Prepared in cooperation with the Tennessee Duck River Agency

Estimated Use of Water in the Upper Duck River Watershed, Central Tennessee, and Water-Demand Projections through 2030

Scientific Investigations Report 2008-5058

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph. The Duck River in Tennessee. (Photograph by Rodney R. Knight.)

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Suggested citation:
Hutson, S.S., 2008, Estimated use of water in the upper Duck River watershed, central Tennessee, and water-demand projections through 2030: U.S. Geological Survey Scientific Investigations Report 2008-5058, 16 p.

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Conversion Factors

Multiply	By	To obtain
	Area	
inch	2.54	centimeter (cm)
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per day per square mile [(gal/d)/mi^2]	0.001461	cubic meter per day per square kilometer [(m^3/d)/km^2]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,461	cubic meter per day per square kilometer [(m^3/d)/km^2]
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F–32)/1.8

Horizontal coordinate information (lat/long) is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Additional abbreviations used in this report

DP	departure from normal precipitation
DRATAC	Duck River Agency Technical Advisory Committee
DRWRC	Duck River Water Resources Council
FY	fiscal year
Gal/mo	gallons per month
IWR-MAIN	Institute for Water Resources–Municipal and Industrial Needs
MMMT	mean monthly maximum air temperature
NOAA	National Oceanic and Atmospheric Administration
TDRA	Tennessee Duck River Agency
TVA	Tennessee Valley Authority
USGS	U.S. Geological Survey
WSA	water-service area

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Abstract

Future municipal water demand was estimated for the Bedford, Coffee, Marshall, and Maury-southern Williamson water-service areas in the upper Duck River watershed in central Tennessee through 2030. The Duck River, a primary source of municipal water, provided a total of 24.3 million gallons per day (Mgal/d) or 92 percent of the total water use in the study area during 2000. Municipal water use increased 46 percent from 1981 to 2000 (from 18.0 to 26.3 Mgal/d). Water demand for municipal use is expected to continue to increase through 2030 because of the recent intensive and anticipated growth in the residential and commercial sectors.

Constant-rate models were used to estimate future municipal water demand. Data on residential and nonresidential billing accounts and estimates of public use and losses were used to calibrate the models. Two watershed scenarios for each water-supply system that depends on the Duck River for supply were simulated. Scenario 1 considered monthly water demand during typical weather conditions as represented by monthly per account use during 2003 and a rate of growth in customer accounts from 1999 to 2003. Results showed that total municipal water use could increase about 104 percent to 51 Mgal/d by 2030, residential water use could increase about 140 percent to 24 Mgal/d, nonresidential water use could increase about 110 percent to 17 Mgal/d, and public use and losses could increase about 83 percent to 11 Mgal/d.

Scenario 2 considered monthly water demand during drought conditions as represented by monthly per account use during 2000 and recent growth in customer accounts from 1999 to 2003 or, for selected water-supply systems, an increasing rate of growth. Results showed that total municipal water use could increase about 120 percent to 55 Mgal/d, residential water use could increase about 160 percent to 26 Mgal/d, nonresidential water use could increase about 122 percent to 18 Mgal/d, and public use and losses could double and increase to 12 Mgal/d. For both scenarios the model assumed that the Duck River would supply all future surface-water needs in the study area, that ground-water resources would be sufficient to meet growing demands of the water-supply systems that depend on ground water, and that the amount of surface water sold to water-supply systems primarily dependent on ground water would remain the same through 2030.

Introduction

A continuing assessment of water availability and demand is basic to the economic health and future of the State of Tennessee. Population growth in many parts of the State has resulted in increased competition for available water resources. This competition includes off-stream uses for domestic, agricultural, and industrial use as well as in-stream use for maintenance of aquatic habitat and species diversity. Accurate **water-use**[1] information and water-demand projections are required for sound management decisions within this competitive framework.

