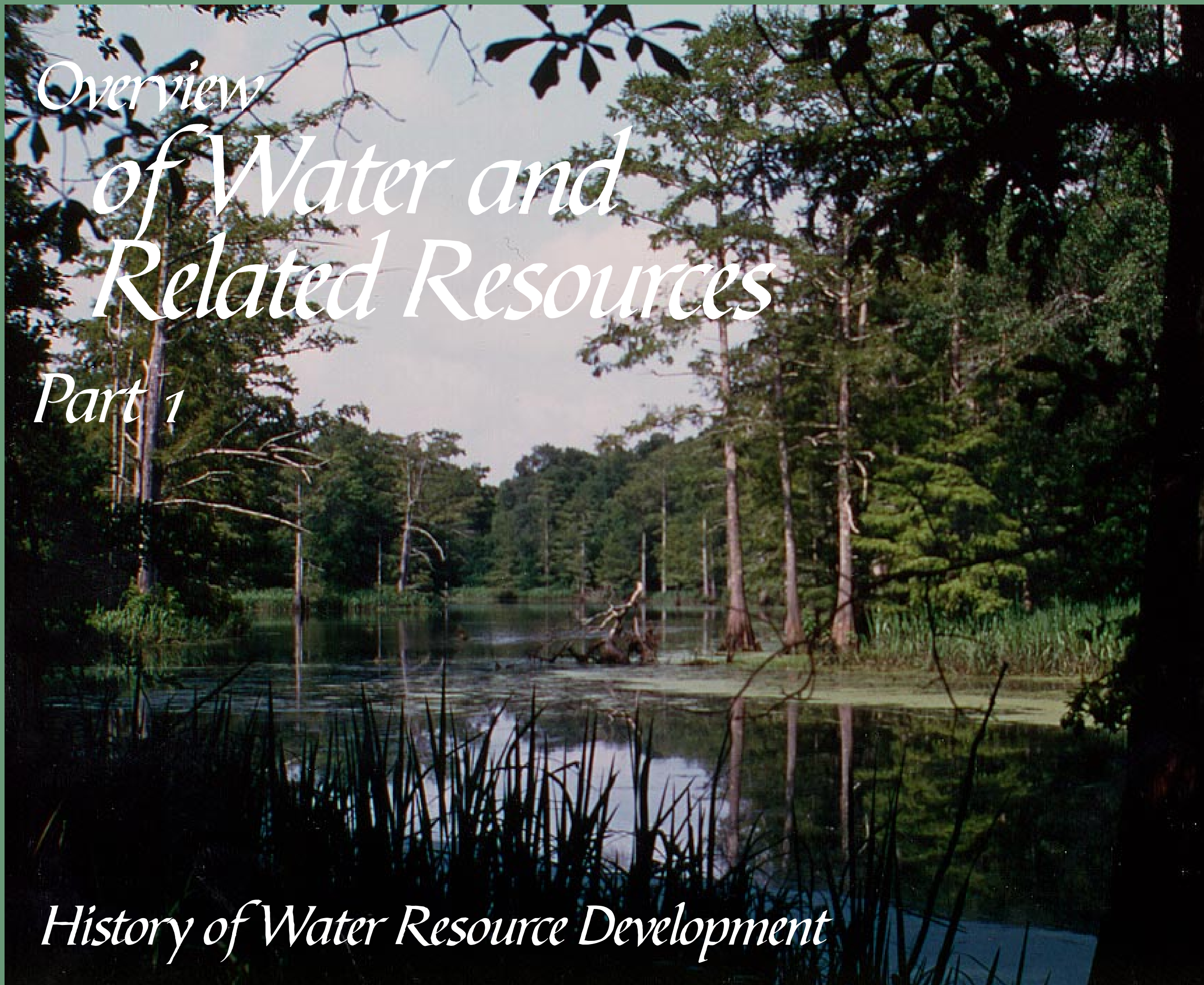


Overview of Water and Related Resources

Part 1

History of Water Resource Development

Acute interest in water and water development began before statehood. The oldest right for the use of stream water (a water right that is still valid) was issued to a farm family near Boise City in 1899. Their claim entitled them to a prior right of 52 acre-feet per year from Marcelus Canyon Creek, a tributary of the Cimarron River, for the irrigation of 26 acres of land. The water right is numbered 99-1, signifying the year 1899, permit number one. The oldest right to the use of groundwater is that of the City of Norman, claiming a prior right to 12 acre-feet of water per year from the Garber-Wellington Aquifer, based on municipal use dating back to 1894.

In 1902, President Theodore Roosevelt signed into law the Reclamation Act to aid arid western states, and the following year investigations were begun in Oklahoma Territory to determine how water supplies could be beneficially used. The Eighth Legislative Assembly of Oklahoma Territory enacted the first water law in 1905, outlining the procedure for acquiring water rights, regulating the use of water and creating the post of territorial engineer.

With the coming of statehood, the office of territorial engineer became state engineer, responsibilities of that post were expanded and new water laws were enacted. Many of those original laws, which primarily spelled out water ownership and irrigation rights, remain in effect and have since been extended to include municipal and industrial water supply, streamflow regulation, water resource planning, water quality regulation and data collection. Of course, as the population increased, so did the number of water users and problems related to water use. In the 1920's, the Conservation Commission was created to deal with the state's expanding water issues. Also at that time, Oklahoma citizens were drinking water for the first time from new Lake Overholser and Tulsa had just completed its water supply, Spavinaw Lake.

As the seeds of the Great Depression were being sown, the attention of the nation turned to flooding on the Mississippi River. The river mocked and devastated the people of its valley. Although the Corps of Engineers built levees higher and higher and invested $300 million along the lower Mississippi between 1886 and 1926, they met with little success in controlling the river and its tributaries which again left their banks in the catastrophic floods of the 1920's. Finally, a plan emerged to hold back floods by constructing upstream storage basins in the veins pouring into the Mississippi -- a revolutionary strategy originating from similar problems in Oklahoma City.

The North Canadian River regularly washed over the flat capital city in the spring while, in late summer, streams dried up and water supplies diminished. In the 1923 record flood, the rampaging river broke the Lake Overholser municipal water dam and washed out nearly every wagon and railroad bridge in the central part of the state. This made a powerful case for holding more water in upstream reservoirs. In the flood of 1927, water levels on the Arkansas River were the highest in 99 years. The entire Mississippi Valley was an enormous muddy reservoir a thousand miles long and 50 to 150 miles wide.

By the early 1930's, rural Oklahoma farm families, burned out by drought and hot, dry winds, retreated from their tortured lands to regroup farther west. Meanwhile, dry fields piled up in high sand dunes while lighter silt rose in dust clouds, some five miles high, and swept east to the Atlantic in "black blizzards." During a single day in 1934, it is estimated that some 300 million tons of soil were swept from the Great Plains. Armies of Civilian Conservation Corps (CCC) and Soil Conservation Service (SCS) workers moved over the land, healing it with plantings of grass and shelter belts, filling in deep gullies and coaching farmers in conservation practices.

In response to widespread water problems, the Oklahoma Legislature created the State Planning and Resources Board in 1935 and included in its jurisdiction parks, forestry and water resources. In 1937, Lake Murray was completed in Murray County as a project of the state while the CCC and Works Progress Administration continued to work on bank stabilization and other water-related tasks. Lake Carl Blackwell, a project of the SCS, was completed as a water supply for Oklahoma A&M College, and soon after, Grand River Dam Authority completed Grand Lake O' the Cherokees on the Grand (Neosho) River in northeastern Oklahoma. In addition, two Corps of Engineers lakes authorized by the Flood Control Act, Great Salt Plains and Fort Supply, were completed early in the 1940's.

The years of searing drought in the west and devastating floods in the east outraged Oklahomans and called conservationists, flood control advocates and navigation interests to march, but not before the Arkansas River had again rampaged in 1943. Beginning May 7, rain fell for days on end; skies cleared only to succumb to faint and faraway rumbles of thunder heralding still more storms. Ninety percent of the crops over hundreds of square miles were destroyed. In some places, 15 inches of rain fell in two days; Tulsa had 16 inches of almost continual rainfall. The Arkansas climbed to six feet over flood stage at Muskogee and, in a 500-mile swath of reckless anger, the river rolled on, plunging fertile farms to the bottom of a deep, mud-stained lake.

Three years later, a comprehensive plan of development for the Arkansas River -- uniting advocates of soil and water conservation, hydropower, flood control and navigation -- was authorized by Congress through the River and Harbor Act.

While eastern Oklahoma was waterlogged with repeated floods, the arid west had focused on developing a reservoir for irrigation, with the added benefits of flood control and water supply. The W.C. Austin Project (Lugert-Altus Reservoir), a project of the Bureau of Reclamation, was completed in 1948.

Spurred by a Congressional appropriation in 1949, the U.S. Army Corps of Engineers began construction in Oklahoma on the largest civil works project it had ever undertaken. Completed in 1971, some 63 years after the last of the river steamers had climbed the Arkansas River from Fort Smith to Muskogee, the McClellan-Kerr Arkansas River Navigation System was named in tribute to two far-sighted statesmen who had labored to see the vast inland waterway project become a reality.

One of these "water boomers," Senator Robert S. Kerr -- elected governor in 1943, U.S. Senator in 1948, then appointed to the powerful Public Works Committee -- was also instrumental in setting in motion an enormous program of water development throughout the 1950's and 60's. In Oklahoma, the first four years of the fifties produced four major reservoirs: Heyburn in 1950, Hulah in 1951, and Tenkiller and Fort Gibson in 1953 -- all projects of the Corps of Engineers.

In 1955, House Joint Resolution 520 created a water study committee composed of legislators and citizens, and chaired by Dr. Lloyd E. Church, of Wilburton. The committee surveyed Oklahoma's water problems and recommended the establishment of a separate water authority with responsibilities in water rights administration, federal contracts negotiation and the development of state and local projects to assure the most efficient use of all water resources. In 1957, the Twenty-Sixth Oklahoma Legislature authorized creation of the Oklahoma Water Resources Board, a panel of seven chaired by Guy H. James. In 1972, two at-large seats were added to the Board.

Most of the state's major reservoir construction has occurred since 1959, with that year seeing completion of Fort Cobb, followed by Foss Reservoir in 1961; Oologah's initial phase in 1963; Keystone, Eufaula, and Hudson in 1964; Thunderbird in 1965; Lake of the Arbuckles in 1967; Pine Creek in 1969; and Broken Bow in 1970. The seventies brought to completion Robert S. Kerr and Webbers Falls Reservoirs in 1970; Hugo in 1974; Tom Steed in 1975; Kaw in 1976; Waurika and Birch in 1977; and Optima in 1978. Prior to 1990, five more reservoirs had been completed: Sardis in 1982; Copan in 1983; Skiatook in 1984; Arcadia in 1986; and McGee Creek in 1987. Although construction of Candy Lake, in Osage County, was partially complete in 1990, a dispute concerning petroleum/mineral rights at the site forced abandonment of the project.

Seven lakes authorized for federal construction, but not yet funded, could add to Oklahoma's future surface water supply. They are Candy (still authorized); Lukfata, on the Glover River in McCurtain County; Boswell, on Boggy Creek in Choctaw County; Sand, on Sand Creek in Osage County; Shidler, on Salt Creek in Osage County; Tuskahoma, on the Kiamichi River in Pushmataha County; and Parker, on Muddy Boggy Creek in Coal County.

Water Resources

Oklahoma is blessed with abundant water resources, both on the surface and underground, that provide ample supply for various uses. The amount of water withdrawn from groundwater sources slightly exceeds that of surface water; however, on an annual basis, use of the two sources is virtually even. In 1994, almost 1.4 million acre-feet of water was withdrawn for agricultural, municipal and industrial, and power purposes. Irrigation is the number one use of water in Oklahoma; water supply is a close second, followed distantly by livestock.

The three Panhandle counties of Texas, Cimarron and Beaver are the largest irrigation water users, respectively. Rogers, Mayes and Oklahoma Counties withdrew the most under the water supply category while livestock use was greatest in Grady, Caddo and Bryan Counties. Muskogee, Pawnee and Seminole Counties account for approximately three-fourths of the state's total water used for thermoelectric power generation.

Except for domestic purposes, the Oklahoma Water Resources Board permits the use of state waters. As of August 1995, the agency had on file a total of 11,699 permits for the use of 5,675,652 acre-feet per year (ac-ft) of surface and groundwaters in Oklahoma, mostly allocated for irrigation, the state's leading water use, and municipal needs. Seventy-five percent of public water supply comes from the major federal reservoirs in Oklahoma and their smaller municipal lake counterparts.

The majority of the state's surface water (approximately 60 percent) is used for public water supply, especially in the Oklahoma City and Tulsa metropolitan areas, followed by thermoelectric power generation and irrigation. As of August 1995, the OWRB had on file 2,515 permits for the allocated use of 2,603,661 ac-ft of stream water.

