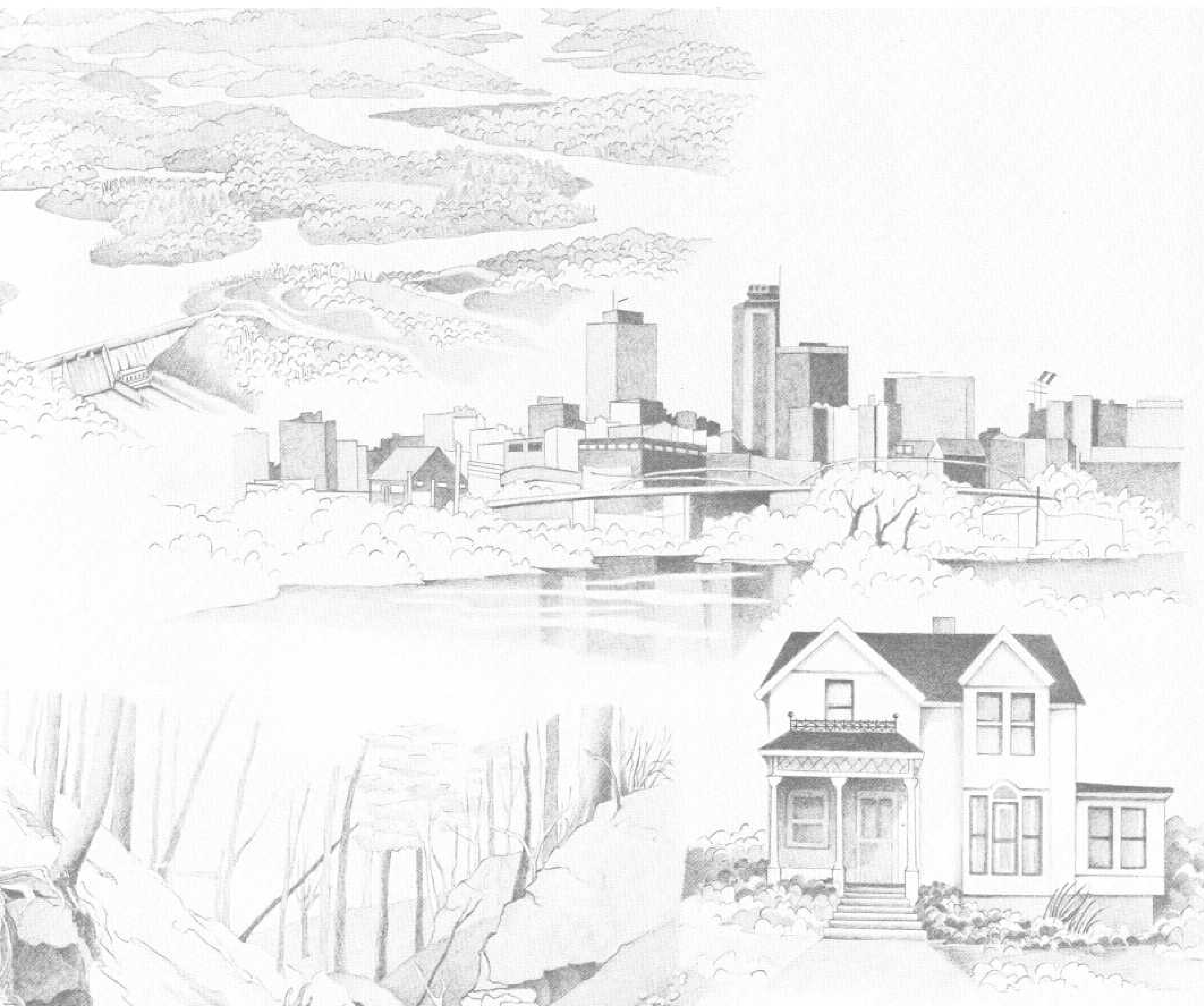
WATER-RESOURCES INVESTIGATIONS REPORT 84-4074

DROUGHT-RELATED IMPACTS ON MUNICIPAL AND MAJOR SELF- SUPPLIED INDUSTRIAL WATER WITHDRAWALS IN TENNESSEE--PART B



USGS
science for a changing world

Prepared by
U. S. GEOLOGICAL SURVEY

in cooperation with
TENNESSEE DEPARTMENT OF HEALTH AND ENVIRONMENT, Division of Water Management
TENNESSEE VALLEY AUTHORITY, Office of Natural Resources and Economic Development, Division of Air and Water Resources, Regional

UPPER CUMBERLAND RIVER BASIN

Basin Description

The Tennessee part of the Upper Cumberland River basin covers 5,505 mi^2 of land and water area and consists of all or parts of the following tributary basins as delineated by the U.S. Geological Survey and the Tennessee Department of Water Management in 1982.

Tributary basin No. (fig. 8)	Basin description	Tennessee drainage area (square miles)
1	Clear Fork and Jellico Creek from headwaters to Tennessee-Kentucky State line.	318
2A	New River and Clear Fork from headwaters to confluence.	679
2B	South Fork Cumberland River from confluence New River and Clear Fork to Tennessee-Kentucky State line.	299
3A	East and West Forks Obey River from headwaters to mouth.	413
3B	Obey River from confluence of East and West Forks to Tennessee-Kentucky State line.	369
4A	Cumberland River and minor tributaries from below the Obey River to above Caney Fork.	795
4B	Cumberland River and minor tributaries between the Tennessee-Kentucky State line and the Obey River.	33
5A	Caney Fork above Great Falls Dam, excluding Collins River.	885
5B	Collins River	791
5C	Caney Fork from Great Falls Dam to mouth	909
47	Yellow Creek above Tennessee-Kentucky State line.	14

The Upper Cumberland River basin includes all or major parts of Cannon, Clay, DeKalb, Fentress, Grundy, Jackson, Overton, Pickett, Putnam, Van Buren, Warren, and White Counties and minor parts of Anderson, Bledsoe, Campbell, Claiborne, Coffee, Cumberland, Macon, Morgan, Sequatchie, Smith, and Wilson Counties. A map of the northeast part of the Cumberland River basin which delineates the area drained by the Upper Cumberland River basin in Tennessee is shown in figure 8.

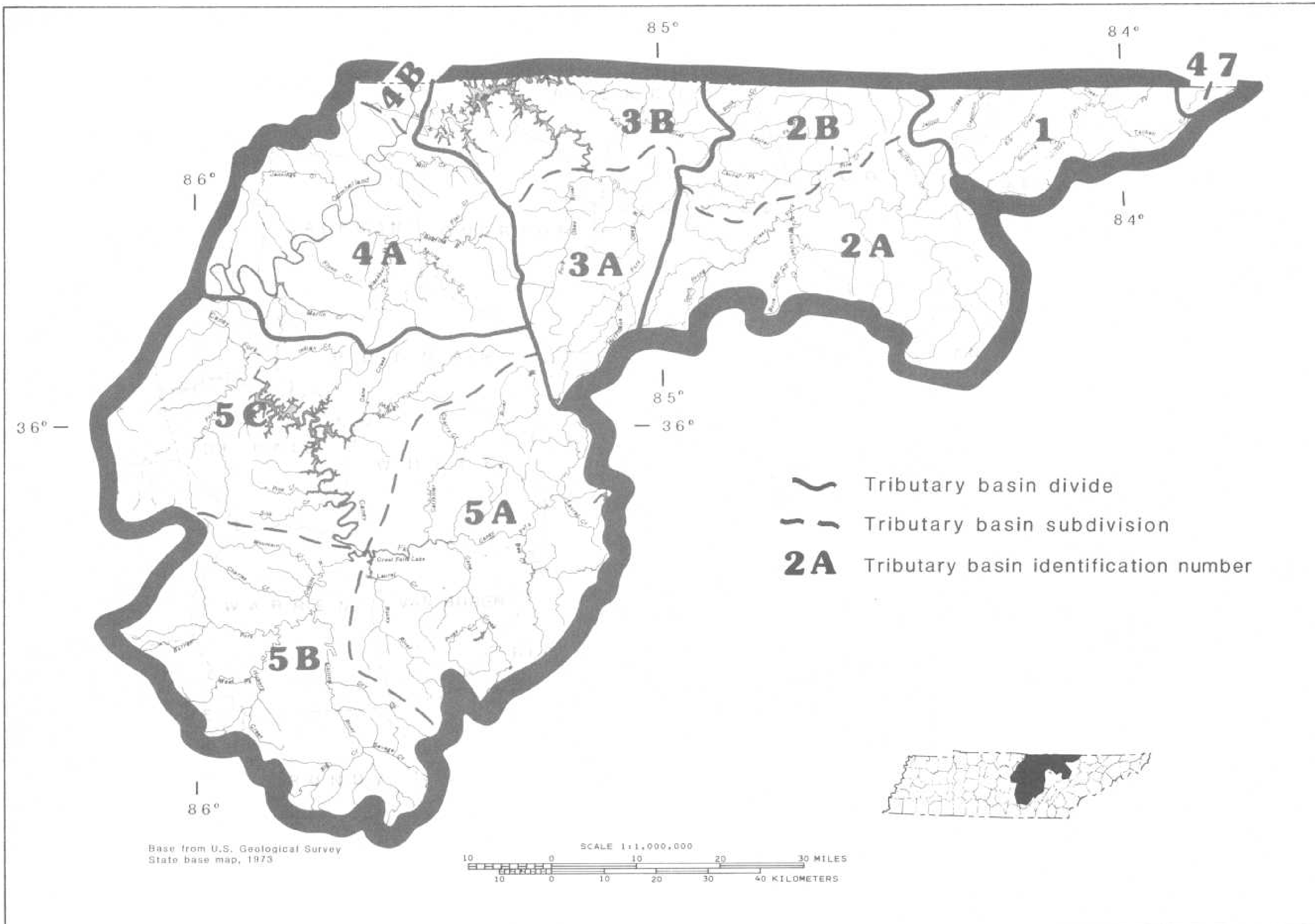


Figure 8.--Upper Cumberland River basin.