The Tennessee Duck River Agency (TDRA), the Duck River Agency Technical Advisory Committee (DRATAC), and the Duck River Water Resources Council (DRWRC) have recognized that population growth in the upper Duck River watershed could further increase water-supply demands. Past studies in the upper Duck River basin include water-demand projections for the period 2000 to 2050 developed by the U.S. Geological Survey (USGS) for Bedford, Marshall, Maury, and southern Williamson Counties in 1993 (Hutson and Schwarz, 1996) and for Coffee County in 2001 (Susan S. Hutson, U.S. Geological Survey, written commun., 2001). During 2002, estimates of water withdrawals between 1981 and 2000 (Randall Braker, General Manager, Duck River Utility Commission, written commun., 2004) and water-demand projections were input to a watershed model, Oasis, as part of a water-needs analysis of the upper Duck River watershed by HydroLogics, Inc. (Larry A. Murdock, Executive Director, Tennessee Duck River Agency, written commun., 2004). While these analyses indicated that the natural flows in the upper Duck River could meet the water-supply needs of the watershed, continuing growth and changing demographics highlight the need for periodic updates.

Purpose and Scope

This report provides estimates of water demand for the upper Duck River watershed through 2030. Water-demand estimates are limited to **municipal water** delivered to residential, commercial, and industrial customers and **public use**

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[1] Terms in bold can be found in the glossary.

and losses. The investigation includes an inventory of the municipal water use in the study area. An inventory of private wells for industrial, irrigation, or residential purposes or an assessment of the effect of water withdrawals or return flow on streamflow was not included in the study. For this study, the upper Duck River watershed study area is divided into four municipal water-service areas (WSAs), whose boundaries closely coincide with their respective county boundaries. The four WSAs are Bedford, Coffee, Marshall, and Maury-southern Williamson (fig. 1). Water-demand estimates were prepared only for water-supply systems that depend on the upper Duck River. Future water demand from the Elk, Barren Fork, or Cumberland Rivers was not considered.

Approach

The following approach was used to characterize water use and estimate future water demand for the upper Duck River watershed study area.

- Compile historical water-use data.
- Construct base-year modeling scenarios from water-supply system monthly summary billing account records and climatological data.
- Determine a rate of future growth for the residential and nonresidential customers based on short-term trends in billing account records and guidance from local and regional officials and planners and water-supply system managers.
- Calibrate constant-rate water-demand models.
- Simulate water demand using the Institute for Water Resources–Municipal and Industrial Needs Water Demand Management Suite software (IWR-MAIN).