Groundwater is the prevalent source of water in the western half of the state, accounting for almost 90 percent of total irrigation water use in Oklahoma. More than 700 million gallons are withdrawn for use each day. As of August 1995, the OWRB had on file 9,184 permits for the use of 3,071,991 ac-ft of groundwater.

STREAM WATER RESOURCES

Oklahoma's terrain is dominated by two major river basins, the Arkansas and Red, which were generally established within the last one million years during the Pleistocene Epoch, a time characterized by significant erosion. The Red River drains the southern one-third of the state while the Arkansas River drains the remaining two-thirds of Oklahoma's northern land area. Considering those two rivers and their tributaries (including rivers, streams and creeks with a length of 20 miles or more), the state has a combined stream length of 12, 294 miles.

The Arkansas and Red Rivers and their countless tributaries flow into Oklahoma from the state's six neighbors, but this water leaves through only four watercourses (the Red, Arkansas and Little Rivers and Lee Creek) into the State of Arkansas. The rivers and tributaries flow in a predominantly southeasterly direction, often winding in and out of Oklahoma on their long, arduous journey to the Mississippi River and Gulf of Mexico. The Red River forms the state's southern border with Texas but small sections of three other rivers and streams also mark Oklahoma's eastern border with Arkansas: 1.6 miles of the Poteau River, .5 mile of the Arkansas River and .12 mile of Mill Creek -- all near Ft. Smith, Arkansas. An overview of the state's major river basins, reservoirs, streams and their principal tributaries is provided in the following section.

Thirty-four major reservoirs dot the Oklahoma landscape, primarily in the east with its relatively high precipitation rate and advantageous topography for dam building (Figure 2). These important sources of water for the public, industry, power, recreation and various other uses have a combined surface area of 543,450 acres and collectively store well in excess of 13 million acre-feet of water (Table 1). Most were constructed by the U.S. Army Corps of Engineers and Bureau of Reclamation during the federal water development boom from the 1930's through the 60's. Two projects, Grand Lake and Hudson, were constructed by the Grand River Dam Authority, a state agency responsible for the general operation and management of waters in the Grand (Neosho) River Basin. (Flood control is the statewide responsibility of the Corps of Engineers.) Few major projects have been established in western Oklahoma where flat lands, low runoff and high evaporation make it poorly-suited to reservoir construction.

The state's largest reservoir, in terms of conservation storage, is Lake Texoma which holds 2,580,386 ac-ft of water under normal conditions. The next largest are Eufaula and Grand Lake O' the Cherokees. By surface area, the largest lake is Eufaula, covering approximately 105,500 acres, followed by Texoma and Grand Lake.

To satisfy the enormous construction costs associated with large water development projects and to provide the maximum benefit to users, major reservoirs are designed to accommodate multiple purposes. Sufficient storage space is reserved in multipurpose projects to fulfill each pre-ordained project benefit -- i.e., flood control, water supply, irrigation, hydroelectric power generation, water quality control and/or navigation. While projects are frequently authorized for recreation and fish and wildlife uses, storage space is rarely set aside expressly for those purposes.

The flood control pool of a multipurpose reservoir is designed to accommodate the most severe potential flood and is based upon the project's drainage basin, historical hydrologic information and related factors. Oklahoma's major reservoirs, which have prevented billions of dollars in potential flooding damages, are built with sufficient space to contain and safely release a collective 13.6 million acre-feet of floodwaters. Lake Texoma, among the nation's largest, contains more than 2.6 million ac-ft of flood storage. Eufaula, Keystone and Oologah all have sufficient capacity to hold in excess of one million ac-ft of floodwaters.

Water supply storage in federal reservoirs is normally purchased by water users through repayment contracts with the construction agency. This storage is reserved for hundreds of municipalities and industries across the state whose very existence depends upon timely water releases for drinking and domestic use and various industrial and manufacturing processes. In western Oklahoma, the irrigation component of several large water supply projects is relied upon by farmers who supplement relatively modest rainfall with reservoir supplies, groundwater sources and direct diversions from streams. Water supply storage in Oklahoma's major reservoirs amounts to approximately 2.9 million acre-feet; the yield of those reservoirs, that water which may be safely relied upon in the event of a drought of record, amounts to almost 1.8 million ac-ft. The three largest water supply projects in Oklahoma are Kaw Lake (230,720 ac-ft of yield), Broken Bow (196,000 ac-ft) and Oologah (172,480 ac-ft).

Though incidental to water supply, recreation is an important and common component of reservoir projects, attracting millions of visitors to the state each year and boosting local economies from Woodward to Idabel. While recreation benefits, as well as those associated with fish and wildlife, are normally unprotected from lake fluctuations caused by increased water supply usage and/or drought conditions, contractual provisions are allowed for non-consumptive water storage. In addition, periodic releases from fish and wildlife storage may be made to supplement downstream flows upon which certain species may depend. Though seldom authorized or used, water quality storage is utilized in much the same way. Water quality releases are normally made in response to emergency conditions downstream, such as fish kills, increased pollution loading during drought conditions, or aesthetics problems.

Many federal projects in Oklahoma have set aside space for hydroelectric power generation; 12 currently support power facilities. GRDA and Southwestern Power Administration market all hydroelectric power produced in Oklahoma. The navigation benefit of Oklahoma reservoirs is realized primarily through channel maintenance of the McClellan-Kerr Arkansas River Navigation System.

In addition to the 34 major projects, numerous smaller lakes play a vital role in water supply, recreation and other uses of water in Oklahoma. Throughout the state, there are more than 2,300 public and private lakes many constructed for municipal use, and almost 2,000 watershed protection structures covering some 144,000 acres and impounding 2.2 million acre-feet of water. (Table 2 shows the major municipal and private lakes in Oklahoma.) The combined shoreline length of state lakes with a surface area of 100 acres or more totals almost 7,000 miles. In addition, it is estimated that Oklahoma contains more than 220,000 farm ponds with a combined surface area of approximately 33,000 acres.

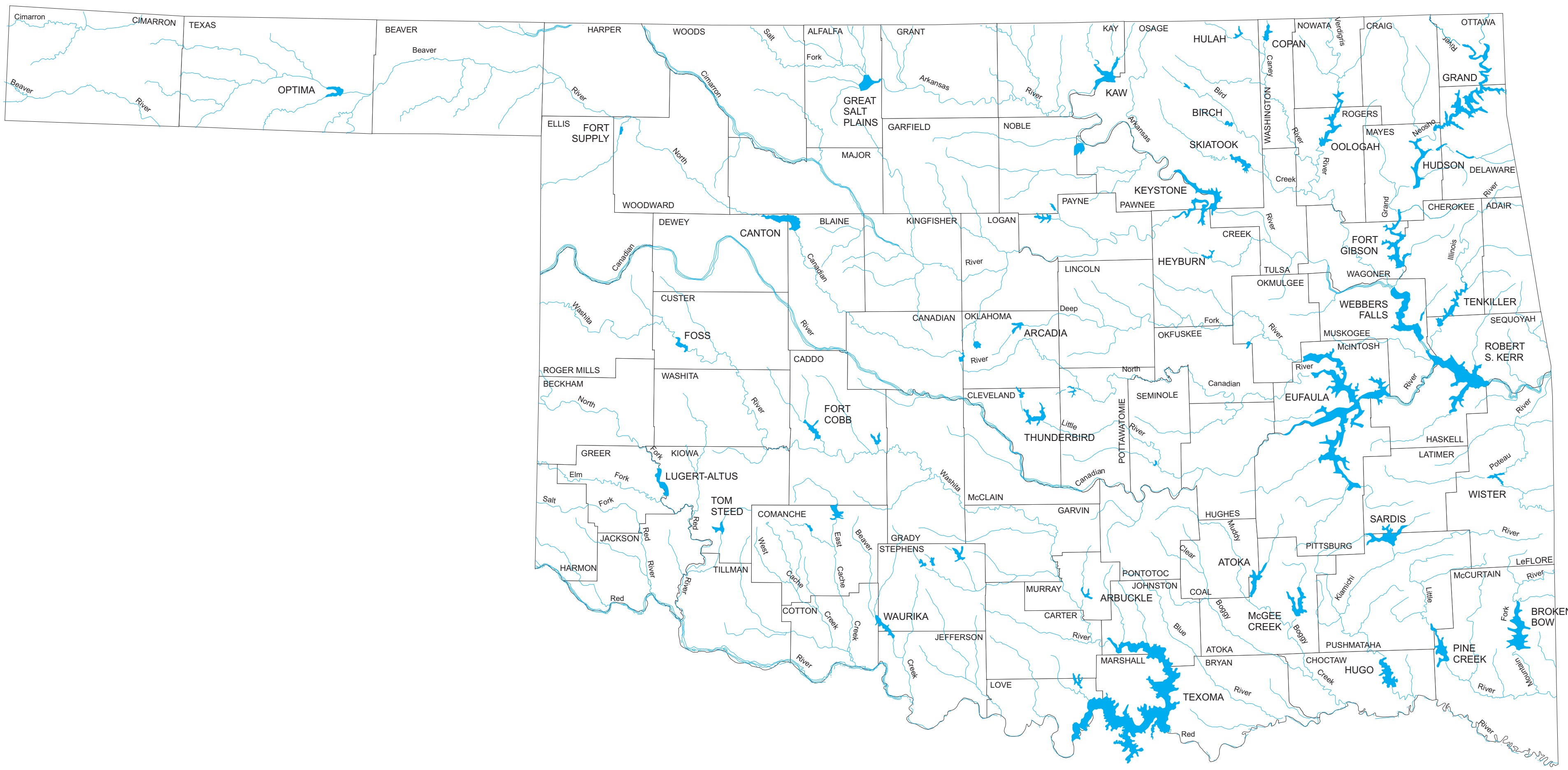
Relatively insignificant, though still important, state water resources include playa and oxbow lakes. Playas, shallow depressions formed by wind erosion up to 17,000 years ago, are transient water supplies which hold water only during and following the state's rainy seasons, unless nourished by irrigation runoff. Primarily a feature of the Panhandle region, playas vary in diameter from a few hundred feet to one mile; in depth, from a few feet to as much as 40 feet. During their brief lifespan, they primarily serve the three-fold purpose of irrigation supply, livestock watering and habitat for migratory waterfowl. The state's largest playa is 34-acre Wildhorse Lake, in Texas County, which has been deepened by lo-