The Cumberland River originates in Harlan County, Ky., at the confluence of the Clover Fork and Poor Fork at a point 694.2 miles above its mouth. The Upper Cumberland River basin in Tennessee includes 14 mi^2 of the Yellow Creek basin and that part of the Cumberland River from the Tennessee-Kentucky State line at river mile 385.5 to the mouth of and including the Caney Fork River at river mile 309.2.

Topography

From the Tennessee-Kentucky State line, the Cumberland River flows in a southwesterly direction through an area of steep hills which are about 70 percent forested. Elevations of the drainage basin range from about 450 feet at the mouth of the Caney Fork to about 3,500 feet above sea level atop Cross Mountain on the Anderson-Campbell County line. Water-surface elevations from the Caney Fork to the Tennessee-Kentucky State line are controlled by two reservoirs, Old Hickory and Cordell Hull. The normal pool elevation of Old Hickory Reservoir is 445 feet above sea level, which would affect that part of the river from mile 309.2 to mile 313.5. Cordell Hull Reservoir has normal summer season and winter season pool elevations of 504.0 feet and 501.0 feet above sea level, respectively. These elevations affect that part of the river between river miles 313.5 and 385.5. Major tributaries to the Cumberland River include the Caney Fork, Obey River, and Roaring River.

Major streams and tributaries draining this basin include:

Obey River. East Fork Obey River, West Fork Obey River, and Wolf River.

Caney Fork. Bee Creek, Calfkiller River, Cane Creek, Collins River, Falling Water River, Indian Creek, Laurel Creek, Pine Creek, Rocky River, Sink Creek, and Smith Fork.

Roaring River. Blackburn Fork, Flat Creek, and Spring Creek.

Cumberland River Minor Tributaries. Defeated, Flynn, Jennings, Martin, and Mill Creeks.

Hydrology

Surface Water

Surface- and ground-water resources in this part of the basin are fed by ample rainfall whose long-term (1941-70) average equals 53.13 inches. From 1970-79, the average precipitation equaled 57.73 inches ranging from a low of 46.16 inches in 1978 to a high of 69.84 inches in 1973. A summary of average precipitation data (Corps of Engineers, unpublished data) for the basin's watershed subdivisions during the period from 1970 to 1979 is presented in table 9. Precipitation data for 1979 and for the period 1941-70 for selected NWS rainfall stations (Department of Commerce 1977 and 1979, Water Information Center, 1974) in the Upper Cumberland River basin are presented in table 10.

Table 9.--Precipitation data by watershed subdivision for the period 1970-79[a], Upper Cumberland River basin

Watershed description	Precipitation (inches)				
	High	Year	Low	Year	10-year average
Cumberland River upstream from Wolf Creek Dam.	64.16	1972	46.36	1976	54.82
Cumberland River from Wolf Creek Dam to Celina.	67.01	1979	48.24	1971	57.36
Cumberland River upstream from Dale Hollow Dam.	67.86	1979	47.44	1970	58.57
Cumberland River from Celina to Cordell Hull Dam.	70.76	1979	47.53	1976	58.65
Cumberland River from Cordell Hull Dam to Carthage.	73.91	1979	46.95	1976	59.55
Caney Fork River above Center Hill Dam.	69.84	1973	46.16	1978	57.44

[a] Precipitation data were obtained from the U.S. Army Corps of Engineers.

Table 10.--Precipitation data for 1979 and for the period 1941-70 for selected rainfall stations, Upper Cumberland River basin

Station location	Station owner	Elevation above sea level (feet)	Period of record (years)	1979 Precipitation (inches)	Long-term annual precipitation (inches)
Sparta	NWS	950	39	[a] 66.43	53.56
McMinnville	NWS	940	99	59.39	52.96
Celina	NWS	550	31	71.02	50.91
Allardt	NWS	1,672	31	64.07	55.10

a Estimated.

In the Upper Cumberland River basin, the months of August, September, and October generally have the least rainfall during the year. The average rainfall over the basin ranges from 2.57 inches in October to 3.77 inches in September. During the remainder of the year, the average rainfall over the basin ranges from 3.97 to 5.57 inches with March having the greatest rainfall. Analysis of long-term precipitation records for the period 1941 to 1970 for selected rainfall stations at Celina, Crossville, and McMinnville indicate the driest months of the year generally are August, September, and October with precipitation ranging from 2.49 to 4.09 inches. During the rest of the year, monthly precipitation ranged from 3.65 to 6.08 inches with January, February, and March being the wettest months.

Average annual runoff in this basin generally ranges from 19 to 39 inches. Most of this runoff occurs during the winter and spring months. Average discharge data for selected hydrologic data stations in the Upper Cumberland River basin is shown in table 11.

Major Reservoirs

Major reservoirs located in the basin and their total storage in acre-feet at normal minimum pool are Dale Hollow (857,000), Cordell Hull (204,800), Great Falls (2,980), and Center Hill (837,400). Detailed information describing the reservoirs' location and operation pattern follows:

Center Hill Reservoir

Location and drainage area.--Center Hill Reservoir is formed by Center Hill Dam which is located on the Caney Fork at river mile 26.6 in DeKalb County. Center Hill Dam controls 2,174 mi^2 of drainage area.

Reference period.--1951-82.

Reservior discharge (minimum daily average flow).--During the reference period, minimum daily average discharge at Center Hill Dam was zero in each year.

Average number of days of zero flow.--From 1951-82, Center Hill Dam has averaged about 46 days of zero discharge per year ranging from a low of 19 days in 1975 and 1979 to a high of 144 days in 1952. Zero discharge days were most common during the months of July, August, September, and October. During the reference period there were 80 instances of zero discharge for 3 or more consecutive days from Center Hill Dam. In six of these instances, consecutive days of zero discharge from Center Hill Dam ranged from a low of 7 days in 1956 and 1966 to a high of 16 days in 1952.

Existing agreements regarding reservoir releases.--Although no formal agreement exists, the Corps of Engineers releases discharge from at least one turbine unit for a minimum of 1 hour within any 48 hour period to maintain fish life below the dam between June 1 and November 30.

Table 11.--Average discharge data for selected hydrologic data stations operated by the U.S. Geological Survey, Upper Cumberland River basin

Station name and location (county)	River mile	Drainage area (square miles)	Period of record (years)	Average discharge: Cubic feet per second	Average discharge: Inches per year	Average discharge: Cubic feet per second per square mile
Bills Branch near Hembree (Scott).	0.7	0.67	5	1.91	38.71	2.85
New River at New River (Scott).	8.6	382	46	745	26.48	1.95
Clear Fork near Robbins (Scott).	3.7	272	46	473	23.62	1.74
East Fork Obey River near Jamestown (Fentress).	12.7	202	38	424	28.51	2.10
West Fork Obey River near Alpine (Overton).	8.0	115	30	160	18.89	1.39
Wolf River near Byrdstown (Pickett).	26.2	106	38	192	24.60	1.81
Cumberland River at Celina (Clay).	380.8	7,307	58	11,800	21.93	1.61
Roaring River upstream from Gainesboro (Jackson).	9.1	210	6	315	20.37	1.50
Collins River near McMinnville (Warren).	19.5	640	56	1,178	25.00	1.84
Caney Fork near Rock Island (White).	90.3	1,678	66	3,218	26.04	1.92

Cordell Hull Reservoir

Location and drainage area.--Cordell Hull Reservoir is formed by Cordell Hull Dam which is located on the Cumberland River at river mile 313.5 in Smith County. Cordell Hull Dam controls 8,095 mi^2 of drainage area.

Reference period.--1974-82.