Hydrologic Setting

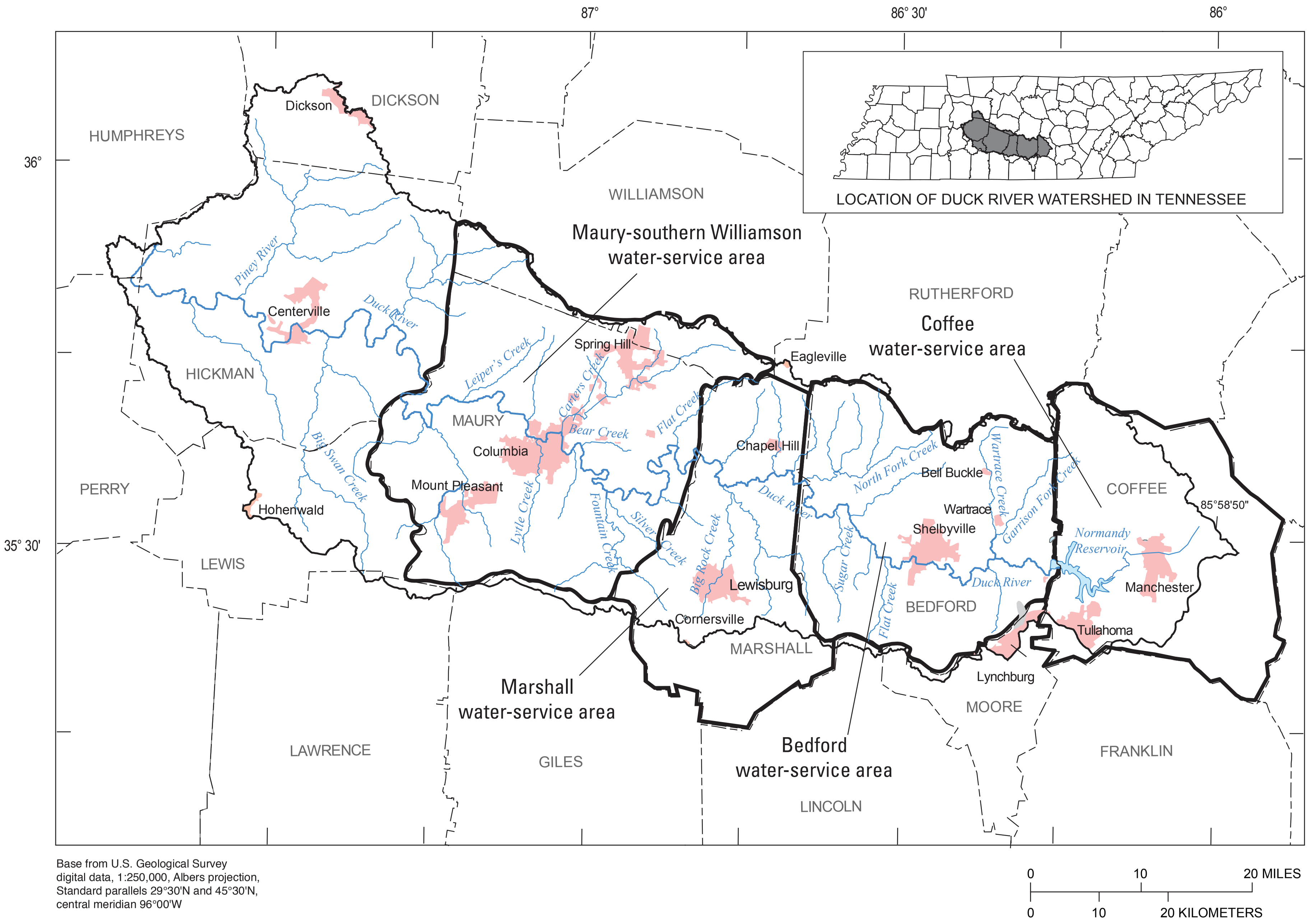
The Duck River is a tributary to the Tennessee River and drains parts of the Highland Rim and Central Basin physiographic regions of central Tennessee (Miller, 1974; fig. 2). The climate of the area is moderate, and long-term precipitation ranges from 56 inches per year in the western part of the watershed to 60 inches in the eastern part of the watershed (Blaise L. Merchlewitz, National Forecast Office, Memphis, Tennessee, written commun., April 2004). The river flows from the dissected limestone highlands in northern Coffee County into Normandy Reservoir, which was completed by the Tennessee Valley Authority (TVA) in 1976. The reservoir, with a capacity of 117,000 acre-feet and a normal maximum headwater elevation of 875 feet, is used for flood control, water supply, water-quality enhancements, and recreation. Normandy Reservoir supplied 5.20 million gallons per day (Mgal/d) to Manchester, Tullahoma, and other communities in Coffee County during 2000. Downstream from Normandy Dam, the river flows into Bedford County and through the city of Shelbyville where municipal withdrawals were 5.74 Mgal/d during 2000. There are no major urban areas as the river traverses Marshall County, although the river supplied 2.76 Mgal/d during 2000 to the city of Lewisburg and other smaller communities. In Maury County, the river supplies water to the city of Columbia (10.6 Mgal/d during 2000) and, beginning in 2003, the city of Spring Hill (0.48 Mgal/d). The total drainage area of the watershed at the western Maury County boundary is 1,700 square miles. Ground-water use for municipal supply in the watershed was about 2.01 Mgal/d during 2000 for the cities of Chapel Hill, Mount Pleasant, and Wartrace.