Table 1
MAJOR FEDERAL & STATE WATER RESOURCE DEVELOPMENT PROJECTS IN OKLAHOMA

Official Name	Source	Purpose	Flood Control Storage (ac-ft)	Normal Operating Capacity (ac-ft)	Water[1] Supply Storage (ac-ft)	Water Supply Yield (ac-ft)	Normal Surface Area (ac-ft)	Construction Agency & Completion Date
Arbuckles	Rock Creek	ws, fc, r, fw	36,400	72,400	62,600	24,000	2,350	BuRec; 1967
Arcadia	Deep Fork	ws, fc, r	64,430	27,520	27,380	12,320	1,820	COE; 1984
Birch	Birch Creek	ws, fc, wq, r, fw	39,805	19,225	15,165	6,700	1,145	COE; 1977
Broken Bow	Mountain Fork River	ws, fc, p, r, fw	450,160	918,070	152,500	196,000	14,200	COE; 1970
Canton	North Canadian River	ws, fc, I	265,790	111,310	97,170	18,480	7,910	COE; 1948
Copan	Little Caney River	ws, fc, r, fw	184,300	43,400	33,600	21,300	4,850	COE; 1981
Eufaula	Canadian River	ws, fc, p, n	1,510,800	2,314,600	56,000	56,000	105,500	COE; 1964
Fort Cobb	Cobb Creek	ws, fc, r, fw	63,730	80,010	78,350	18,000	4,070	BuRec; 1959
Fort Gibson	Grand (Neosho) River	fc, p	919,200	365,200	n/a	n/a	19,900	COE; 1953
Fort Supply	Wolf Creek	ws, fc	86,800	13,900	400	224	1,820	COE; 1942
Foss Reservoir	Washita River	ws, fc, I, r	180,410	165,480	165,480	18,000	6,800	BuRec; 1961
Grand	Grand (Neosho) River	fc, p	525,000	1,672,000	n/a	n/a	46,500	GRDA; 1940
Great Salt Plains	Salt Fork/Arkansas River	ws, fc, r, fw	239,980	31,420	n/a	n/a	8,690	COE; 1941
Heyburn	Polecat Creek	ws, fc, r, fw	48,290	7,105	2,340	1,904	880	COE; 1950
Hudson (Markham Ferry)	Grand (Neosho) River	fc, p	244,200	200,300	n/a	n/a	10,900	GRDA; 1964
Hugo	Kiamichi River	ws, fc, wq, r, fw	808,300	158,617	121,500	165,800	13,144	COE; 1974
Hulah	Caney River	ws, fc, flow	257,900	31,160	26,960	18,928	3,570	COE; 1951
Kaw	Arkansas River	ws, fc, wq, r, fw	867,310	459,850	203,000	230,720	18,775	COE; 1976
Keystone	Arkansas River	ws, fc, p, fw, n	1,167,232	505,381	20,000	22,400	22,420	COE; 1964
Lugert-Altus	North Fork/Red River	ws, fc, I	19,600	132,830	132,830	47,100	6,260	BuRec; 1948
McGee Creek	McGee Creek	ws, fc, r, fw, wq	85,340	113,930	107,980	71,800	3,810	BuRec; 1985
Oologah	Verdigris River	ws, fc, r, fw, n	1,007,060	552,210	342,600	172,480	31,040	COE; 1974
Optima	North Canadian River	ws, fc, r, fw	71,800	129,000	76,200	n/a	5,340	COE; 1978
Pine Creek	Little River	ws, fc, wq, r, fw	388,080	53,750	70,560	134,400	3,750	COE; 1969
Robert S. Kerr	Arkansas River	p, r, n	n/a	525,700	n/a	n/a	32,800	COE; 1970
Sardis	Jackfork Creek	ws, fc, r, fw	121,670	274,330	270,270	156,800	13,610	COE; 1981
Skiatook	Hominy Creek	ws, fc, wq, r, fw	176,100	322,700	280,200	85,130	10,190	COE; 1984
Tenkiller Ferry	Illinois River	fc, p	576,700	654,100	25,400	29,792	12,900	COE; 1953
Texoma	Red River	ws, fc, p, r, n, flow	2,613,777	2,580,386	150,000	168,000[2]	86,910	COE; 1944
Thunderbird	Little River	ws, fc, r	76,600	119,600	105,900	21,700	6,070	BuRec; 1965
Tom Steed	Otter Creek	ws, fc, r, fw	20,310	88,970	88,970	16,000	6,400	BuRec; 1977
Waurika	Beaver Creek	ws, fc, I, wq, r, fw	131,900	190,200	170,200	45,590	10,100	COE; 1977
Webbers Falls	Arkansas River	p, n	n/a	170,100	n/a	n/a	11,640	COE; 1970
Wister	Poteau River	ws, fc, r, fw	388,399	61,423	39,082	31,400	7,386	COE; 1949
			13,637,373	**13,166,177**	**2,922,637**	**1,790,968**	**543,450**	

[1] Includes water quality storage, where applicable.
[2] Oklahoma portion of total yield.

n/a = not applicable; ws = water supply; fc = flood control; I = irrigation; r = recreation; fw = fish & wildlife; wq = water quality; p = power; n = navigation; flow = low flow regulation.



OKLAHOMA COMPREHENSIVE
WATER PLAN

Figure 2
MAJOR WATER RESOURCE
DEVELOPMENT PROJECTS

cal landowners to store irrigation water throughout the year. During the rainy season, nearly 600 playa lakes, covering almost 10,000 acres, exist in the High Plains of Oklahoma.

An oxbow lake forms when deposits of sediment fill in the open end of a U-shaped bend in a river, land-locking a small new lake from the river channel. Primarily occurring along the Red River -- especially in McCurtain County, where 26 oxbows exist -- these water resources are nourished only by rainfall, runoff and, in some cases, the underlying alluvium of the old river. Oklahoma is home to 62 oxbow lakes which are 10 acres or larger in size; the largest of these is the 272-acre 1941 Cut-Off in McCurtain County.

Transitional areas between land and water, wetlands are also important water resource components. Though not prolific sources of water, wetlands serve several crucial water-related purposes, including flood control, improved water quality, aquifer recharge, flow stabilization of streams and rivers, and habitat for fish and wildlife. Oklahoma's wetlands fall into three broad classifications (related to size, location, dominant vegetation and related characteristics) under the system used by the U.S. Fish and Wildlife Service's National Wetland Inventory (NWI) -- riverine, lacustrine and palustrine. While often a feature of floodplains statewide, wetlands are more frequently found along river corridors in eastern Oklahoma where approximately 61 percent of the state's 687,000 wetland acres are found.

The following section presents a detailed description of the Red and Arkansas Rivers and their major tributaries (Figure 3), followed by a separate discussion of generalized water quality information for selected stream gages and stream systems.

Red River and Tributaries

The trek of the Red River begins with two small tributaries in eastern New Mexico, about 30 miles south of Tucumcari. The river then flows across the Texas Panhandle, along the Oklahoma/Texas border, through Arkansas and Louisiana, and finally to its confluence with the Atchafalaya River and the mighty Mississippi.

Tierra Blanca and Palo Duro Creeks, in the flatlands of the Texas Panhandle, flow easterly toward their confluence prior to entering scenic Palo Duro Canyon, south of Amarillo. Here begins the Prairie Dog Town Fork of the Red River which flows southeasterly then easterly to begin, more or less, the southern border of Oklahoma at river mile 1,050. Only a few miles downstream, the Prairie Dog Town Fork encounters Buck Creek, where it becomes the Red River proper. In Jackson County, the Red River is united with two of its more significant tributaries, Sandy and Gypsum Creeks. Its two major contributors, the Salt Fork and North Fork of the Red River, join the river south of Altus. As the state's southern border, the Red River spans 517 miles from the Texas Panhandle to southwestern Arkansas. Oklahoma contributes 22,971 square miles of drainage to the Red River. Massive Lake Texoma -- the nations' seventh biggest and Oklahoma's largest reservoir-- is the only major reservoir project on the mainstem of the Red River in Oklahoma.

The Salt Fork of the Red River heads in the High Plains of southern Carson and northern Armstrong Counties, Texas, and flows in a southeasterly direction for 97 miles where it enters Oklahoma in rural Harmon County. It continues in the same general direction for 73 miles to its confluence with the mainstem of the Red River near Elmer, Oklahoma -- a total of 167

Table 2
MAJOR MUNICIPAL AND PRIVATE WATER RESOURCE DEVELOPMENT PROJECTS IN OKLAHOMA

Official Name	Source	Purpose	Normal Operating Capacity (ac-ft)	Water Supply Storage (ac-ft)	Water Supply Storage (ac-ft)	Normal Surface Area (acres)	Owner & Completion Date
Atoka [1]	North Boggy Creek	ws, r	125,000	123,500	700	5,700	City of Oklahoma City; 1964
Bluestem [2]	Middle Bird Creek	ws,r	17,000	—	—	762	City of Pawhuska; 1958
Carl Blackwell	Stillwater Creek	ws, r	61,500	61,500	7,000	3,370	Oklahoma State University; 1937
Chickasha	Spring Creek	ws, r	41,080	41,080	7,500	820	City of Chickasha; 1958
Dripping Springs	Salt Creek	ws, r, fc	16,200	16,200	7,412	1,150	City of Okmulgee; 1976
Ellsworth	East Cache Creek	ws, r	72,500	65,500	23,500	5,600	City of Lawton; 1962
Eucha	Spavinaw Creek	ws, r	79,567	79,567	84,000	2,860	City of Tulsa; 1952
Fuqua [3]	Black Bear Creek	ws, r, fc	21,100	17,600	2,654	1,500	City of Duncan; 1962
Hefner [4]	Bluff Creek	ws, r	75,000	75,000	—	2,500	City of Oklahoma City; 1943
Konawa	Jumper Creek	cw	23,000	23,000	—	1,350	Oklahoma Gas & Electric; 1968
Lawtonka	Medicine Creek	ws, r	56,574	56,574	23,500	2,398	City of Lawton; 1905
McMurtry	North Stillwater Creek	ws, r, fc	19,733	13,500	3,002	1,155	City of Stillwater; 1971
Murray	Anadarche Creek	r	153,250	153,250	—	5,728	State of Oklahoma; 1937
Overholser [5]	North Canadian River	ws, r	15,000	15,000	5,000	1,500	City of Oklahoma City; 1919
Shawnee	South Deer Creek	ws, r	34,000	34,000	4,400	2,436	City of Shawnee; 1935 & 60
Sooner [6]	Greasy Creek	ws, r, fc, cw	149,000	149,000	3,600	5,400	Oklahoma Gas & Electric; 1972
Spavinaw [7]	Spavinaw Creek	ws, r, fw	38,000	30,600	—	1,584	City of Tulsa; 1924
Stanley Draper [8]	East Elm Creek	ws, r	100,000	100,000	—	2,900	City Oklahoma City.; 1962
			1,097,504	**1,054,871**	**172,268**	**48,713**	

[1] Yield does not include supply pumped from McGee Creek Reservoir for transfer to Lake Stanley Draper.
[2] Water supply information not available.
[3] Yield includes that of Clear Creek and Duncan Lakes which provide supply for City of Duncan.
[4] Dependable yield negligible.
[5] Yield does not include releases from Canton Lake.
includes potential yield from drainage basin.
[7] Yield negligible; serves as terminal storage for releases from Eucha Lake.
[8] Yield negligible; serves as terminal storage for water pumped from Atoka Lake and McGee Creek Reservoirs.

n/a = not applicable; ws = water supply; r = recreation; fc = flood control; cw = cooling water; fw = fish & wildlife; p = power.

miles. More than 2,000 square miles of land area make up the Salt Fork drainage, 708 square miles of it in Oklahoma.

The North Fork of the Red River originates in Carson County, Texas and flows eastward for a river distance of 72 miles where it enters the state several miles north of Interstate 40 near Texola, Oklahoma. After passing near Sayre, it turns southeasterly and southerly passing through Lugert-Altus Reservoir to its confluence with the mainstem of the Red River west of Davidson, a total distance of 220 river miles, with 148 miles in Oklahoma. The North Fork has a 4,828-square mile drainage area, 3,605 square miles of which is in Oklahoma. Otter Creek, a major tributary of the North Fork, impounds Tom Steed Reservoir.

The Elm Fork of the North Fork of the Red River begins in the southwestern part of Wheeler County, Texas, and flows east-southeasterly where it enters Oklahoma near the Harmon/Beckham County line. It continues in the same general direction until it enters the North Fork at river mile 70. The Elm Fork has total drainage area of 915 square miles, 540 square miles in Oklahoma. The tributary has a total length of 97 miles, 68 miles in the state.

Cache Creek, which consists of a relatively short mainstem less than eight miles long, forms near the Oklahoma/Texas border at the confluence of its two relatively large tributaries, East Cache (101 miles long) and West Cache (61 miles) Creeks. These two important tributaries traverse Caddo, Comanche, Tillman and Cotton Counties and drain approximately 773 square miles. The total area of the Cache Creek Basin is 1,895 square miles, of which 617 square miles is in Deep Red Creek, a 62-mile long tributary of West Cache Creek. Following the confluence, Cache Creek flows southerly and southwesterly prior to joining the mainstem of the Red River at mile 912. East Cache Creek impounds Lake Ellsworth, one of Lawton's two major water supplies. Medicine Creek, a contributor to East Cache, impounds Lake Lawtonka near the slopes of Mount Scott in the granitic Wichita Mountains.

Beaver Creek, 76 miles long, originates in northwestern Comanche County and southwestern Grady County. It flows in a southerly direction through Waurika Lake prior to its confluence with the mainstem of the Red River at mile 882. Beaver Creek has a drainage area of 865 square miles.

Mud Creek originates in the southwest part of Stephens County and runs 75 miles in a southeasterly direction through Jefferson County prior to joining the Red River in southwest Love County. It has a drainage area of 688 square miles.

Walnut Bayou Creek heads in Carter County and extends 32 miles south through Love County to its confluence with the Red River at mile 808. Walnut Bayou has a drainage area of 334 square miles.

The flow of the Washita River begins in southeastern Roberts County, Texas, and runs in an easterly direction to the Texas/Oklahoma state line. The turbid river then enters Oklahoma in Roger Mills County, extending southeasterly through Beckham, Dewey, Custer (where it impounds Foss Reservoir), Washita, Kiowa, Caddo, Canadian, Comanche, Grady, Stephens, McClain, Garvin, Murray, Carter, Pontotoc, Johnston, Marshall and Bryan Counties to its confluence with the Red River in Lake Texoma at mile 732. It extends a total of 626 miles (580 miles in Oklahoma) and covers 7,945 square miles of drainage area. Lake Chickasha and Arbuckle Reservoir lie on two of the Washita River's major tributaries -- Spring and Rock Creeks. Another tributary, Cobb Creek, impounds Fort Cobb Reservoir northwest of Carnegie.

The spring-fed Blue River heads in Pontotoc County, near Roff, and flows 147 miles in a southeasterly direction to its confluence with the Red River near Wade, in Bryan County. The Blue River basin is long and narrow with a maximum width of about 14 miles and a total drainage area of 676 square miles.