Reservoir discharge (minimum daily average flow).--During the reference period, minimum daily average discharge from Cordell Hull Dam ranged from no flow in 1980 to a high of about 3,080 ft^3/s in 1982. The average 1-day minimum discharge for the reference period was about 1,130 ft^3/s.

Average number of days of zero flow.--From 1974-82 only 1 day of zero discharge has occurred at Cordell Hull Dam. This was on November 2, 1980.

Existing agreements regarding reservoir releases.--None.

Dale Hollow Reservoir

Location and drainage area.--Dale Hollow Reservoir is formed by Dale Hollow Dam which is located on the Obey River at river mile 7.3 in Clay County. Dale Hollow Dam controls 936 mi^2 of drainage area.

Reference Period.--1946-82.

Reservoir discharge (minimum daily average flow).--During the reference period, minimum daily average discharge was zero discharge for 21 years (1946-66). From 1967-82, the minimum daily average discharge ranged from a low of 6 ft^3/s in 1968 to a high of 18 ft^3/s in 1973-75.

Average number of days of zero flow.--From 1946-66, Dale Hollow Dam has averaged about 100 days of zero flow per year ranging from a low of 36 days in 1949 to a high of 275 days in 1948. From 1967-82, there were 298 days of no discharge through the turbines; however, water was released through the gates to supply a fish hatchery below the dam. These no-discharge days ranged from a low of 1 day in 1972 and 1981 to a high of 63 days in 1978.

Existing agreements regarding reservoir releases.--Although no formal agreement exists regarding reservoir releases, the Corps of Engineers maintains a minimum of one turbine unit of discharge for at least 1 hour within any 48 hour period to maintain fish life below the dam between June 1 and November 30.

Ground Water

The Upper Cumberland River basin lies within three physiographic provinces each with characteristic rocks and ground-water resources.

The eastern third of the basin is within the Cumberland Plateau physiographic province where ground water occurs in weathered fractures and bedding-plane openings in the sandstones that are interbedded with siltstone, shale and coal. The sandy regolith (soil and weathered rock) is thin and stores very little water for recharging the water-bearing openings in the rock below. Supplies of 5 to 10 gal/min for domestic use are obtained from small springs and from dug wells in the regolith and shallow drilled wells (less than 150 feet deep) in the rock. The shallow water-bearing openings do not have great lateral extent and, consequently, a significant number of holes are dry or fail to obtain an adequate supply at times. Supplies of greater than 100 gal/min are available but difficult to locate. Wells with large yields seem to be associated either with unusual fracturing or faulting of the rock or with valley locations where the rocks have been arched upward by the removal of overlying rock and by stress of the weight of the rocks in the adjacent valley walls. This phenomenon is known as stress relief (Wyrick and Borchers, 1981, p. 12). Oil exploration wells in the northeastern corner of the Upper Cumberland River basin in Tennessee frequently obtain 50 gal/min of water from sandstones where the sandstone-shale section is at least 600 feet thick, and occasionally obtain 500 gal/min. The availability of these large supplies rarely can be determined without a detailed geologic and hydrologic investigation and test drilling at any site in question.

The average rate of ground-water recharge in the Tennessee Region is about 0.5 (Mgal/d)/mi^2 of drainage area (Zurawski, 1978, p. L5). Part of the Cumberland Plateau is in the Tennessee Region; and based on hydrograph separations for six stations in the Region, the recharge rate for the Cumberland Plateau would range from 0.43 to 0.66 (Mgal/d)/mi^2.

Ground water in the Cumberland Plateau is soft to moderately hard with relatively low dissolved solids concentrations compared to ground water in the other physiographic sections. It often requires no more than chlorination to make it suitable for public supply; however, iron and manganese concentrations frequently are high enough to stain laundry and plumbing fixtures. Only a tenth as much iron and manganese occur in the sandstones deeper than 300 feet compared to the shallower sandstones (Wilson, 1965).

The middle third of the Upper Cumberland River basin is within the Highland Rim physiographic section where ground water occurs in the thick regolith as well as in solution openings in the interbedded carbonate and silicified carbonate bedrock. Domestic supplies of 5 to 10 gal/min are obtained almost everywhere from dug wells in the regolith where it is thicker than 50 feet or from drilled wells penetrating water-bearing openings in the upper 50 to 100 feet of the bedrock. Dry holes are rare. Supplies of 100 to 500 gal/min are locally available where the regolith is at least 100 feet thick, and the base of the regolith contains coarse rock rubble weathered from the coarser-grained, silicified carbonate bedrock. The availability of these large supplies cannot be determined without test drilling and aquifer testing locally. However, there are many areas in which large supplies are simply not available. Based on computations of hydrograph separations for Buffalo River near Lobelville, Tenn. (1968 water year), the recharge rate for the Highland Rim ranges from 0.54 to 0.76 (Mgal/d)/mi^2.

The water from the regolith in the Highland Rim may be soft and may be so corrosive as to corrode steel well casing and pumping equipment. Water from the bedrock is moderately hard to hard with local iron and manganese staining problems.

The western third of the Upper Cumberland River basin is within the Central Basin physiographic section where ground water occurs in solution-widened joints and bedding planes in the limestone bedrock. The clay-rich regolith is thin and stores little if any water for recharging openings in the underlying bedrock. Supplies of 5 to 10 gal/min for domestic use are obtained from small springs and from wells drilled to depths of about 100 feet below the top of the bedrock. The water-bearing openings in the rock are often only a fraction of an inch to a couple of inches high, rarely occur at depths greater than 100 feet in this area, and commonly extend laterally only a few hundred feet to a few thousand feet. Consequently, many holes are dry or fail to yield an adequate supply. Supplies of greater than 50 gal/min are available near major streams, but are rarely located without detailed geologic and streamflow data derived from a careful survey of changes in streamflow and geology from one stream reach to another. Based on computations of hydrograph separations for Wartrace Creek at Bell Buckle, Tenn. (1968 water year), the recharge rate for the Central Basin was found to range from 0.47 to 0.73 (Mgal/d)/mi^2.

The ground water in the Central Basin is hard to very hard. Depending upon the degree of interconnection with local streams, the water may remain clear and bacteria-free at all times, or may become turbid and contain measurable bacteria following heavy rainfall. In most cases, the water is suitable for drinking water use without treatment.

Demography

Historical (1970) and recent (1980) population and employment and per capita personal income (1980) data for the county boundary approximation of the basin are summarized in table 12. Counties included are Clay, DeKalb, Fentress, Grundy, Jackson, Overton, Pickett, Putnam, Scott, Van Buren, Warren, and White. Urban and metropolitan centers in the basin and their 1980 populations are Cookeville (20,535), Gainesboro (1,119), Jamestown (2,364), Livingston (3,372), McMinnville (10,683), Oneida (3,717), and Sparta (4,864).

Public and Self-Supplied Commercial and Industrial Water Users

Currently, there are a total of 48 public, community water-supply facilities and one large, self-supplied industrial water user whose use exceeds 0.1 Mgal/d in the Upper Cumberland basin. Detailed inventories containing pertinent information and data relative to each community or self-supplied user's source of water, average daily water use, source capacity, population served, treatment plant and storage capacities, and water-supply quantity-related problems are found in tables 5 and 6 of appendix I, respectively. Total water use or withdrawal for public and large, self-supplied commercial and industrial users in the basin equals about 19.2 Mgal/d. The general location and water-supply source of all public and large, self-supplied commercial and industrial water users inventoried in the Upper Cumberland River basin are shown in figures 9 and 10, respectively.

Public water systems currently serve about 162,000 or about 79 percent of the basin's 1980 population. Total water use or withdrawal for public purposes averages about 18.4 Mgal/d of which 18.3 Mgal/d or 99 percent is withdrawn from surface-water sources and 0.1 Mgal/d or 1 percent from ground-water

Table 12.--County population, employment, and per capita personal income data, Upper Cumberland River basin

[Per capita income based on 1970 income converted to 1980 dollars]

County	Population		Employment		Per capita personal income 1980 dollars	
	1970	1980	1970	1980	1970	1980
Clay	6,624	7,676	1,096	1,809	$3,559	$4,873
DeKalb	11,151	13,589	3,332	3,727	5,201	6,145
Fentress	12,593	14,826	2,987	3,982	3,724	4,215
Grundy	10,631	13,787	1,729	2,199	4,197	4,758
Jackson	8,141	9,398	1,603	1,844	4,042	4,572
Overton	14,866	17,575	3,561	3,645	3,938	4,731
Pickett	3,774	4,358	972	932	3,824	4,080
Putnam	35,487	47,690	12,028	18,309	5,186	6,405
Scott	14,762	19,259	3,476	4,878	3,826	5,191
Van Buren	3,758	4,728	814	907	3,514	3,892
Warren	26,972	32,653	11,277	13,129	6,001	6,783
White	16,329	19,567	4,636	5,682	5,144	5,391
Total	165,088	205,106	47,511	61,043	-	-

Figure 9--Explanation

Site No.	Facility name
1	Jellico WD
2	Celina WS
3	Dowelltown-Liberty UD
4	Smithville WS
5	Jamestown WD
6	Gainesboro WD
7	Livingston WD
8	Byrdstown WD
9	Cookeville WD
10	Monterey WD
11	Oneida Water and Sewer Commission
12	Carthage WD
13	Smith UD
14	Spencer UD
15	Taft Youth Center WD
16	McMinnville WD
17	Bon de Croft UD
18	Sparta WS

sources. Major public water-supply facilities whose average daily use exceeds 1.0 Mgal/d include the following:

Facility name	Average water use (Mgal/d)
Cookeville WD	6.500
Oneida Water and Sewer Commission	1.000
McMinnville WD	2.850
Sparta	2.000

Together, these systems account for about 67 percent of the total water use for public purposes.