Water Use

Water withdrawals for Bedford, Coffee, Marshall, and Maury Counties in the upper Duck River watershed study area totaled 28.6 Mgal/d for municipal supply, self-supplied industry, and self-supplied irrigation during 2000 (U.S. Geological Survey, June 2004; table 1). Withdrawals from private wells or springs for residential use, from farm ponds, other surface-water sources, wells, or springs for livestock watering were not estimated. Nearly all of the water withdrawals were from the upper Duck River (about 92 percent or 26.4 Mgal/d). The remaining ground-water withdrawals (2.26 Mgal/d) were from the Ordovician carbonate and Mississippi carbonate rock aquifers (fig. 2). Nearly all of the ground-water public-supply withdrawals were from the Ordovician carbonate aquifer (2.01 Mgal/d; Webbers, 2003).

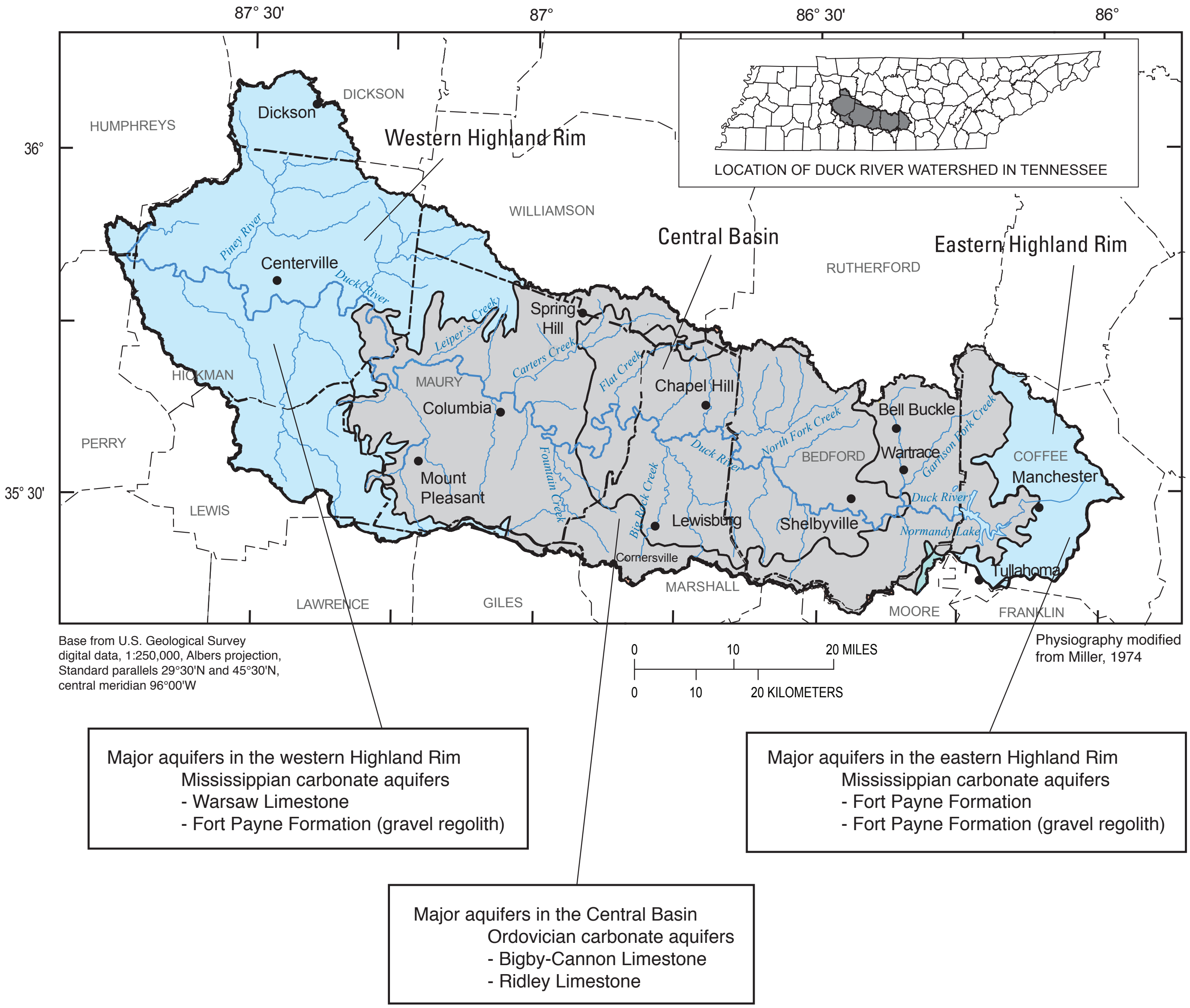
During 2000, most of the water withdrawals in the study area were for municipal supply (92 percent or 26.3 Mgal/d). Industrial withdrawals from surface water were 1.44 Mgal/d and from ground water about 0.04 Mgal/d. Irrigation water withdrawals of 0.85 Mgal/d were chiefly from surface water and mostly used for golf course irrigation (0.77 Mgal/d). The Maury-southern Williamson WSA accounted for 47 percent of the total water withdrawals or 13.4 Mgal/d, 47 percent of the total surface-water withdrawals or 12.3 Mgal/d, and 49 percent of the total ground-water withdrawals or 1.1 Mgal/d (table 1). The remaining withdrawals occurred in the Bedford (23 percent or 6.58 Mgal/d), Coffee (20 percent or 5.66 Mgal/d), and Marshall (10 percent or 3.00 Mgal/d) WSAs.