Boggy Creek starts in eastern Pontotoc and southwestern Hughes Counties, then flows more than 24 miles in a southerly and southeasterly direction to its confluence with the Red River at about mile 644, near Hugo. The Boggy and its two large tributaries, Muddy Boggy Creek (131 miles long) and Clear Boggy Creek (88 miles), make up 2,429 square miles of drainage area. Two of Oklahoma City's water supply lakes in the southeast, Atoka Lake and McGee Creek Reservoir, lie on other smaller tributaries of the Muddy Boggy.

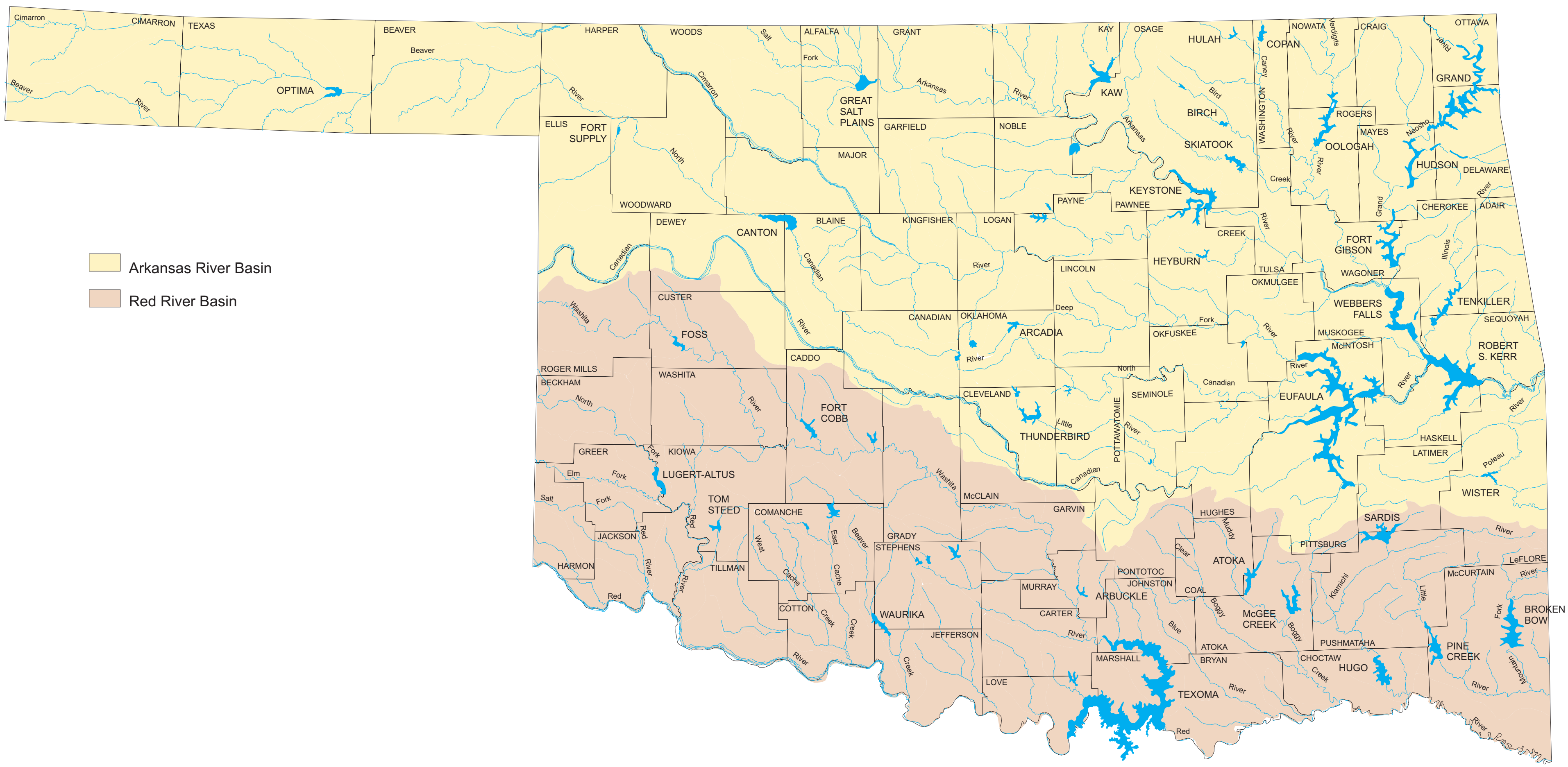
The Kiamichi River has its source in the Kiamichi and Ouachita Mountain ranges in southeastern LeFlore County, Oklahoma. It flows 169 miles in a westerly path through Latimer and Pittsburg Counties, then south through Atoka, Pushmataha and Choctaw Counties, where it impounds Hugo Lake prior to entering the Red River at mile 607. It has a drainage area of 1,830 square miles and is a major tributary of the Red River. Jackfork Creek, a tributary of the Kiamichi, impounds Sardis Lake.

The Little River, which has a total length of 217 miles (130 in Oklahoma), heads in the southern portion of LeFlore County, extends for a few miles into Arkansas and then back into Oklahoma before crossing over the Pushmataha County line. Following this horseshoe route, the Little River traverses southerly and southeasterly into McCurtain County (where it impounds Pine Creek Lake), turns easterly near Idabel and continues in the same general direction until it leaves the state at river mile 78. With its two crystal clear tributaries, Mountain Fork River and Glover Creek, it has a total combined drainage area of 2,269 square miles at the state line and 2,029 miles in Oklahoma, excluding a portion of its headwaters in Arkansas. A section of the upper Mountain Fork River, which flows into Broken Bow Lake, is noted for its high quality and has been designated as one of Oklahoma's six "scenic rivers," protected by the State Legislature due to their unique free-flowing beauty and recreational value to state citizens.

Arkansas River and Tributaries

The Arkansas River Basin, home of the state's five remaining scenic rivers, is the other major river basin in Oklahoma. From its source near the historic mining town of Leadville, in the heart of the Rocky Mountains in central Colorado, the Arkansas River flows southerly, then easterly, crossing the Kansas State line near Coolidge, Kansas. It proceeds generally easterly then northeasterly to Great Bend, Kansas, where it turns southeasterly and enters Kay County, Oklahoma, just south of Arkansas City, Kansas.

Extending southeasterly through Kaw Lake as the county line between Osage, Noble and Pawnee Counties, the Arkansas River reaches Keystone Lake. From Keystone, it continues its southeasterly direction through Tulsa County and the City of Tulsa, then becomes the county line between Wagoner and Muskogee Counties. Within Muskogee County, the Arkansas flows into Webbers Falls Reservoir,



OKLAHOMA COMPREHENSIVE WATER PLAN

Figure 3
RED AND ARKANSAS RIVER BASINS AND MAJOR TRIBUTARIES

then into Robert S. Kerr Reservoir, and after forming the county line between Sequoyah and LeFlore Counties, it leaves the state at mile 361 before it runs through Little Rock, Arkansas, and joins the Mississippi River. Much of the Arkansas River comprises the McClellan-Kerr Navigation System which links Oklahoma with foreign markets through New Orleans, the nation's second busiest port. The Arkansas River drains about two-thirds of the state's land area and 328 miles of its length lie in Oklahoma.

The Poteau River heads in Scott County, Arkansas, and enters Oklahoma in southeast LeFlore County, then begins a westerly to northwesterly trek to Wister Lake. At the confluence of Fourche Maline Creek it turns easterly and flows north, uncharacteristic of most state rivers, ending at its confluence with the Arkansas River at mile 362 at the Oklahoma/Arkansas border near Fort Smith. The 96-mile long Poteau River and its tributaries drain an area of 1,888 square miles, 1,328 square miles of which is in Oklahoma.

Originating in Colfax County, New Mexico, and flowing southeasterly through New Mexico and easterly through the Texas Panhandle, the Canadian River (often mistakenly referred to as the South Canadian) enters Oklahoma as the meandering boundary between Ellis and Roger Mills Counties. Moving easterly through Dewey County, then southeasterly through the northeast tip of Custer County and the southwest tip of Blaine County, it crosses the southwest portion of Canadian County and forms the line between Canadian, Grady, Cleveland, McClain, Pottawatomie, Seminole, Pontotoc, Hughes, Pittsburg and McIntosh Counties. The Canadian flows through Eufaula Lake and joins the Arkansas River prior to entering Robert S. Kerr Reservoir, completing its 411 miles trek across Oklahoma. The Canadian River has a total drainage area of 19,487 square miles in the state.

The North Canadian River has its source in northern Union County, New Mexico. It enters Oklahoma in southwest Cimarron County, loops south and flows through the State of Texas for about 12 miles until it again winds back into Oklahoma, impounding Optima Lake in Texas County. The North Canadian then takes a sharp northeasterly turn before assuming a primarily eastward path through Beaver County. After entering Harper County, a southeasterly direction is maintained through Woodward, Major, Dewey, Blaine, Canadian, Oklahoma, Lincoln and Pottawatomie Counties. Canton Lake lies on the North Canadian at river mile 394 while Wolf Creek, a tributary, impounds Fort Supply Lake 12 miles northwest of Woodward. After forming the county line between Pottawatomie, Seminole and Okfuskee Counties, the river enters Hughes County. It then reenters Okfuskee County before flowing into McIntosh County and Eufaula Lake. Following its hefty 747 mile trek through Oklahoma, making it the state's longest river, it joins the Canadian River near the town of Eufaula. The North Canadian impounds Lake Overholser which, in tandem with Lake Hefner, an off-channel reservoir, makes up Oklahoma City's venerable water supply system. Due to Hefner's small contributing drainage area, the lake depends almost entirely on water furnished through a five-mile long canal from Overholser. The North Canadian has approximately 9,100 square miles of drainage.

The Deep Fork of the North Canadian River (more commonly referred to as the Deep Fork River) heads in Oklahoma County, impounding Arcadia Lake, and then flows easterly through Lincoln, Creek, Okfuskee, Okmulgee and McIntosh Counties. After entering McIntosh County, it flows into Eufaula Lake and finally to its confluence with the North Canadian River at mile 14.4. The Deep Fork River has a drainage area of 2,548 square miles and a length of 230 miles.

The source of the Little River is in Oklahoma and Cleveland Counties. Flowing easterly through Lake Thunderbird, the Little River bisects Pottawatomie and Seminole Counties, then flows southeasterly into Hughes County to its confluence with the Canadian River near Holdenville. The Little River, not to be confused with the river of the same name in the Red River Basin, has a drainage area of 1,973 square miles and spans 120 miles across central Oklahoma.

The brackish Cimarron River originates in northeastern New Mexico near Raton. It begins near the Colorado State line as a small tributary called Cimarron Creek which becomes the Dry Cimarron River northeast of Capulin Mountain. Flowing easterly, the river enters Oklahoma near the town of Kenton in Cimarron County, then proceeds easterly and northeasterly where it enters Colorado near the northeast corner of the county. The river reenters Oklahoma at the northeast corner of Beaver County, exits the state again in northwest Harper County, then enters the state for a third time to form part of the eastern Harper County line. The river flows in a southeasterly direction to mark the county line between Woodward, Woods and Major Counties. Entering Kingfisher County, it flows eastward through Logan County to form a portion of the county line between Logan and Payne Counties. After entering Creek County, it continues eastward to its termination in Keystone Lake. Lake McMurtry and Lake Carl Blackwell, both near Stillwater, are located on tributaries of the Cimarron. The Cimarron River has 18,927 square miles of drainage area and a length of 698 miles, about 410 miles of which is in Oklahoma.

The Salt Fork of the Arkansas River enters Oklahoma from Kansas in the northeast section of Woods County and flows eastward through Alfalfa County to Great Salt Plains Lake. The Salt Fork continues its eastward route through Grant and Kay Counties and terminates at the confluence with the Arkansas River in Kay County at mile 637.8. The Salt Fork drains an area of 6,764 square miles and meanders 160 miles across northern Oklahoma.

The Chikaskia River heads in south central Pratt County, Kansas. Flowing southeasterly, it enters Oklahoma between Grant and Kay Counties, then continues southeasterly to its confluence with the Salt Fork of the Arkansas River in Kay County. The Chikaskia River has 3,340 square miles of drainage in Oklahoma and a total length of 145 miles, 49 of which is in Oklahoma.

From its source in Greenwood County, Kansas, the Verdigris River flows southerly where it enters Oklahoma in northern Nowata County. As a principal artery of the Arkansas River, it flows in a southerly direction through Oologah Lake into Rogers and Wagoner Counties, then enters Muskogee County and joins the Arkansas River at mile 460.2. The Verdigris drains 4,290 square miles within Oklahoma and has a total length of 162 miles within the state.