Self-supplied commercial and industrial users currently use or withdraw about 0.8 Mgal/d all of which is obtained from surface-water sources. This water is used by Jersey Miniere Zinc Co. which is the only large self-supplied user in the basin.

Summarized below is a list of the specific water-supply problems experienced in the basin during the period surveyed. The number in parentheses following each identified problem indicates the number of communities or self-supplied water users who are now or have experienced this problem in the past. Note, these are not listed in order of frequency of occurrence or overall severity.

- o Periodic water-supply shortage during extended droughts. (7)
- o Occasional water-quality problems. (1)

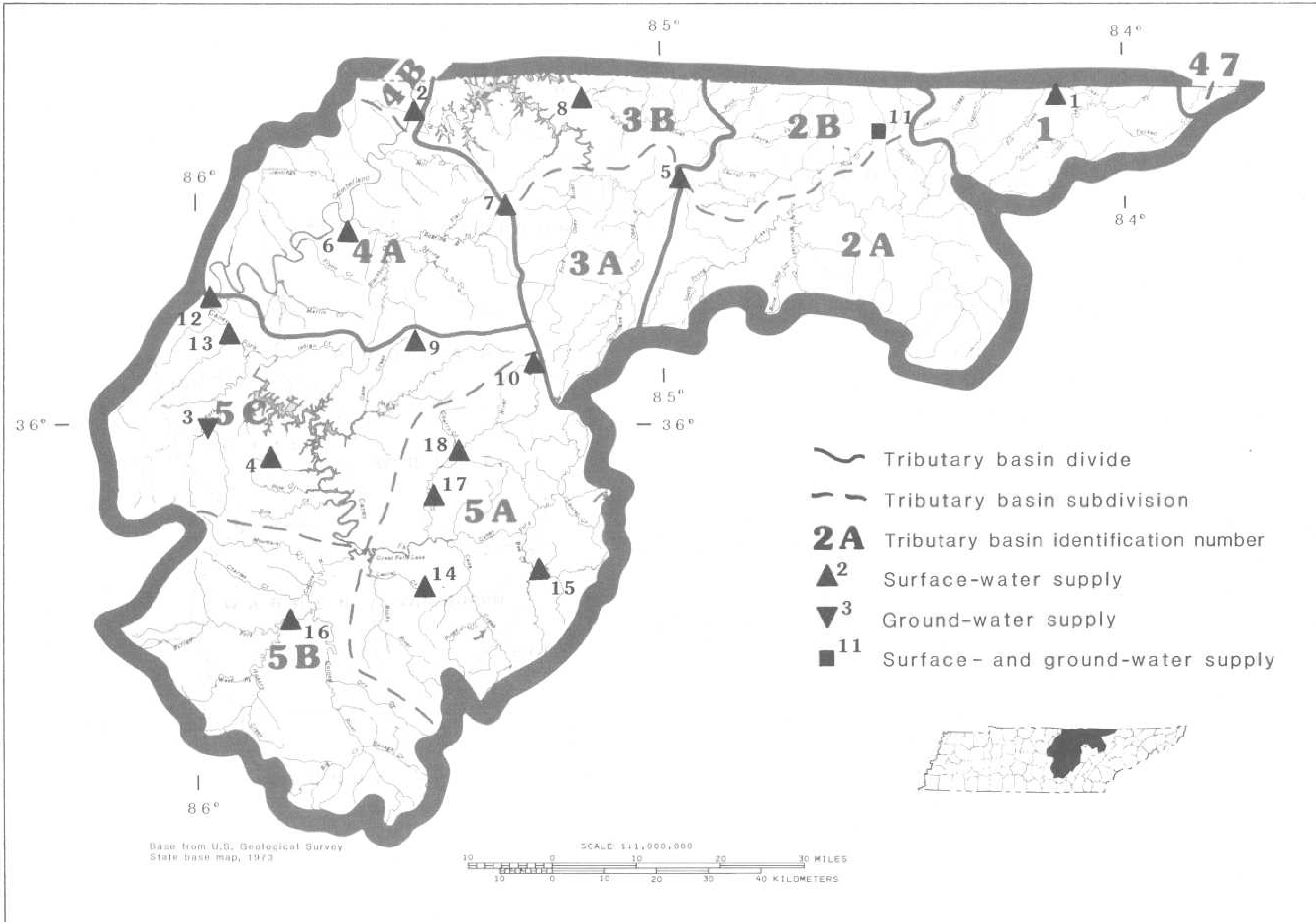


Figure 9.--Public water-supply facilities, Upper Cumberland River basin.

Figure 10--Explanation

Site No.	Facility name
1	Jersey Miniere Zinc Co.

- Occasional flooding problem. (3)
- Occasional turbidity problem following heavy rainfall. (2)
- Problem with algae in summer months. (1)
- Inadequate treatment capacity at times. (1)
- Inadequate storage capacity. (2)
- Occasional loss of pressure due to leaks. (1)
- Occasional odor problem. (1)

Water-Supply Adequacy Analysis

The Upper Cumberland River basin covers 5,505 mi^2 (3,514,000 acres) of land and water area. This basin's surface- and ground-water resources are replenished by substantial rainfall whose long-term (1941-70) average equals 53.13 inches. Average annual runoff generally ranges from 19 to 39 inches with the heaviest runoff occurring in the Caney Fork basin and along the northern boundary of the State in Scott and Fentress Counties. The driest months of the year are generally August, September, and October with January, February, and March being the wettest months.

Total average daily water use or withdrawal for public and large, self-supplied commercial and industrial water users in the Upper Cumberland River basin equals approximately 19.2 Mgal/d. Of that amount, about 18.4 Mgal/d are withdrawn for public water-supply purposes with 18.3 Mgal/d or 99 percent coming from surface-water sources and 0.1 Mgal/d or 1 percent from ground-water sources. Self-supplied water users withdraw approximately 0.8 Mgal/d from surface-water sources. Jersey Miniere Zinc Co. at Elmwood is the only large self-supplied water user in the basin (0.8 Mgal/d). Consumptive water use is about 0.007 Mgal/d.

Most of the basin's public water-supply systems have an adequate source of supply. However, four systems (Jellico WD, Monterey WD, Spencer UD, and Taft Youth Center WD) are located on small streams which have no flow at times during dry summers. The Oneida Water and Sewer Commission, which has an average water use of 1.000 Mgal/d is supplied by a small stream and two wells and has storage facilities for 200 million gallons of untreated water (Howard H. Baker Lake), experiences water shortages during severe droughts. Two systems (Jamestown WD and Livingston WD) obtain water from streams whose minimum flows (3-day, 2 year) are less than their average daily use. However, both systems have sufficient storage facilities for untreated water that they normally do not have shortage problems during severe droughts. Although the McMinnville WD has an adequate water supply, shortages occur during dry, hot summers because of inadequate treatment capacity. The Dowelltown-Liberty UD is presently using ground-water sources of unknown capacity.