Water-use trends based on calendar year data indicate that public-supply water withdrawals increased 46 percent or 8.3 Mgal/d (from 18.0 to 26.3 Mgal/d) from 1981 to 2000 (1981 data, Alexander and others, 1984; 1985, 1990, 1995, and 2000 data, U.S. Geological Survey, 2004; table 2). Most of the increase in water use was from surface water (7.40 Mgal/d), although the greatest percentage increase was from ground water (82 percent, from 1.11 to 2.02 Mgal/d). Industrial water withdrawals decreased from 40.2 Mgal/d in 1981 to 1.48 Mgal/d in 2000. During 1981, nearly all of the industrial water use was by the chemical industry predominantly for



Base from U.S. Geological Survey
digital data, 1:250,000, Albers projection,
Standard parallels 29°30'N and 45°30'N,
central meridian 96°00'W

Figure 1. Upper Duck River study area and the Maury-southern Williamson, Marshall, Bedford, and Coffee water-service areas.



Base from U.S. Geological Survey digital data, 1:250,000, Albers projection, Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Physiography modified from Miller, 1974

Major aquifers in the western Highland Rim
Mississippian carbonate aquifers
- Warsaw Limestone
- Fort Payne Formation (gravel regolith)

Major aquifers in the eastern Highland Rim
Mississippian carbonate aquifers
- Fort Payne Formation
- Fort Payne Formation (gravel regolith)

Major aquifers in the Central Basin
Ordovician carbonate aquifers
- Bigby-Cannon Limestone
- Ridley Limestone

Figure 2. Physiographic regions and major aquifers in the upper Duck River watershed.

washing phosphate ore and processing elemental phosphorous and occurred downstream from the city of Columbia and the area of water-supply concerns in the watershed. Similarly, self-supplied industrial withdrawals during 2000 were principally for the chemical industry and also occurred downstream from the city of Columbia (U.S. Geological Survey, 2004). During this same period, the study area population excluding southern Williamson County increased 32 percent from 138,300 persons to 181,870 persons (table 2).