Bird Creek, located primarily in Osage and Tulsa Counties, is 111 miles long and has its 1,137-square mile drainage area entirely within Oklahoma. Bird Creek enters the Verdigris River at mile 78.3.

The Caney River originates in southwestern Elk County, Kansas, then flows southerly and southeasterly where it enters Oklahoma and Hulah Lake in the northeast portion of Osage County. It continues easterly into Washington and Rogers Counties to its confluence with the Verdigris River near Claremore in central Rogers County. The Little Caney River impounds Copan Lake in Washington County. The Caney River has a total length of 118 miles and a drainage area of 1,616 square miles within Oklahoma.

The Illinois River, which has its source in the Boston Mountains of northwest Arkansas, enters Oklahoma in Adair County near the town of Watts and travels southwesterly through Cherokee and Sequoyah Counties before its confluence with the Arkansas River at mile 427. Another scenic river which is an exceedingly popular spot for weekend canoeists and other recreationists, the Illinois stretches through 110 miles of eastern Oklahoma cliffs and countryside. Tenkiller Ferry Lake, a haven for scuba divers, is formed on the Illinois River and utilizes a large part of the river's 1,660 square miles of total drainage area. Two of its tributaries, Flint and Baron Fork Creeks, have also been designated as scenic rivers.

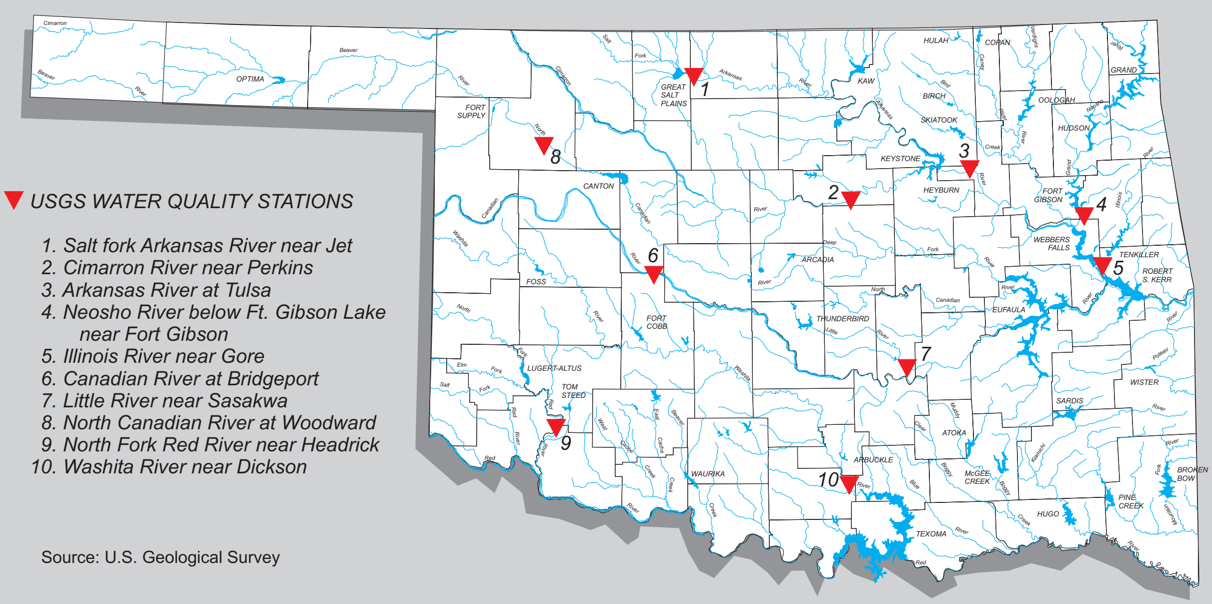
The Grand (Neosho) River, another major contributor to the Arkansas River, has its source in Mavis County, Kansas, then flows southerly and southeasterly where it enters the Ozark Region of northeast Oklahoma forming a portion of the Craig/Ottawa County line. Impounding the serpentine Grand Lake O' the Cherokees, Lake Hudson and Fort Gibson Lake, the Grand River winds through lush valleys in Delaware, Mayes, Wagoner and Cherokee Counties before joining the Arkansas River in Muskogee County at mile 459.5. Grand Lake is one of Oklahoma's most popular tourist and recreation spots. Spavinaw and Eucha Lakes -- on Spavinaw Creek, a major tributary of the Grand River -- are two high quality water supply reservoirs operated by the City of Tulsa. The Grand River has approximately 12,520 square miles of total drainage, with 6,727 square miles in Oklahoma. It has a total length of 450 miles, 164 miles in Oklahoma.

STREAM WATER QUALITY

With few exceptions, surface water in western Oklahoma is unsuitable for public supply due to undependable flows and large concentrations of dissolved minerals. In the east, however, surface supplies are normally of sufficient quantity and quality for public use and consumption. Point source discharges from municipalities and various industries, though now effectively regulated in the state and nationwide, still pose a potential threat to Oklahoma's streams and rivers. However, nonpoint source pollution -- determined to a great extent by land use in a particular drainage basin as well as by local physiography, climate, geological and related characteristics -- has become a major determinant of surface water quality in the state. Common pollutants of state stream waters from various sources include oilwell drilling wastes, sewage, poultry wastes, oil, saltwater from oil and gas extraction, pesticides, fertilizers, gasoline, diesel fuel, lawn chemicals, cattle and horse manure, nitrates, sulfuric acid, hydrogen sulfide and dissolved metals.

Water quality standards specific to designated beneficial uses of state waters have been promulgated by the OWRB. All Oklahoma streams and rivers have state-designated beneficial uses of recreation and fish and wildlife propagation. Although 19,791 miles of streams and rivers were directly assigned beneficial uses in the 1988 Oklahoma Water Quality Standards, only 4,393 miles have been assessed first-hand to determine whether they meet state standards for each designated use. Of the assessed rivers and streams, 269 miles (6 percent) fully support designated uses, 2,299 miles (52 percent) fully support designated uses but are threatened, and 1,825 miles (42 percent) partially support designated uses. A stream is classified as partially supporting designated

Figure 4
WATER QUALITY MONITORING SITES



beneficial uses if one or more of its beneficial uses is partially supported.

A general summary of water quality in the state's major river basins and subbasins -- garnered from data collected, analyzed and maintained by the U.S. Geological Survey and U.S. Environmental Protection Agency, with assistance from the Oklahoma Conservation Commission, Oklahoma Department of Wildlife Conservation and OWRB (from the USGS National Water Summary, 1990-91) -- is presented here. Much of the information was obtained from water samples collected at 10 selected monitoring stations located throughout Oklahoma for water years (for hydrologic data purposes, the period October 1 through September 30) 1987-89 (Figure 4). In addition, upward and downward trends in certain water quality parameters from 1980-89 are noted. Local water quality problems that affect aquatic life or public health are not fully addressed.

The Salt Fork of the Arkansas River and Cimarron River basins, underlain by massive gypsum deposits, are the location of numerous natural brine seeps and springs. Agriculture is the principal land use in the region which includes grassland and grazing land. The Salt Fork just downstream of Great Salt Plains Lake suffers somewhat from excessive concentrations of chloride, dissolved solids, nutrients, pesticides, toxic chemicals and suspended sediment. Great Salt Plains Lake itself has been partially filled with sediment and, in most areas, water is only about four feet deep. Fertilizers and pesticides from agricultural operations in the basin contribute nutrients (nitrogen and phosphorus) and organic compounds to the reservoir. While the shallow depth of the lake enables wind mixing to keep the reservoir aerobic, it also allows nutrient- and pesticide-bearing sediment particles to remain in suspension.

Median concentrations of sulfate (500 mg/L), chloride (920 mg/L) and dissolved solids (2,400 mg/L) in water samples from the Great Salt Plains site were among the largest for the 10 monitoring stations. All sulfate, chloride and dissolved-solids concentrations at the site exceeded concentrations recommended by the state for recreation (250 mg/L) and fish and wildlife propagation (500 mg/L).

Agricultural cropland is the principal land use upstream of the Perkins area (Payne County) on the Cimarron River. Oil production, however, has had a significant effect on water quality. Also, large concentrations of chlordane from an unknown source have been detected in the river. Fecal coliform bacteria concentrations are greater than the state standard for water supply (a monthly geometric mean of 5,000 colonies per 100 ml), perhaps owing to runoff from livestock grazing and feedlot areas. Upstream and downstream from the site, river water quality is affected by oil and grease, fecal coliform bacteria, chlorides, dissolved solids, pesticides and suspended solids. Natural brine seeps and springs (and, to a lesser extent, oilfield activities) contribute large quantities of chloride to streams in the area, making the water unsuitable for irrigation and industrial and commercial uses. Although downward trends have been reported in dissolved chlorides and dissolved solids, an upward trend is noted in dissolved sulfate.

Samples collected at the Perkins site had among the largest median concentrations of fecal coliform bacteria (180 col/100 ml), chloride (1,400 mg/L), dissolved solids (3,240 mg/L), nitrite plus nitrate (0.69 mg/L), phosphate (0.08 mg/L) and suspended sediment (126 mg/L). Extensive agricultural activities in the basin may be a contributor to these large concentrations.

Much of the Arkansas River basin in Oklahoma is underlain by shale, limestone and fine-to-course-grained sandstone. Water flowing through these rocks may dissolve large quantities of minerals, primarily sodium and sulfate. The Salt Fork of the Arkansas and Cimarron Rivers, two primary tributaries of the Arkansas, add highly mineralized water to the river. Water quality also is affected by oilfield activities, agriculture and municipal wastewater discharges. Large chlordane and polychlorinated biphenyl concentrations have been detected in the river at Tulsa, downstream of Keystone Lake. Both upstream and downstream from the site, the river contains elevated concentrations of pesticides, organic compounds and pathogenic indicators, although downward trends are reported in fecal coliform bacteria.

Samples collected at the site had a median suspended sediment concentration of 21 mg/L, among the lowest for the 10 monitoring stations. This level of concentration might have been the result of sediment entrapment in Keystone Lake.

The Neosho and Illinois Rivers, which flow through the Ozark Plateaus, are located in one of the state's most popular tourist and recreation areas. The rivers are impounded by a series of reservoirs located in low mountains and underlain by chert, limestone, shale and sandstone.

Human activities in the two river basins have had a detrimental impact upon water quality. Extensive lead and zinc mining in the Neosho River basin has increased concentrations of these trace metals in the river. Just upstream of the monitoring station, located below Fort Gibson Lake but above the Neosho's confluence with the Arkansas and Verdigris Rivers, the river contains excessive levels of organic compounds, toxic metals, pH and suspended solids.

Median concentrations of sulfate (34 mg/L), chloride (8.7 mg/L) and dissolved solids (155 mg/L) in water samples from the Neosho River site were among the smallest for the 10 stream sites. The Neosho River also had the smallest median suspended sediment concentration (12 mg/L), due in part to the site's location downstream from a series of large, sediment-trapping reservoirs. Trends in water quality indicate reductions in dissolved sulfate, chloride and solids.

The Illinois River has been designated by the Oklahoma State Legislature as a state scenic river. However, widespread development in the Illinois River basin has led to increased nitrate and phosphorus concentrations contributed by nonpoint source discharges. The Illinois River contains excessive levels of nutrients, suspended solids and organic compounds. Although recent USGS data do not indicate a problem, the Oklahoma Conservation Commission reports violations of the state's dissolved oxygen standard more than 20 percent of the time at the monitoring station near Gore, just upstream of the Illinois' confluence with the Arkansas River. These conditions affect fishery resources and recreation in the area. As in the Neosho River, median concentrations of sulfate (9.9 mg/L), chloride (11 mg/L) and dissolved solids (114 mg/L) in the Illinois River site were relatively small in comparison to most other stream sites.

Upstream from the Blaine/Canadian/Caddo County Line, the Canadian River lies entirely within the Central Lowland which, along with land use in the basin (cropland), contributes significantly to the water quality characteristics of the river.

The basin is underlain by fine-grained sandstone, dolomite, shale and gypsum. The median concentration of sulfate (560 mg/L) at the Bridgeport site, in Caddo County, was among the largest measured at the 10 monitoring stations. It is likely that this sulfate is contributed by one or more agricultural compounds, such as ammonium sulfate, poultry-dusting powders, sulfur-containing fungicides and, especially, gypsum.

The headwaters of the Little River are located in central Oklahoma. Land in the basin, which is underlain primarily by shale and fine-grained sandstone, is commonly used for pasture and growing hay, although the Cities of Moore and Norman are near the headwaters. Human activity affects the river in those urban areas where large concentrations of cadmium, chromium and lead have been identified. The exact sources of these toxic metals are unknown, but could be contributed by industry in the Moore/Norman area. Cadmium and chromium have not been detected in excessive concentrations at the site near Sasakwa, in southern Seminole County. Some upstream tributaries of the river contain high levels of pesticides and toxic metals.