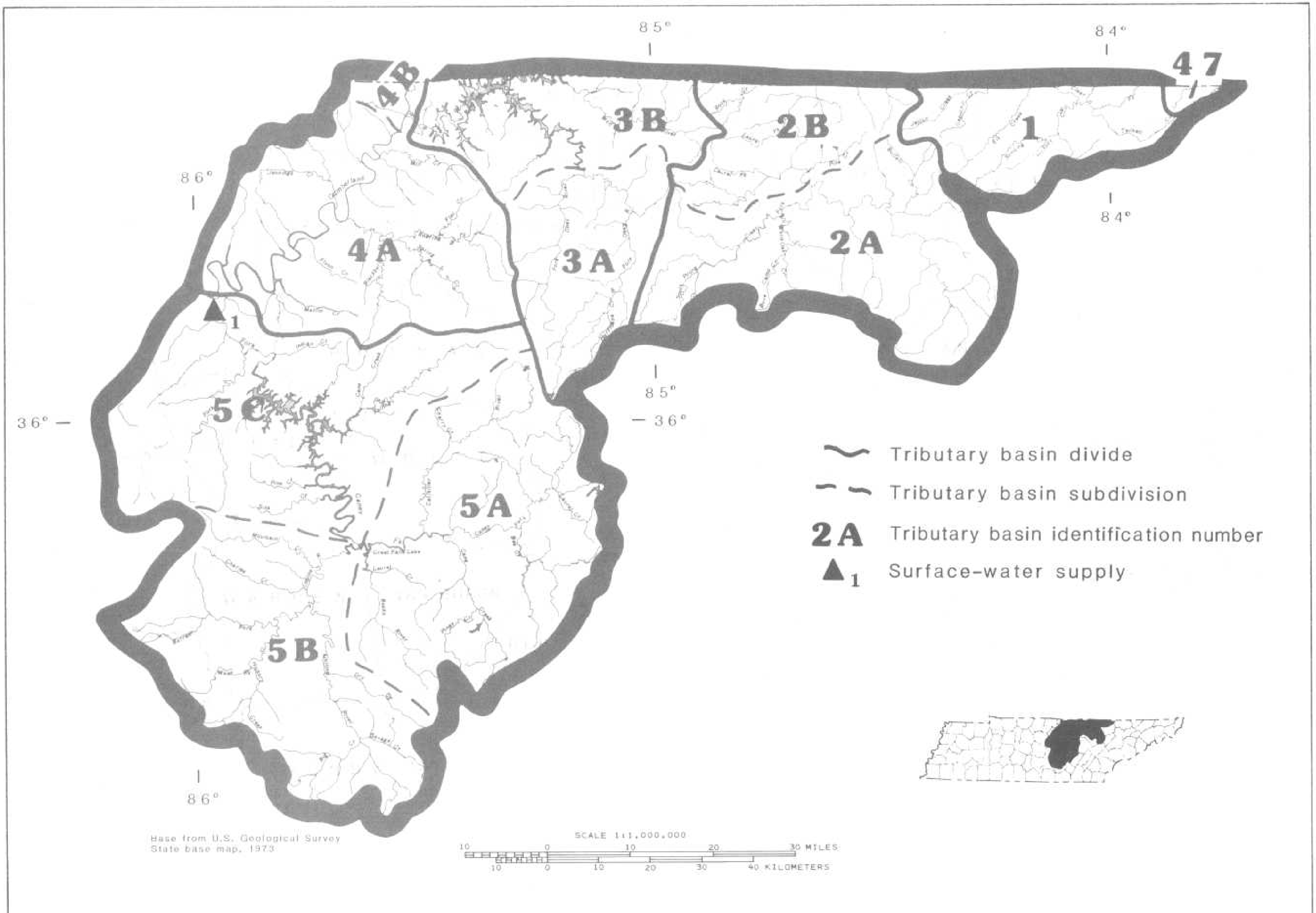


Figure 10.--Self-supplied commercial and industrial water users, Upper Cumberland River basin.

Water systems which are currently utilizing surface- and (or) ground-water resources which are inadequate or of unknown capacity should consider exploring the availability of alternative, cost-effective water-supply sources to augment or meet their future water needs if necessary. While the basin's water resources are subject to contamination from a variety of sources; existing and pending Federal, State, and local statutes relative to water-quality protection and maintenance or improvement should ensure that current water quality will be maintained with little, if any, future degradation of the basin's water resources. Potential sources of contamination include (1) leachate from municipal and industrial water disposal facilities and septic tank systems; (2) agricultural pollution from fertilizers, pesticides and herbicides, and livestock wastes; and (3) runoff from surface mine lands and quarries.

Although there are periods of extended drought which cause seasonal water table declines and periodic local problems with adequate ground-water supplies, observation-well data indicate there are no long-term, regional water table declines. Periodic local problems associated with a decline in an area's water table are caused by excessive withdrawals. To alleviate this problem, optimum ground-water withdrawal rates should be determined during the initial test pumping of the source.

DUCK-BUFFALO RIVER BASIN

Basin Description

The Duck-Buffalo River basin drains 3,500 mi^2 of land and water area and consists of all or parts of the following tributary basins as delineated by the Geological Survey and Tennessee Department of Water Management in 1982.

Tributary basin No. (fig. 11)	Basin description	Tennessee drainage area (square miles)
34A	Duck River headwaters to below Flat Creek 2 miles west of Shelbyville.	481
34B	Duck River from below Flat Creek to Columbia.	727
34C	Duck River from Columbia to Centerville.	840
34D	Duck River from Centerville to its mouth excluding the Buffalo River.	688
35	Buffalo River	764

The Duck-Buffalo River basin encompasses all or major parts of Bedford, Coffee, Hickman, Lewis, Marshall, and Maury Counties and minor parts of Dickson, Humphreys, Lawrence, Perry, Rutherford, Wayne, and Williamson Counties. A map of the west-central Tennessee part of the Tennessee River basin which delineates the area drained by the Duck-Buffalo River basin is shown in figure 11.

Topography

The Duck River originates on the western edge of the Cumberland Plateau in an area which is characterized by unusually level terrain and numerous swamplike areas. From its headwaters, the river flows generally westward through the basin's gently rolling to hilly terrain. While the main river gradients are relatively flat, the river is fed by somewhat steeper, meandering tributaries. The Buffalo River and western part of the Duck River basin are characterized by a dissected, rolling terrain that is crossed by numerous streams. Major streams and tributaries draining this basin include:

- Duck River. Beaverdam, Big Bigby, Big Swan, Blue, East Rock, Flat, Hurricane, Lick, Little Bigby, Rutherford, Sinking, Spring, Sugar, Thompson, Tumbling, and Wartrace Creeks.

- Buffalo River. Little Buffalo and Green Rivers plus Big Oppossum, Brush, Cane, Coon, Fortyweight, Grinders, Hurricane, Rockhouse, Sinking, Saw, Short, and Trace Creeks.

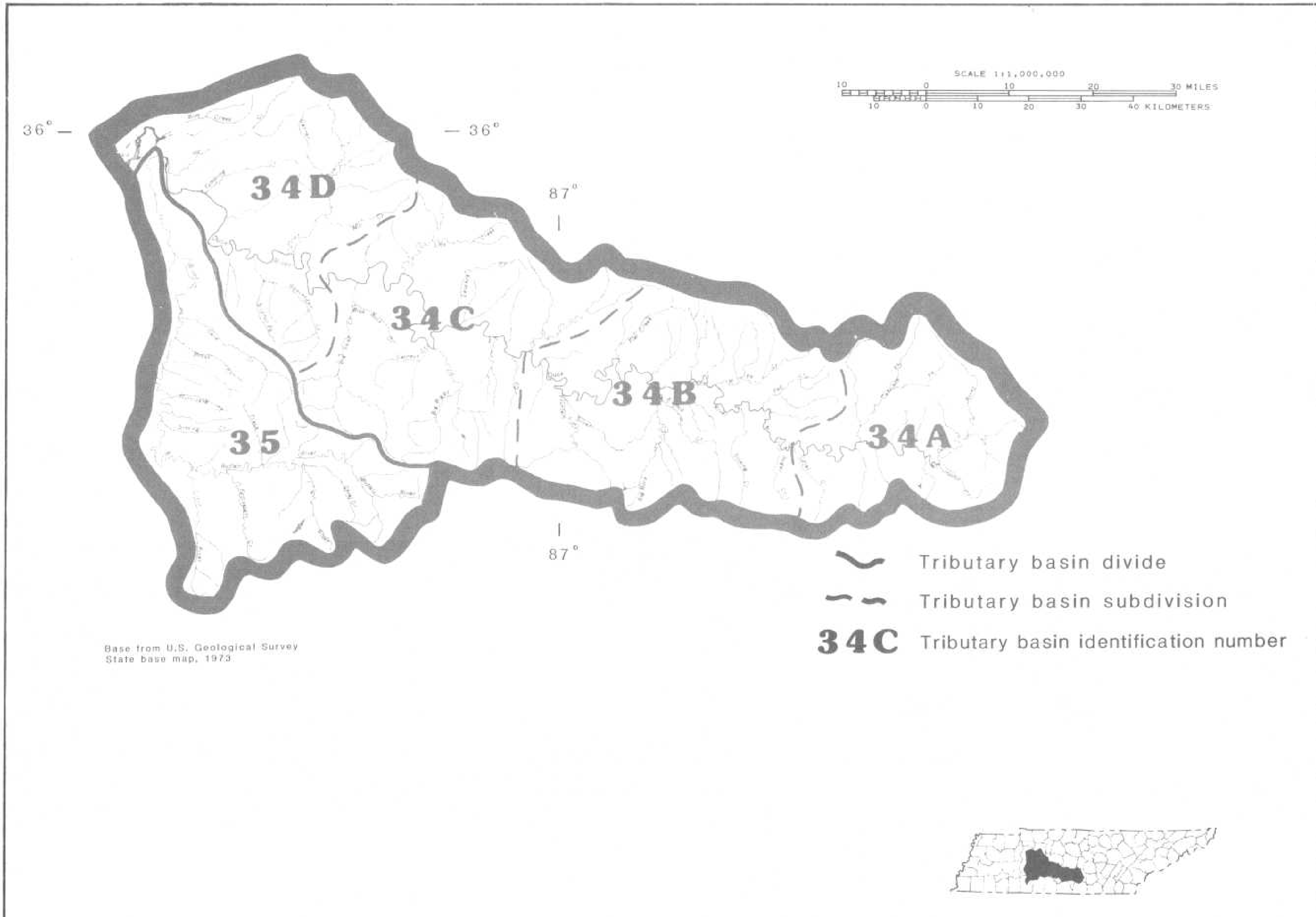


Figure 11.--Duck-Buffalo River basin.