The western reach of the North Canadian River drains cropland in the Great Plains. Downstream from the Woodward monitoring site, excessive sedimentation and high turbidity levels adversely affect the fishery resource of Canton Lake. There are also concerns that the fishery is being impacted by agricultural runoff containing pesticides and excess nutrients. The area has had several fishkills, some likely caused by aerial pesticide application. Gypsum beds in the underlying geologic formations might have been the source of excessive sulfate (median, 230 mg/L) and dissolved solids (median, 1,080 mg/L) in the river beginning around 1987. The large concentration of fecal coliform bacteria at the site could be a result of runoff from area feedlots. Trends show a reduction in dissolved phosphate.

The North Fork of the Red River lies within the Central Lowland in southwestern Oklahoma and land use in the basin is primarily cropland. The river downstream of Headrick, east of Altus in Jackson County, has been assessed as fully supporting designated uses but threatened by pesticides, metals and suspended solids. The reach upstream from the site was assessed as fully supporting designated uses.

Dissolution of gypsum beds contributes large quantities of sulfate to the river. Water samples from the Headrick site had the largest median concentrations of sulfate (830 mg/L) and dissolved solids (3,420 mg/L) for the 10 monitoring stations; the median concentration of chloride (1,100 mg/L) was the second largest. Natural brine discharges increase the chloride concentration and make several streams in southwest Oklahoma unsuitable for municipal use or irrigation. The median concentration of nitrite plus nitrate (1.3 mg/L), probably contributed by agricultural runoff, was relatively large and trends indicate a recent increase in that contaminant.

The Washita River basin, dominated by grazed, open woodland, is underlain by shale, siltstone, sandstone and interbedded gypsum deposits. The river suffers from excessive concentrations of chloride, nutrients, pesticides and suspended sediment. Solution of gypsum is the primary source of dissolved sulfate in the Washita and limits the river's use as a public water supply. The median concentration of sulfate in water samples collected near Dickson, east of Ardmore in Carter County, was 460 mg/L during water years 1987-89, indicating a recent increase in dissolved sulfate, along with dissolved solids. Past cultivation practices in the primarily agricultural region have resulted in large suspended sediment concentrations in the river upstream from the Dickson site. The median concentration of suspended sediment (376 mg/L) was the largest for the monitoring stations that had sufficient data for statistical analysis.

While southeast Oklahoma water quality is not represented by any of the 10 sites summarized above, quality in the Kiamichi River Basin is generally considered excellent and there are no concerns that should preclude any of the river's designated beneficial uses. The water is suitable for irrigation and, with treatment, is an excellent source for municipal and industrial purposes. However, heavy metals (including cadmium, mercury, lead and arsenic), usually associated with increases in sediment loading during periods of high runoff, may create occasional problems for those diverting water directly from the river for various uses. Dissolved solids generally increase in the lower reaches of the river due to calcium carbonate hardness.

Lakes, unlike most watercourses, have relatively limited ability to cleanse themselves. As a result, they are particularly susceptible to contamination. Major water quality problems that impair Oklahoma lakes include nonpoint pollution from various sources and activities in the watershed; excessive concentrations of inorganic suspended solids and/or turbidity levels which often result from nonpoint sources; toxicity concerns due to a myriad of pollutants; and excessive productivity and oxygen depletion which often results in lake eutrophy.

The OWRB continually monitors the quality of selected Oklahoma lakes as part of the Statewide Lakes Water Quality Assessment. Researchers have determined that, of the total lake surface acres in the state (excluding farm ponds), approximately three-quarters have nonpoint pollution concerns; one-third have recreational concerns; and almost one-half have toxicity concerns. In addition, 60 percent of the total surface acreage is considered to be eutrophic or hypereutrophic.

GROUNDWATER RESOURCES

Groundwater is water that has percolated downward from the surface, filling voids or open spaces in the rock formations. Lying almost motionless beneath the earth's surface, groundwater is truly Oklahoma's buried treasure to recover as the need arises and to preserve when surface sources yield adequate supplies. Oklahoma is underlain by 23 major groundwater basins containing an estimated 320 million acre-feet of water in storage, perhaps half of which is recoverable for beneficial use. Many of the minor basins may also yield significant amounts of fresh water. Wells and springs supply more than 60 percent of the total water use, including almost 90 percent of the state's irrigation needs, and provide municipal water for more than 300 Oklahoma cities and towns.

The underground zone of water saturation begins at the point where subsurface voids are full or completely saturated. A rock formation, or group of formations, that contains sufficient saturated material to yield significant quantities of water to wells and springs is called a groundwater basin, or aquifer. The amount of water available to wells depends on the saturated thickness (the thickness of the zone below the water table in which all the interstices are filled with groundwater), area of the basin and specific yield (the ratio of the volume of water a given mass of saturated material will yield by gravity to the volume of that mass). The amount of water that can be pumped from a well perennially, without depletion of the groundwater in storage, depends upon the amount of recharge from precipitation or runoff.

Western Oklahoma, though lacking in surface supplies, has tapped tremendous groundwater sources for use in irrigation and cattle feedlot operations. Texas County, in the Panhandle, is the largest water user among Oklahoma's 77 counties. The Ogallala Aquifer, an extensive bedrock formation in the Panhandle and northwestern Oklahoma, provides nearly all of the Panhandle's irrigation needs.

Oklahoma's major water-bearing formations may be divided into four general groups: semi-consolidated sand and gravel underlying the High Plains; unconsolidated alluvial deposits of sand and gravel along streams and adjacent to valleys; sandstone aquifers; and limestone (including dolomite and gypsum) aquifers. They range in age from Cambrian and Ordovician (represented by the Arbuckle Group) to Quaternary stream-laid deposits.

Due to an absence of available stream water, groundwater development is greatest in the west where it is used for irrigation and municipal, industrial and domestic purposes. In eastern areas, where surface water supplies are more abundant, groundwater resources are utilized primarily by small towns and rural homeowners.

Alluvial and terrace deposits are found along rivers, the terrace deposits lying higher than the alluvial basins. Geologically, they constitute a single water-bearing unit. Terraces represent older, higher stages of the rivers that have since cut their channels deeper. Water in the terrace accumulates from rainfall on the deposits and influent seepage of streams crossing it. Alluvial deposits of gravels, silts, sands and clays are still being laid down by streams in Oklahoma valleys. Throughout its history, a river has alternate periods of cutting and deposition as it meanders from side to side, widening its valley and irregularly depositing both coarse and fine sediments. Water enters the alluvium through direct rainfall, runoff and influent seepage from the river and its tributaries as they cross the alluvium.

Alluvial and terrace deposits along the major rivers -- the Arkansas, Salt Fork of the Arkansas, Red, North Canadian, Canadian, Washita, North Fork of the Red River and Cimarron -- extend from one to 15 miles from the river banks. The thickness of these deposits ranges from a few feet to about 200 feet. Yields of wells in these basins range from 100 to 1200 gpm. The deposits are unconfined and consist of sand, clay, silt and gravel.

In estimating the yield of a groundwater basin, these factors must be considered: well spacing, number of wells, rate and schedule of pumping, methods of well construction and development, and hydrogeologic characteristics. Unless the overlying property owner(s) chooses to drill a well, the water remains in the basin. In other cases, as the basin is de-watered, wells must be drilled deeper and water lifted greater distances to the surface. Although a groundwater basin is never completely depleted, higher pumping costs may eventually make use of a well infeasible.

Nearly one-half of Oklahoma's groundwater is found in the prolific bedrock basins of the west, including the massive Ogallala Formation and western alluvial and terrace deposits. Wells in those formations commonly yield as much as 2,000 gpm, but average about 300 gpm. Central Oklahoma contains about one-third of the state's groundwater resources where major aquifers generally yield 200 gpm, a generous supply for rural homes and some communities and industries. The average yield of aquifers underlying eastern Oklahoma is approximately 100 gpm. Specific information on the state's major groundwater basins is provided in the following section. Oklahoma's major bedrock and alluvial and terrace aquifers are delineated in Figures 5 and 6.

Whether referred to as stream or groundwater, springs remain an important source of supply for domestic, municipal, industrial, agriculture and other uses of water in the state. In addition, many springs supplement the flow -- or, in some cases, provide the headwaters and base flow -- for numerous rivers and streams in Oklahoma. Most springs of notable size in the state issue from aquifers in limestone and/or sandstone formations such as those in the Arbuckle Mountains, the Ozark region of the northeast, and the Black Mesa region of the Panhandle. Johnston County, much of which is underlain by the prolific Arbuckle-Simpson Aquifer, is likely home to the greatest density of measurable springs in Oklahoma that contribute substantially to the flows of Blue, Honey, Pennington and Mill Creeks as well as other streams draining mountains in the region.

Western Groundwater Basins

Withdrawals from the prolific aquifers in western Oklahoma account for approximately 80 percent of the state's total groundwater use. Major basins in the west are the Arbuckle-Timbered Hills Group, Blaine Formation, Rush Springs Sandstone, Elk City Sandstone, Cedar Hills Sandstone, Ogallala Formation and alluvial and terrace deposits.

The most prolific aquifer of the west -- and indeed, of the state -- is the Ogallala Formation underlying the Panhandle and parts of extreme western and northwestern counties. The Ogallala's areal extent, thickness and high permeability contribute to its capacity to store some 86.6 million acre-feet of water. Estimates in 1988 showed that 205,873 acres were irrigated from the Ogallala -- more than 90 percent of that total lying in the three Panhandle counties. In addition, it was estimated that some 3,200 high-capacity wells tapped the Ogallala region.

The greatest concentrations of high-capacity wells lie in south central (near Guymon) and northwestern Texas County. In Cimarron County, heavily developed well fields are found near Boise City and in the southwestern corner, near Felt. Overdevelopment and high pumpage could threaten the well-being of the aquifer and the agricultural economy it sustains. Overpumping of closely spaced wells can create a cone of depression, causing interference between wells and reducing the amount of water available to them. Such drawdown is common in more heavily irrigated areas. The long-term consequences of this situation include a decrease in the rate at which the pumps will deliver water, higher pumping costs, lower well yields, saline water encroachment and depletion of the aquifer. However, during the past several years, depressed markets for agricultural products and high fuel costs have encouraged some growers to return to dryland farming, allowing water levels in the Ogallala to stabilize somewhat.

In the southwest, reliance on groundwater is great and some areas are threatened by overdevelopment. The number of high-capacity wells has increased markedly over the past 30 years with groundwater supplying domestic, municipal and irrigation needs in the region. Pressure on groundwater supplies for irrigation is relieved somewhat in the Altus area where the W.C. Austin Project supplies stream water from Lugert-Altus Reservoir for irrigation of about 48,000 acres.

The climate in the southwest is semiarid; the 27 inches of annual rainfall is poorly distributed and droughts are frequent. Recharge from precipitation is much less than the amount of water withdrawn each year. Overdevelopment of groundwater resources is a problem in several basins of the southwest. The number of irrigation wells supplied by the Tillman Terrace deposits has increased from 80 in 1952 to 1,100 in 1988, resulting in water level declines around Tipton and Frederick. Dramatic changes in water levels have also been noted in the Rush Springs Sandstone of Caddo County, where declines have been reported in the Sickles area. The Blaine Formation also appears to be overdeveloped.

The Arbuckle-Timbered Hills Group (Cambrian-Ordovician in age) consists predominantly of carbonate rocks (limestone and dolomite) that outcrop in Comanche, Caddo and Kiowa Counties. The aquifer, approximately 6,000 feet in thickness, locally has high porosity and wells generally yield between 25 and 500 gpm. The aquifer is largely undeveloped and is used primarily for drinking water.

The Blaine Formation (Permian) occurs in Harmon and parts of Jackson, Greer and Beckham Counties. The groundwater basin, used almost exclusively for irrigation, consists of interbedded shale, gypsum, anhydride, dolomite and limestone that are characterized by solution channels and zones of secondary porosity. The yield from wells tapping the Blaine can reach as much as 2,500 gpm. However, due to the erratic nature of solution channels and cavities, it is difficult to predict yield or estimate amounts in storage. For a well to yield enough water for irrigation, it must tap a water-filled solution cavity in the aquifer. Water levels in the groundwater basin respond rapidly to infiltration of precipitation and to the effects of pumping.

The Rush Springs Sandstone (Permian) is an extensive groundwater basin outcropping throughout an area of 1,900 square miles from Stephens County in the south to Harper County in the north. It is a fine-grained, cross-bedded sandstone containing irregular silty lenses. Thickness ranges from less than 200 feet in the south to about 330 feet in northern areas of the basin. Well yields average about 400 gpm. The primary use of the aquifer is for irrigation.

The Cedar Hills Sandstone (Permian) is found in Woods, Alfalfa and Major Counties. It is a fine- to medium-grained, reddish-brown sandstone, siltstone and silty shale. Thickness ranges from 150 to 180 feet. Well yields range from 150 to 300 gpm.

The Elk City Sandstone (Permian) occurs in western Washita and eastern Beckham Counties. It is similar to the Rush Springs basin in being a fine-grained sandstone with little or no shale; however, it differs from the Rush Springs in its smaller areal extent and relative thinness. Well yields range from 60 to 200 gpm.

The Ogallala Formation (Tertiary) consists of interbedded sand, siltstone, clay, lenses of gravel, thin limestone and caliche. The Ogallala, also referred to as the High Plains Aquifer, underlies almost the entire Panhandle region and extends into portions of Harper, Ellis, Woodward and Dewey Counties. Total thickness ranges from a few feet to more than 500 feet due to the irregular surface on which the Ogallala was deposited. Average thickness in the Panhandle is 300 feet.

The Ogallala is the major source of water in the Oklahoma Panhandle. While public suppliers throughout the region rely upon the aquifer, irrigation is by far the primary use of the Ogallala. More than 2,500 irrigation wells have been drilled in this area, many yielding as much as 1,000 gpm. In western Roger Mills and northern Beckham Counties, the Ogallala is partly eroded and thins to the east. Yields may be as great as 800 gpm, but because of thinning and erosion of the formation, typical yields are about 200 gpm.

In the northwest, the most prolific alluvial and terrace deposits lie along the North Canadian, Canadian and Cimarron Rivers where deposits are thick and yield as much as 700 gpm. Average yields for the alluvium and terrace are between 100 and 300 gpm. In the southwest, the deposits provide water in areas adjacent to the Washita, North Fork of the Red and Red Rivers in Roger Mills, Custer, Beckham, Greer, Kiowa, Jackson, Tillman and Cotton Counties. Total thickness of the alluvial and terrace deposits averages 70 feet, but saturated thickness is zero to 50 feet. Wells generally yield from 200 to 300 gpm, but locally may yield more than 500 gpm.

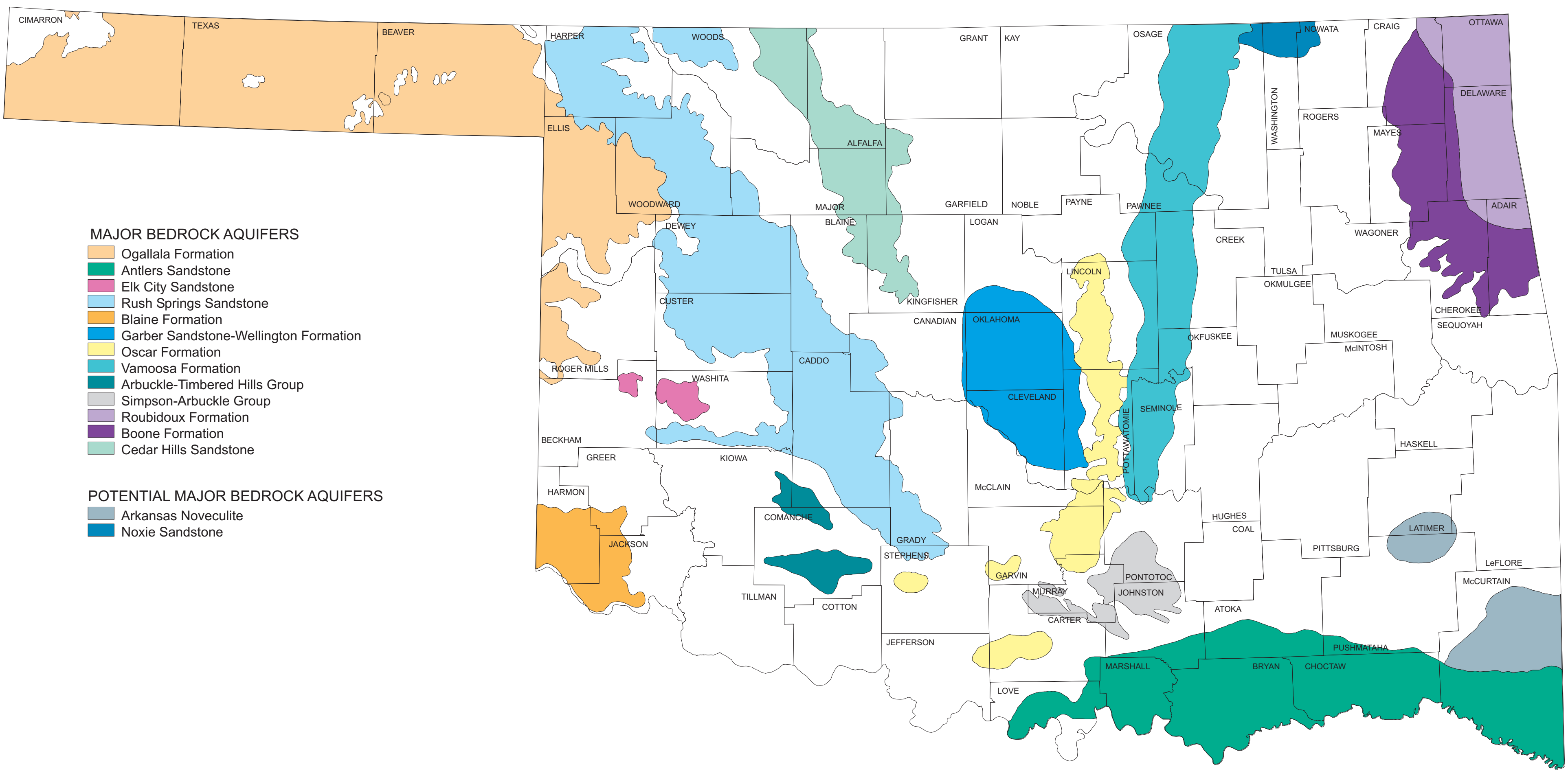
Central Groundwater Basins

Major groundwater basins in central Oklahoma are the Arbuckle-Simpson Group, Ada-Vamoosa Formation, Oscar Formation, Garber-Wellington Formation and alluvial and terrace deposits.

Development of the groundwater resources has increased rapidly due to growth in the cities, towns and rural areas that rely upon wells for domestic, municipal and industrial water. Growth in the suburbs and rural areas surrounding Oklahoma City has put heavy demands on the Garber-Wellington. The alluvial and terrace deposits of the North Canadian River are sources of water supply for many growing cities and for some central Oklahoma industries and irrigators. The Ada-Vamoosa Formation extends in a band from north to south in east central Oklahoma. It remains relatively undeveloped and most of the withdrawals are for municipal and industrial use. Oilfield brines and wastes have caused some local quality problems and overpumping could cause intrusion of saline water. The Arbuckle-Simpson Aquifer is largely undeveloped, although the basin is estimated to contain approximately nine million acre-feet of water in storage. Development in the Oscar Formation is sparse and the basin is of small areal extent.

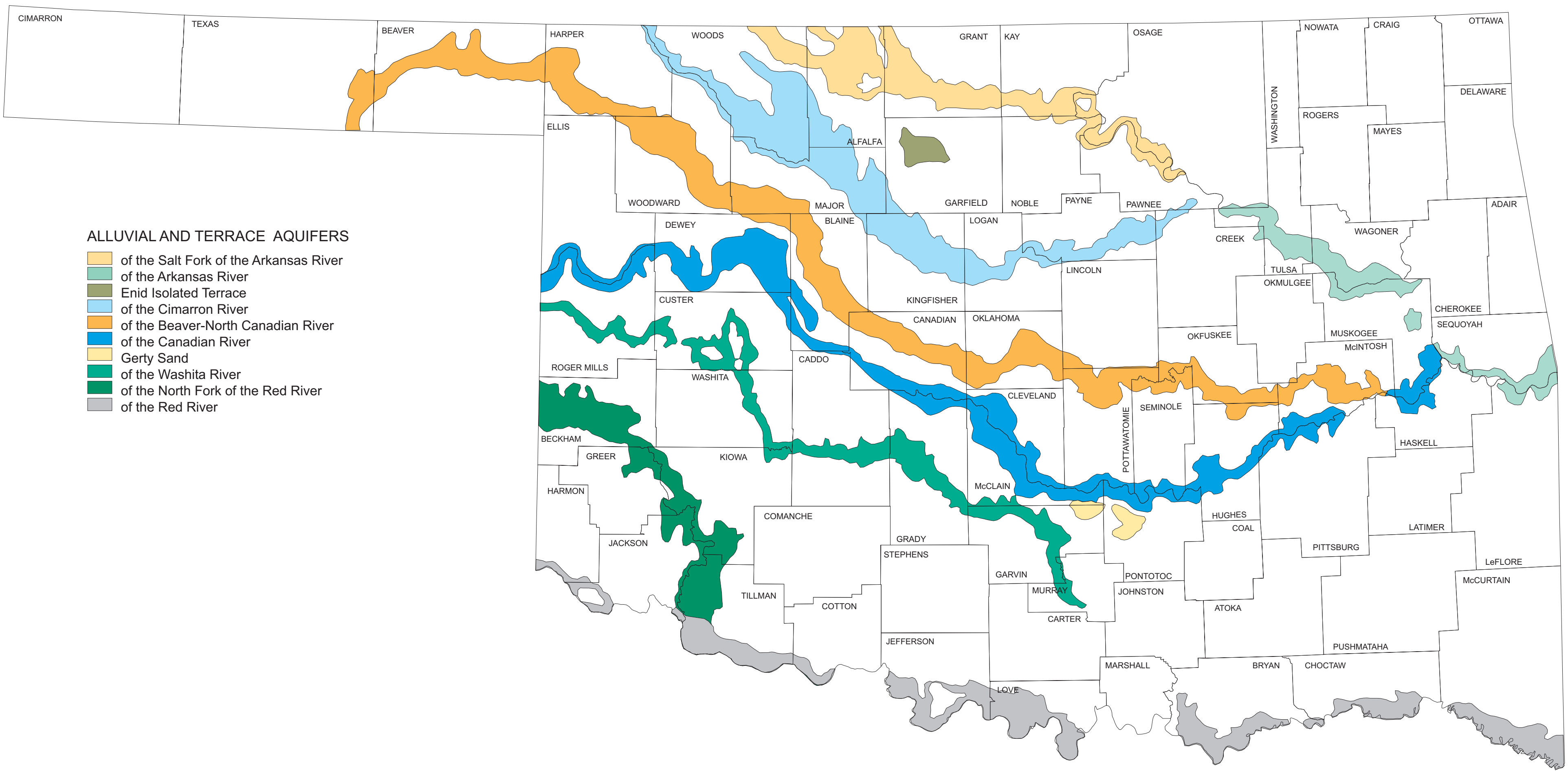
The Arbuckle-Simpson Group, consisting of the Arbuckle and Simpson Formations, is used primarily for drinking water but is largely undeveloped. The Arbuckle Formation (Cambrian-Ordovician) is limestone and dolomite, 5,000 to 6,000 feet thick. Relatively high permeability results from fractures, joints and solution channels in the limestone. In eastern Murray County, the formation is known to produce large quantities of water. Yields of 200 to 500 gpm are common and deeper tests have produced quantities in excess of 2,500 gpm. Well development is currently sparse.

The Simpson Formation (Ordovician) consists of fine-grained, loosely cemented and friable sandstones. The ground-



OKLAHOMA COMPREHENSIVE WATER PLAN

Figure 5
MAJOR GROUNDWATER BASINS
BEDROCK



OKLAHOMA COMPREHENSIVE WATER PLAN

Figure 6
MAJOR GROUNDWATER BASINS
ALLUVIAL AND TERRACE

water basin outcrops in an area of about 40 square miles in southwestern Murray and northeastern Carter Counties. Wells usually yield 100 to 200 gpm.

The Ada-Vamoosa Formation (Upper Pennsylvanian) is composed of 125 to 1,000 feet of interbedded sandstone, shale and conglomerate, with the proportion of shale increasing northward. The Ada-Vamoosa outcrops in Seminole, Okfuskee, Pottawatomie, Osage, Creek, Pawnee, Payne and Lincoln Counties. The formation supplies water for drinking and other municipal purposes as well as oil and gas operations. The most prolific wells are in the Seminole area where they produce up to 500 gpm. Yields change northward, decreasing from 250 gpm to around 10 gpm.

The Oscar Formation (Pennsylvanian) consists of interbedded shale, sandstone and limestone conglomerate with lithology varying from place to place. The formation is 300 to 400 feet thick and occurs in western Stephens, southwestern Garvin, southwestern Carter, western Lincoln and eastern Jefferson Counties. Depth to water is generally 100 feet below the surface. Well yields range from 60 to as much as 400 gpm but average 150 to 180 gpm. The groundwater basin is of major importance locally, but its long-term potential is unknown due to a lack of information and sparse well development.