Average stream slopes in this basin range from 1.59 ft/mi in the lower Duck River watershed between river miles 0 and 133 to 1.83 ft/mi in the upper watershed between river miles 133 and 221. The elevation in this basin generally ranges from 375 to 1,200 feet above sea level. The maximum elevation is about 1,300 feet.

Hydrology

Surface Water

Surface- and ground-water resources in this basin are replenished by ample rainfall whose long-term (1941-70) average equals 52.01 inches. From 1970-79, average annual precipitation equaled 58.81 inches with a low of 47.57 inches in 1978 and a high of 68.48 inches in 1973. Average precipitation data for watershed subdivisions of the Duck-Buffalo River basin during the 1970-79 time period are summarized in table 13. Annual (1979) and long-term (1941-70) precipitation data for selected TVA, NWS, and private (Victor Chemical Works) rainfall stations in the basin are outlined in table 14.

Generally, the months of August, September, and October are the driest months in that part of the Tennessee River basin. During these months, average rainfall varies from 2.57 to 3.54 inches. Throughout the rest of the year, rainfall varies from 4.05 to 5.72 inches with March having the highest rainfall. Analysis of long-term precipitation records for the 1941-70 time period for selected rainfall stations (Lewisburg, Manchester, Pinewood, and Waynesboro) indicates that, in general, the months of August, September, and October are the driest with rainfall ranging from 2.36 to 3.80 inches. During the remaining months, rainfall varies from 3.98 to 6.12 inches with the most rain falling in January, February, and March.

Average annual runoff in the Duck-Buffalo River basin ranges from about 21 to 24 inches as one moves eastward across the basin. A summary of average discharge data for selected hydrologic data stations in the Duck-Buffalo River basin is presented in table 15 (U.S. Geological Survey, 1981). The majority of this runoff occurs during the winter and spring months.

Major Reservoirs

This basin's only major existing reservoir is Normandy Reservoir which has a storage capacity of 66,600 acre-feet at normal minimum pool. Detailed information describing the location and operation pattern of Normandy Reservoir follows:

Normandy Reservoir

Location and drainage area.--Normandy Reservoir is formed by Normandy Dam which is located on the Duck River at river mile 248.6 in Coffee County. Normandy Dam controls 195 mi^2 of drainage area.

Reference Period.--1976-81.

Table 13.--Precipitation data by watershed subdivision for the period 1970-79, Duck-Buffalo River basin

Watershed description	Precipitation (inches)				
	High	Year	Low	Year	10-year average
Duck River from Columbia to the river's mouth.	75.20	1979	44.90	1971	58.05
Duck River above Columbia	74.60	1973	47.60	1978	58.17
Buffalo River upstream from Lobelville.	73.90	1979	47.40	1971	60.77

Table 14.--Precipitation data for 1979 and for the period 1941-70 for selected rainfall stations, Duck-Buffalo River basin

Station location	Station owner	Elevation above sea level (feet)	Period of record (years)	1979 Precipitation (inches)	Long-term annual precipitation (inches)
Hohenwald	TVA	975	92	79.23	51.57
Waynesboro	NWS	750	95	73.63	54.57
Pinewood	TVA	550	64	80.32	48.78
Dickson	NWS	814	88	76.11	50.11
Mt. Pleasant	VCW	720	27	75.91	53.88
Columbia	TVA	620	41	63.69	50.08
Neapolis	TVA	720	28	74.46	53.52
Franklin	NWS	670	91	77.63	49.59
Culleoka	TVA	675	13	73.28	56.17
Lewisburg	NWS	787	86	71.16	52.12
Chapel Hill	TVA	693	44	62.59	50.95
Shelbyville	NWS	785	29	63.54	54.52
Normandy	TVA	880	16	63.03	56.15
Manchester	TVA	1,060	30	57.93	55.58

Table 15.--Average discharge data for selected hydrologic data stations, Duck-Buffalo River basin

Station name and location (county)	River mile	Drainage area (square miles)	Period of record (years)	Average discharge: Cubic feet per second	Average discharge: Inches per year	Average discharge: Cubic feet per second per square mile
Duck River downstream from Manchester (Coffee).	265.4	107	46	189	23.99	1.77
Duck River near Shelbyville (Bedford).	216.2	481	47	832	23.49	1.73
Duck River at Columbia (Maury).	132.8	1,208	64	2,020	22.70	1.67
Big Bigby Creek at Sandy Hook (Maury).	17.9	17.5	27	28.8	22.35	1.65
Piney River at Vernon (Hickman).	8.3	202	55	317	21.31	1.57
Duck River upstream from Hurricane Mills (Humphreys).	26.0	2,557	55	4,151	22.05	1.62
Buffalo River near Flatwoods (Perry).	58.7	447	60	757	23.00	1.69
Buffalo River near Lobelville (Perry).	17.7	707	53	1,197	22.99	1.69

Reservoir discharge (minimum daily average flow).--Minimum daily average discharge from Normandy Dam since its closure in January of 1976 ranged from a low of about 17.0 ft^3/s (11.0 Mgal/d) in 1976 to a high of about 118.0 ft^3/s (76.3 Mgal/d) in 1981. The average, 1-day minimum discharge since the dam's closure was about 53.0 ft^3/s (34.3 Mgal/d).

Average number of days of zero flow.--None

Existing agreements regarding reservoir releases.--Normandy Dam is operated to ensure a minimum instantaneous flow of 158.0 ft^3/s (102.1 Mgal/d), 155.0 ft^3/s for water quality and 3.0 ft^3/s for water supply, across the spillway of Shelbyville Dam located at river mile 221.4 on the Duck River. In addition, Normandy Dam is operated to ensure a minimum instantaneous flow of at least 40.0 ft^3/s (25.8 Mgal/d) immediately below the dam. By 2000, releases from Normandy Dam for water-supply purposes are projected to increase to about 10.0 ft^3/s (6.5 Mgal/d).

Columbia Reservoir

Another reservoir to be impounded by the authorized Columbia Dam is located on the Duck River at river mile 136.9 and will have an estimated storage capacity of 80,000 acre-feet at normal minimum pool when completed. TVA stopped construction on the Columbia Dam project in September 1983 pending determination of the likely success of TVA's mussel conservation program. Water-quality studies, cultural investigations and other planning studies continue. Completion of the project is now scheduled for 1987. Upon completion, Columbia Dam will be operated to provide a minimum release or discharge of 200.0 ft^3/s including 155.0 ft^3/s (100.2 Mgal/d) for water-quality purposes and 45.0 ft^3/s (29.1 Mgal/d) for water-supply purposes. Over the 100-year life of the project, releases for water-supply purposes are projected to increase from 45.0 ft^3/s to a maximum of 150.0 ft^3/s (96.9 Mgal/d). In view of the heavy surface-water losses (20 to 30 ft^3/s) between Shelbyville and Columbia because of evaporation and transpiration losses during prolonged drought periods, Columbia Dam will do much to meet the projected water-supply requirements of the Upper Duck River area (Tennessee Valley Authority, 1979b).

Ground Water

The Duck-Buffalo River basin extends essentially east-west across parts of the eastern Highland Rim, the Central Basin, and the western Highland Rim. The Highland Rim physiographic province is an old erosion surface or peneplain which completely surrounds the Central Basin province. The altitude of the eastern Highland Rim is some 500 feet higher than the altitude of the Central Basin floor, while the altitude of the western Rim is somewhat lower, being about 300 feet or less above the Central Basin floor. There are two modes of occurrence of ground water on the Highland Rim. One is at or near the contact between the relatively thick regolith and the underlying limestone. This residual blanket is composed primarily of clay, chert blocks and fragments, siliceous silt, and some sand. It is generally 30 feet or more in thickness and sometimes reaches 100 feet in thickness. The regolith is capable of storing a large amount of water but commonly furnishes a relatively small amount of water, 25 gal/min or less, to dug or drilled wells. However, a chert rubble zone sometimes occurs at or a few feet above the top of the underlying rock and is capable of furnishing several hundred gallons per minute of water to wells on the eastern Highland Rim. An occurrence of this zone is in the vicinity of Manchester where it is capable of furnishing water in sufficient amounts for industrial purposes. Water quality is usually good. However, it is most often acidic due to dissolved carbon dioxide. If the water is to be used to augment a surface supply for a public system, it may require treatment to raise the pH so as to achieve compatibility. The chert rubble zone does not appear to be present on the western Highland Rim on the basis of present information. However, several wells drilled near Dickson encountered a zone of broken rock at the top of the underlying rock which yielded similar quantities of water. Also, thicknesses of the regolith were reported to be more than 200 feet. The regolith on the western Highland Rim in some areas seems to contain more clay than that on the eastern Highland Rim. Therefore, it is not as permeable and dug wells generally have low yields and often go dry during periods of low rainfall. In these cases, they are sometimes used as cisterns. In a number of minor drainage basins on the western Highland Rim that are underlain by siliceous limestone of the Ft. Payne formation, the regolith below well-drained soil is largely bedded chert which is quite permeable. The lower part of this chert zone furnishes water to a number of domestic wells.

The other occurrence of ground water on the Highland Rim is in solutionally enlarged joints (cracks) and bedding plane openings in limestone. These cracks, caused by the structural upwarping of the Nashville Dome, are subject to the dissolving action of downward percolating ground water. They are generally largest near the rock surface and in perennial stream valleys and become smaller with increased depth. Most often the cracks are not significantly enlarged at depths below 300 feet. Consequently, on the basis of present information, it is not advisable to drill much deeper. Also, the chances of encountering relatively high mineral water increase with depth. Drilling into one of these water-filled openings is a "hit-or-miss" proposition and wells drilled into rock commonly gain no additional water after passing through the regolith. However, some wells encounter rather large openings within the first 100 feet below the top of rock and provide yields of 100 gal/min or more. Water quality is usually good but may be somewhat acidic.

The Highland Rim is underlain at various depths by the Chattanooga Shale. The Chattanooga is a carbonaceous black shale which, when present, acts as an impervious barrier to the downward migration of ground water. It is present in most areas of the Highland Rim escarpment surrounding the Central Basin where it is nearer the land surface. Its impervious nature causes its top to be a prominent spring horizon wherever it crops out along the Highland Rim escarpment. These springs issuing from the overlying limestone are often relatively large, yielding as much as 1,000 gal/min, particularly during the rainy season. The yields of these springs fluctuate seasonally but, because of the Highlnd Rim regolith's ability to store large quantities of water, they do not decrease in flow as much as most limestone springs, particularly as much as those on the floor of the Central Basin. As stated before, the Chattanooga Shale is generally nearer the land surface along the escarpment surrounding the Central Basin and on the spurs and outliers of the rim extending into the Basin. Due to its impervious character almost all of the wells encountering water-filled openings beneath the shale yield water too highly mineralized to be economically treated. Consequently, it is advisable not to drill below the top of the shale. Where the Chattanooga is near the surface, small quantities are encountered in joints in the shale. However, since the

Chattanooga contains considerable quantities of the mineral pyrite (iron sulfide), this water is high in hydrogen sulfide and compounds of iron. The same is true for any springs that might issue from it.

The middle part of the Duck-Buffalo River basin lies in the Central Basin that is often termed the Nashville Basin. This area contains numerous spurs and outlying remnants of the Highland Rim. Ground water is often difficult to obtain in quantity on some of these ridges because of the lack of adequate watershed. The valleys and parts of the Central Basin floor are underlain by limestone formations of varying purity and solubility. Some of these formations are relatively thin-bedded and the individual beds are separated by thin layers of shale that contain considerable clay. This is particularly true of the uppermost limestones which have a thickness of some 200 feet and lie just below the base of the Chattanooga Shale. The presence of these shale layers tends to inhibit the downward migration of ground water and the joints in the rocks are enlarged to a lesser degree than in the purer limestones. Therefore, in these rocks ground water is generally available only in relatively small quantities, if at all. Dry holes are common and sulfur water high in iron is often encountered. In the northern part of the area under discussion, older and purer, more soluble limestones underlie the relatively thin soil of the Central Basin. Here, water in quantities sufficient for domestic use is reasonably easy to obtain. Well yields in the Central Basin part of the Duck-Buffalo River basin are extremely subject to variation with the seasons of low and high rainfall. Wells that can maintain a sustained yield of 50 gal/min or more are rare. Exceptions to this fact may be those wells drilled on the flood plains of larger streams.

The depth to the base of the zone of weathering or the maximum depth at which significantly enlarged openings exist is about 275 feet in this area of the Central Basin. Therefore, it is generally not advisable to drill below this depth. Also, the chances of encountering highly mineralized water increase with depth. The quality of the water from wells is generally good with the exception of those that are high in hydrogen sulfide and iron. Water quality cannot be predicted with accuracy. Springs are common, yielding no more than 40 gal/min for the most part. As with wells, the yield fluctuates with the seasons and many go dry in periods of low rainfall. Water quality is usually good.

There is a relatively deep source of ground water available in the Central Basin from wells that are drilled into the Knox Group - a series of beds of dolomite, dolomitic limestone, and limestone some 5,000 feet in thickness. The top of these rocks occurs from about 650 to 1,100 feet below the surface in the area under discussion depending on topographic location and location with respect to the axis of the Nashville Dome. This source has been under investigation since about 1949 as a possible source of drinking water. Because of its depth and drilling costs to reach it, not as much information has been gathered as in the case of the shallower aquifers. On the basis of present information, the dissolved mineral content of Knox water generally increases with depth. The better quality of water seems to occur within the top 300 feet of the Knox Group. Yields are low and probably do not exceed 15 gal/min. The average yield is probably around 1 gal/min. Water quantity and quality at any given location is impossible to predict at present. However, some areas can be delineated as probably yielding water too high in dissolved solids to be potable. Water from most Knox wells that have currently been drilled on the Highland Rim fall into this category.

Most of these wells listed in the existing ground-water data base were drilled for domestic use and were not located on the basis of geologic studies. Therefore, the true ground-water potential of the Duck-Buffalo River basin needs further study at this time.

Demography

Historical (1970) and recent (1980) population, total wage and salary employment including both full- and part-time workers, and per capita personal income data for the county boundary approximation of the Duck-Buffalo River basin is presented in table 16. Counties included in this approximation are Bedford, Coffee, Hickman, Lewis, Marshall, Maury, and Perry. Principal urban or metropolitan areas in the basin and their 1980 census population are Centerville (2,854), Columbia (26,372), Hohenwald (3,922), Lewisburg (8,760), Manchester (7,250), and Shelbyville (13,530).

Public and Self-Supplied Commercial and Industrial Water Users

Currently, there are a total of 33 public water-supply facilities and 14 large, self-supplied commercial and industrial water users whose use exceeds 0.1 Mgal/d in the Tennessee part of the Duck-Buffalo River basin. Detailed inventories containing pertinent information and data relative to each community or self-supplied user's source of water, average daily water use, source capacity, population served, treatment plant and storage capacities, and water-supply shortage problems are found in tables 7 and 8 of appendix I, respectively. Total water use or withdrawal at the present time for public and large, self-supplied commercial and industrial purposes in the Duck-Buffalo River basin amounts to approximately 71.2 Mgal/d. The general location and water-supply source of all public and large, self-supplied commercial and industrial water users inventoried in the Duck-Buffalo River basin are depicted in figures 12 and 13, respectively.

Public water systems currently serve about 161,000 people or 96 percent of the basin's 1980, county boundary approximated, population. The estimated population served does not include either those people served via the Dickson WD in Dickson County (12,500) since Dickson County was not included in the county boundary population approximation or that part of the HB & TS (Hillsboro and Thompson Station) UD's population served (3,200) by water withdrawals from the Cumberland River via the Harpeth Valley UD. Average daily water use for public purposes equals about 23.1 Mgal/d, of which approximately 19.0 Mgal/d or 82 percent is withdrawn from surface-water sources and 4.1 Mgal/d or 18 percent from ground-water sources. Major public water-supply facilities whose average daily use exceeds 1.0 Mgal/d include the following:

Facility name	Average water use (Mgal/d)
Shelbyville WD	3.500
Manchester WD	1.200
Tullahoma WD	2.300
Dickson WD	1.000
Lewisburg WS	2.268
Columbia WS	7.633

Table 16.--County population, employment, and per capita personal income data, Duck-Buffalo River basin

[Per capita income based on 1970 income converted to 1980 dollars]

County	Population		Employment		Per capita personal income 1980 dollars	
	1970	1980	1970	1980	1970	1980
Bedford	25,039	27,916	10,153	10,709	$6,568	$7,471
Coffee	32,572	38,311	13,394	17,447	6,628	7,690
Hickman	12,096	15,151	2,814	2,997	5,323	6,151
Lewis	6,761	9,700	1,954	3,298	4,762	4,495
Marshall	17,319	19,698	6,636	9,200	6,337	7,243
Maury	44,028	51,095	16,248	20,427	6,560	7,528
Perry	5,238	6,111	1,274	1,577	4,648	5,489
Total	143,053	167,982	52,473	65,655	-	-

Together these systems account for approximately 80 percent of the basin's total water use for public purposes.