The Garber-Wellington Formation (Permian), consisting of the Garber Sandstone and Wellington Formations, is primarily used for public supply and self-supplied domestic use. The two geologic units are considered a single water-bearing aquifer and were deposited under similar conditions, both containing alternating beds of sandstone and shale. The total thickness of the combined formations is 80 to 900 feet. Depth to water varies from 100 to 350 feet or less in areas of outcrop and ranges to 350 feet in structural depressions (such as Midwest City). Well yields range from 50 to more than 500 gpm and average 200 gpm. In Logan County, the aquifer is shaly and yields are 10 gpm or less near Guthrie.

In the north, alluvial and terrace deposits occur along the Salt Fork of the Arkansas River across Grant and Kay Counties, with a minor extension into Pawnee County and along the Cimarron River through Kingfisher County into Logan County. The alluvial and terrace deposits along the Salt Fork of the Arkansas reach a maximum thickness of about 150 feet, while similar deposits along the Cimarron attain a thickness of up to 120 feet. Maximum saturated thicknesses of the Salt Fork and Cimarron are 35 and 50 feet, respectively. Well yields from the alluvium of the Salt Fork average between 100 and 200 gpm, and yields from the terrace are about 100 to 500 gpm. Well yields along the Cimarron range from 1,000 gpm to less than 50 gpm and average between 100 and 500 gpm.

In the Oklahoma City area, the alluvial and terrace deposits occur along the Canadian and North Canadian Rivers and Deep Fork of the North Canadian. Well yields range from less than 100 gpm to as much as 600 gpm, averaging 200 gpm. In the south, alluvial and terrace deposits provide generous quantities of water in areas adjacent to the Washita and Red Rivers. Wells yield a maximum of 400 gpm near Lindsay, 1,000 gpm near Pauls Valley, and 200 gpm near Wynnewood and Davis in areas of maximum saturated thickness and coarsest gravel. However, most wells yield smaller supplies of 20 to 100 gpm due to fine-grain sediments in the alluvial fill.

Eastern Groundwater Basins

Eastern Oklahoma's major groundwater basins are the Roubidoux Formation, Boone Formation, Antlers Sandstone and alluvial and terrace deposits. These major basins offer abundant water to municipalities and industries in the region. Overdevelopment is a problem in the Roubidoux Formation near the City of Miami where clustered wells have resulted in interference between wells and reduction in artesian head. Water that previously flowed at the surface now must be lifted 500 feet or more.

In the northeast, development in the alluvium occurs primarily along the Arkansas River where wells generally yield more than 100 gpm. There is also development potential in the springs of the Boone Formation which consists of fractured chert and cherty limestone. Where it outcrops, the basin produces bountiful springs that flow at the rate of about 100 million gallons per day.

Southeastern groundwater resources remain largely undeveloped because stream water is available in generous supply. Development occurs predominantly in the Antlers Sandstone and alluvial and terrace deposits. The area of greatest potential development lies along the Red River where wells yielding several hundred gallons per minute (gpm) are commonplace. The most favorable well sites are in formations with the greatest saturated thickness and coarsest material, such as the Antlers Sandstone, which supplies water to parts of Atoka, Bryan, Choctaw, Johnston, McCurtain and Pushmataha Counties. Yields range from a few gpm to more than 500 gpm.

The Roubidoux Formation (Upper Cambrian-Lower Ordovician) consists primarily of sandstone and cherty dolomite. The aquifer includes the Cotter, Jefferson City, Roubidoux, Gasconade and Eminence-Potosi Formations, of which the Roubidoux Formation is the principal water-bearing unit. The Roubidoux does not outcrop on the surface, but is deeply buried beneath Ottawa and Delaware Counties and small parts of Craig and Adair Counties at depths of 800 to 1,200 feet. The artesian or confined water is under sufficient pressure to rise above the surface. Due to years of pumpage, the artesian head has declined and, in some wells, water is lifted more than 500 feet to the surface. Yields can exceed 600 gpm, but the average is approximately 150 gpm.

The Antlers Sandstone (Cretaceous) is part of the larger Coastal Plain deposits that crop out in the southern half of the region. The unit is a fine-grained sand interbedded with clay, unconsolidated and friable. It crops out in a 10-mile-wide belt in parts of Atoka, Bryan, Choctaw, Johnston, McCurtain and Pushmataha Counties. The aquifer ranges in thickness from 180 feet in the west to more than 880 feet in the southeastern part of the region. Water occurs under water table and artesian conditions. Well yields range from five to 50 gpm for water table wells to 50 to 650 gpm in artesian wells. An average yield for wells completed in the groundwater basin is 100 to 150 gpm.

The Boone Formation (early to late Mississippian) consists of limestone and cherty limestone averaging about 300 feet in thickness. Containing numerous fractures and solution channels, the Boone is the source of many springs that play an important part in maintaining the year-round flow of area streams.

Alluvial and terrace deposits along the Arkansas River, which occur in a band from one to six miles wide, are extremely generous in their water supply. Near Tulsa, the alluvium is about 30 feet thick while, downstream at Webbers Falls, the thickness is about 55 feet. Yields generally range from 100 to 500 gpm with the greatest yields issuing from sand layers.

Along the Arkansas and Canadian Rivers, total thickness of the deposits averages 42 feet and the saturated thickness is between 25 and 75 feet. Well yields range from 100 to 500 gpm. Along the Canadian River, the alluvium is 35 feet thick locally, yielding up to 200 gpm in most areas. In the southeast, the deposits have a maximum thickness of 100 feet and average 60 feet. They supply moderate to large quantities of water with maximum yields of 600 gpm, averaging about 200 gpm.

GROUNDWATER QUALITY

The natural quality of groundwater reflects the chemical composition of the rocks with which it comes in contact. As water seeps through soil and rock, it takes varying types and concentrations of minerals into solution, depending upon the geologic constituents of individual formations, solubility of minerals in those formations and duration of contact. Groundwater quality is also determined, to a great extent, by human activities which contribute nitrates, chlorides and varying concentrations of numerous other substances to underground supplies.

Due to the potential for harm to human health, state and federal agencies keep a close eye on groundwater quality. Stringent federal standards have been developed for groundwater that is used for drinking while Oklahoma has promulgated separate guidelines to protect underground supplies used by industry, agriculture and other users. In 1982, as a preliminary step toward development of comprehensive groundwater standards for Oklahoma, the OWRB initiated an extensive groundwater quality/well sampling program in cooperation with the U.S. Geological Survey. Although the statewide program was discontinued several years ago, the USGS, OWRB and various other agencies and municipalities continue localized and program- specific groundwater quality monitoring efforts throughout Oklahoma.

The 1982 Oklahoma Water Quality Standards were the first to designate standards and beneficial uses for the state's major groundwater basins while the 1985 document was the first to include specific organic parameters for groundwater. Unlike stream water quality standards, EPA does not approve or disapprove state groundwater quality standards. The standards apply to all fresh groundwater (defined under state law as groundwater with a maximum total dissolved solids concentration of less than 5,000 parts per million) in the state. In general, they require that groundwater be maintained to prevent alteration of its chemical properties by harmful substances not naturally found in groundwater. This is accomplished by utilizing narrative criteria, 36 numeric standards for organic compounds, and a three-tired classification system based on the resource characteristics of each individual groundwater basin. The state continues efforts to develop comprehensive quality standards for Oklahoma groundwaters.

Except for the Dog Creek-Blaine and Arbuckle-Timbered Hills aquifers, where large sulfate and fluoride concentrations, respectively, preclude their general use for public water supply, the majority of the state's principal groundwater formations provide water supplies that generally meet federal and state standards for drinking water. However, not all areas or depths within these aquifers produce water suitable for public supply. In addition, water is hard to very hard in all principal aquifers but the Arbuckle-Timbered Hills and all contain water of acceptable quality for irrigation of at least some crops. Water from Oklahoma's alluvial and terrace aquifers, though typically very hard, is withdrawn primarily for irrigation and domestic supply. However, high nitrate, chloride and sulfate concentrations found in some areas and at various depths decrease the suitability of that water for public supply.

Primarily utilizing representative data provided by the USGS from water samples collected from 1946 to 1986, the following section presents a generalized overview of water quality in the state's major groundwater basins and alluvial and terrace formations.

Western Groundwater Basins

Where permeability is high, water in the Arbuckle-Timbered Hills Group may be suitable for industrial use. The water is soft and of a sodium-potassium mixed type. Throughout much of the formation, chloride concentrations are high and fluoride concentrations are very high. This generally precludes use of the aquifer for public supply.

Water quality in the Blaine Formation is poor due to its hardness and very high calcium sulfate concentrations, primarily resulting from the solution of gypsum and dolomite in the aquifer. Locally, in southeastern and northwestern Harmon County, the water has a high sodium chloride content. Water in the Blaine is used exclusively for irrigation and is unsuitable for public supply.

Most of the water derived from the Rush Springs Sandstone is suitable for domestic, municipal, irrigation and industrial use, although chloride and sulfate concentrations exceed drinking water standards in some areas. However, in most areas, concentrations of dissolved solids are within the recommended level for public supply.

Although limited data is available on water quality in the Cedar Hills Sandstone, it is generally considered suitable for most purposes, as is water from the Elk City Sandstone.

Water yielded from the Panhandle portion of the Ogallala Formation is of a calcium-magnesium chloride-sulfate type. Although hard, the water is suitable for use as public supply. However, excessive concentrations of chloride, sulfate and fluoride make the water unsuitable in some areas.

Water quality in alluvial and terrace deposits in northwest Oklahoma is affected by adjacent streams and the water is generally poor where the deposits directly overlie the Ogallala and are not in contact with Permian red beds in the region. In the southwest, water quality is good and, except for hardness and localized nitrate problems, the water is appropriate for domestic, irrigation, industrial and municipal use.

Central Groundwater Basins

Water in the Arbuckle-Simpson Group is generally very hard and of a calcium magnesium bicarbonate type. In the Simpson Formation at Sulphur, water from the sandstones is of poor quality. Overall, total dissolved solids are relatively low and the quality is good, however, large concentrations of chloride and fluoride in certain areas may make the water unsuitable for public supply.

Although water quality is generally good in the Ada-Vamoosa Formation, iron infiltration and hardness are problems in some areas. The water is of a sodium bicarbonate or sodium calcium bicarbonate type. Chloride and sulfate concentrations are generally low and, except for areas of local contamination resulting from past oil and gas activities, water is suitable for use as public supply. Similarly, water from the Oscar Formation is considered suitable for municipal use and most other purposes.

Water from the Garber-Wellington Formation is of a calcium magnesium bicarbonate type and ranges from hard to very hard. In general, concentrations of dissolved solids, chloride and sulfate are low. Water from the aquifer is normally suitable for public water supply, but concentrations of sulfate, chloride, fluoride or other mineral constituents in some areas may exceed drinking water standards.

The quality of water varies in alluvial and terrace deposits in the central region. Water from the Cimarron and Salt Fork of the Arkansas River terrace deposits is generally suitable for most purposes, except in some areas where saltwater encroachment has precluded its use for domestic purposes. The water is generally hard and of a calcium magnesium bicarbonate type. In most areas, dissolved solids concentrations in the Cimarron and Salt Fork formations are below drinking water standards. Water from the alluvium deposits is generally poor due to high sulfate and chloride concentrations.

Hardness, nitrates and total dissolved solids are the principal water quality problems in alluvial and terrace deposits of the Canadian, North Canadian and Deep Fork of the North Canadian Rivers where water is of a calcium magnesium bicarbonate type. In the south, overall quality is good although water is better in the terrace than alluvium because the terrace deposits generally receive less water from the adjacent bedrock basin and are not affected by influent seepage of sometimes mineralized river water. Overall, dissolved solids concentrations are high in the Red and Washita River alluvial and terrace formations.

Eastern Groundwater Basins

Although water in the Roubidoux Formation is hard, it has a generally low total mineral content. In Ottawa County, the water is a calcium bicarbonate type of good quality and is widely used for public supply. However, in some areas, especially farther west, concentrations of chloride, sulfate and fluoride exceed drinking water standards. Except for moderate hardness, water from the adjacent Boone Formation is of good quality but, due to its lithology, the aquifer is susceptible to contamination from surface sources.

The quality of water is good in the outcrop areas of the Antlers Sandstone and is suitable for industrial, municipal and irrigation use. Downdip from the outcrop, the quality of the water deteriorates somewhat.

Alluvial and terrace deposits in the east yield water which is generally hard. Water in the Arkansas River alluvium, typically of a sodium or calcium bicarbonate type, exceeds drinking water standards in some areas. Water in the Canadian River alluvium is predominantly of a calcium magnesium bicarbonate type and variable in dissolved solids content. It is generally suitable for most purposes.