Figure 12--Explanation

Site No.	Facility name
1	Shelbyville WD
2	Wartrace WS
3	Duck River Utility Commission
4	Dickson WD
5	Bon Aqua-Lyles UD
6	Centerville WS
7	Turney Center WS
8	McEwen WD
9	Waverly WS
10	Summertown WS
11	Hohenwald WS
12	Lewisburg WS
13	Columbia WS
14	Mount Pleasant WS
15	Linden WD
16	Lobelville WD
17	Waynesboro WS

Self-supplied commercial and industrial water users currently use or withdraw approximately 48.2 Mgal/d with all but 0.5 Mgal/d or 99 percent being withdrawn from surface-water sources. The basin's major self-supplied industrial water users include Occidental Chemical Corp. (9.5 Mgal/d at three plants) and Monsanto Industrial Chemicals Co. (33.1 Mgal/d) in Maury County. Consumptive water use by large, self-supplied commercial and industrial water users in the basin equals slightly less than 2.5 Mgal/d.

Summarized below is a list of the specific water-supply problems now being experienced by individual communities and self-supplied commercial and industrial users in the Duck-Buffalo River basin. The number in parentheses following each identified problem indicates the number of communities and (or) self-supplied water users who are now or have experienced this problem in the past. Note, these problems are not listed in order of frequency of occurrence or overall severity.

- Excessive concentrations of manganese and iron due to reservoir releases from Normandy Dam. (1)
- Periodic water shortages during severe and extended droughts. (2)
- Serious water losses due to deteriorating water mains and lines. (1)
- Occasional taste and odor in the Duck River due to reservoir releases from Normandy Dam. (1)
- Seasonal problems caused by algae growth which results in increased treatment costs. (1)
- Inadequate water pressure in distribution mains and lines due to increased demands by neighboring water users. (1)
- Occasional flooding and turbidity problems following heavy rains. (2)

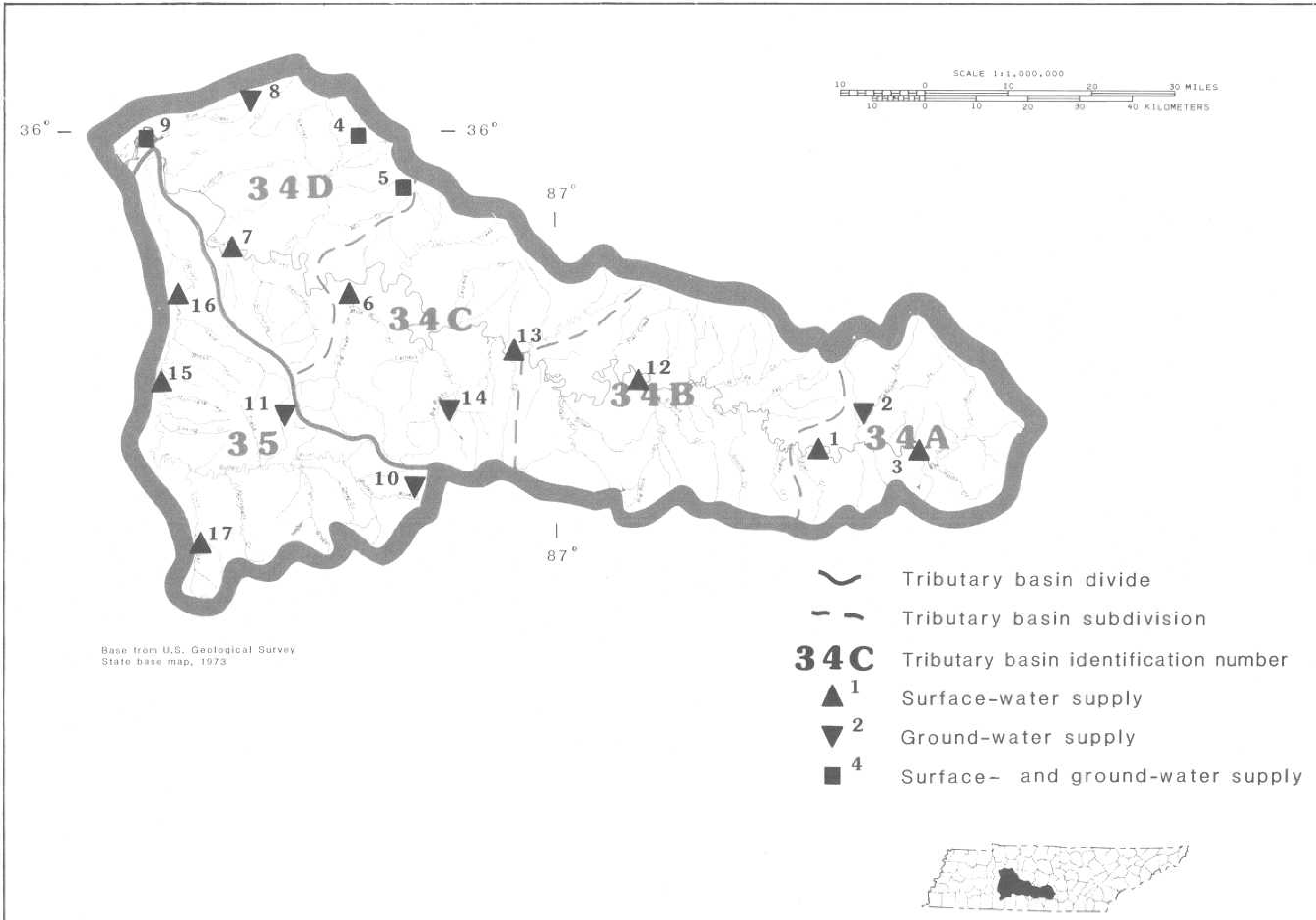


Figure 12.--Public water-supply facilities, Duck-Buffalo River basin.

Figure 13--Explanation

Site No.	Facility name
1	Levi Strauss and Co. (Centerville)
2	M. C. West and Co. (Columbia)
3	Lewis Products (Hohenwald)
4	Lewisburg Materials (Lewisburg)
5	Dupont E.I. DeNemours and Co., Inc. (Columbia)
6	Occidental Chemical Corp., Godwin Washer Plant (Columbia)
7	Occidental Chemical Corp., Williamsport Washer Plant (Columbia)
8	Occidental Chemical Corp., Furnace Plant (Columbia)
9	Monsanto Industrial Chemicals Co. (Columbia)
10	Presnell Phosphate Co., Inc. (Columbia)
11	Stauffer Chemical Co., Inc. (Mount Pleasant)
12	Stauffer Chemical Co., Globe Plant (Mount Pleasant)
13	Stauffer Furnace Plant (Mount Pleasant)
14	True Temper Corp. (Waynesboro)

Water-Supply Adequacy Analysis

About 3,500 mi^2 or 2,240,000 acres of land and water area are drained by the Duck-Buffalo River basin. This basin's surface- and ground-water supplies are replenished by extensive rainfall whose long-term (1941-70) average equals 52.01 inches. Average annual runoff in this basin ranges from about 21 to 24 inches as one moves eastward across the basin. Generally, the months of August through October are the driest months with the greatest precipitation coming during the first 3 months of the year.

Average daily water use for public and self-supplied commercial and industrial water users exceeding 0.1 Mgal/d in the Duck-Buffalo River basin equals approximately 71.2 Mgal/d. Of this amount, about 23.1 Mgal/d are withdrawn for public-water supply use with 19.0 Mgal/d or 82 percent coming from surface-water sources and 4.1 Mgal/d or 18 percent from ground-water sources. Water use by self-supplied commercial and industrial facilities equals about 48.2 Mgal/d with 47.7 Mgal/d or 99 percent being supplied by surface-water resources and 0.5 Mgal/d or 1 percent from ground-water resources. Major self-supplied water users in this basin include Occidental Chemical Corp. (9.5 Mgal/d) and Monsanto Industrial Chemicals Co. (33.1 Mgal/d) in Maury County. Consumptive water use by self-supplied commercial and industrial facilities equals about 2.5 Mgal/d.

The majority of this basin's public and self-supplied commercial and industrial water use is supplied by surface-water resources. This is due primarily to the existence of large surface-water resources such as Normandy Reservoir, the Duck and Buffalo Rivers, and the limited ground-water development studies which have been completed in the basin to date. However, it is possible for trained geo-