In 2002, estimates of long-term surface-water withdrawals were compiled by DRATAC as part of a water-needs analysis of the upper Duck River watershed conducted by HydroLogics, Inc. (Randall Braker, General Manager, Duck River Utility Commission, written commun., 2004; fig. 3). The estimates were based on fiscal-year (FY) water-sales data (July 1 to June 30) for 1981 through 2000 with a multiplicative factor of 1.20 to account for public use and losses. This FY data set represents the only complete, readily available set of annual estimates of water withdrawals for the study area. Estimates of water withdrawals for the Duck River Utility Commission were compiled from the water sales for Manchester Water Department and Tullahoma Board of Utilities. From FY1981 to FY2000, surface-water withdrawals increased 39 percent from 15.2 to 21.2 Mgal/d. The FY data indicate that water demand has steadily increased for all water-supply systems with some annual variability. By volume, withdrawals increased the most for the Columbia Water System (3.07 Mgal/d); by percentage, withdrawals increased the most for the Bedford County Utility District (100 percent, 1993–2000 [0.60 Mgal/d to 1.20 Mgal/d, respectively]) followed by the Manchester Water Department (80 percent, 1981–2000 [1.14 Mgal/d to 2.06 Mgal/d, respectively]).

Table 1. Surface-water and ground-water withdrawals by water-use category in the upper Duck River watershed, 2000.

[Totals may not add to sums because of independent rounding. Population is expressed to two decimal places. Water withdrawal values are expressed as three significant figures or if the value is less than 1, to two decimal places]

Water-service area	Population,[a] in thousands	Municipal supply		Self-supplied industry		Self-supplied irrigation		Study area		
		Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Total water
		Million gallons per day								
Bedford	37.59	5.74	0.83	0.00	0.00	0.01	0.00	5.75	0.83	6.58
Coffee	48.01	5.20	.01	.00	.040	.36	.05	5.56	.10	5.66
Marshall	26.77	2.76	.15	.00	.00	.01	.08	2.77	.23	3.00
Maury-southern Williamson	69.50[b]	10.6	1.03	1.44	.00	.27	.07	12.3	1.10	13.4
Watershed total	181.87[b]	24.3	2.02	1.44	.04	.65	.20	26.4	2.26	28.6

[a] Population and water withdrawals are from the U.S. Geological Survey, Aggregated Water Use Data System (2004)

[b] Population total excludes southern Williamson County

Table 2. Total surface-water and ground-water withdrawals for municipal-supply use in 1981, 1985, 1990, 1995, and 2000 for the upper Duck River watershed study area.

[Mgal/d, million gallons per day. Totals may not add to sums because of independent rounding. Population and water-use data are from Alexander and others (1981); population and water withdrawals for 1985–2000 are from U.S. Geological Survey (2004)]

Municipal supply	Water withdrawals, in Mgal/d					Rate of change in use from 1981 to 2000, in Mgal/d	Rate of change in use from 1981 to 2000, in percent
	1981	1985	1990	1995	2000		
Ground water	1.11	1.40	1.48	1.85	2.02	0.91	82
Surface water	16.9	20.4	19.5	22.3	24.3	7.40	44
Total water	18.0	21.8	21.0	24.1	26.3	8.3	46
	Population, in thousands						
Study area population[a]	138.33	142.80	147.10	166.94	181.87		32

[a] Excludes population for southern Williamson County

Estimated Water Demand

Water demand was estimated using the IWR-MAIN Water Demand Management Suite software. The Forecast Manager module of the IWR-MAIN software provides accounting and analytical tools for estimating municipal demand. The user's manual and suite description provide additional details for much of the discussion presented in this section of this report (Planning and Management Consultants, Ltd., 1999). The water-use forecasting algorithm of Forecast Manager is built to operate on data corresponding to a study area or subarea (such as a WSA or a water-supply system), water-use sectors and subsectors, months, and forecast years. Forecasts were devised for the residential (combined single- and multifamily subsectors) and nonresidential (combined or separate commercial and industrial subsectors) sectors and for public use and losses.

Several assumptions about the character of the data and about the structure of climatological, demographic, and socioeconomic conditions in future years were necessary to estimate water demand through 2030. The model assumed that the Duck River would supply all future surface-water needs within the study area, that available ground-water resources would meet the demands of the ground-water-based water-supply systems, and that the sale of supplemental surface water to ground-water-based water-supply systems in 2000 would remain constant through 2030. Other assumptions are detailed within each of the respective sections in this report.

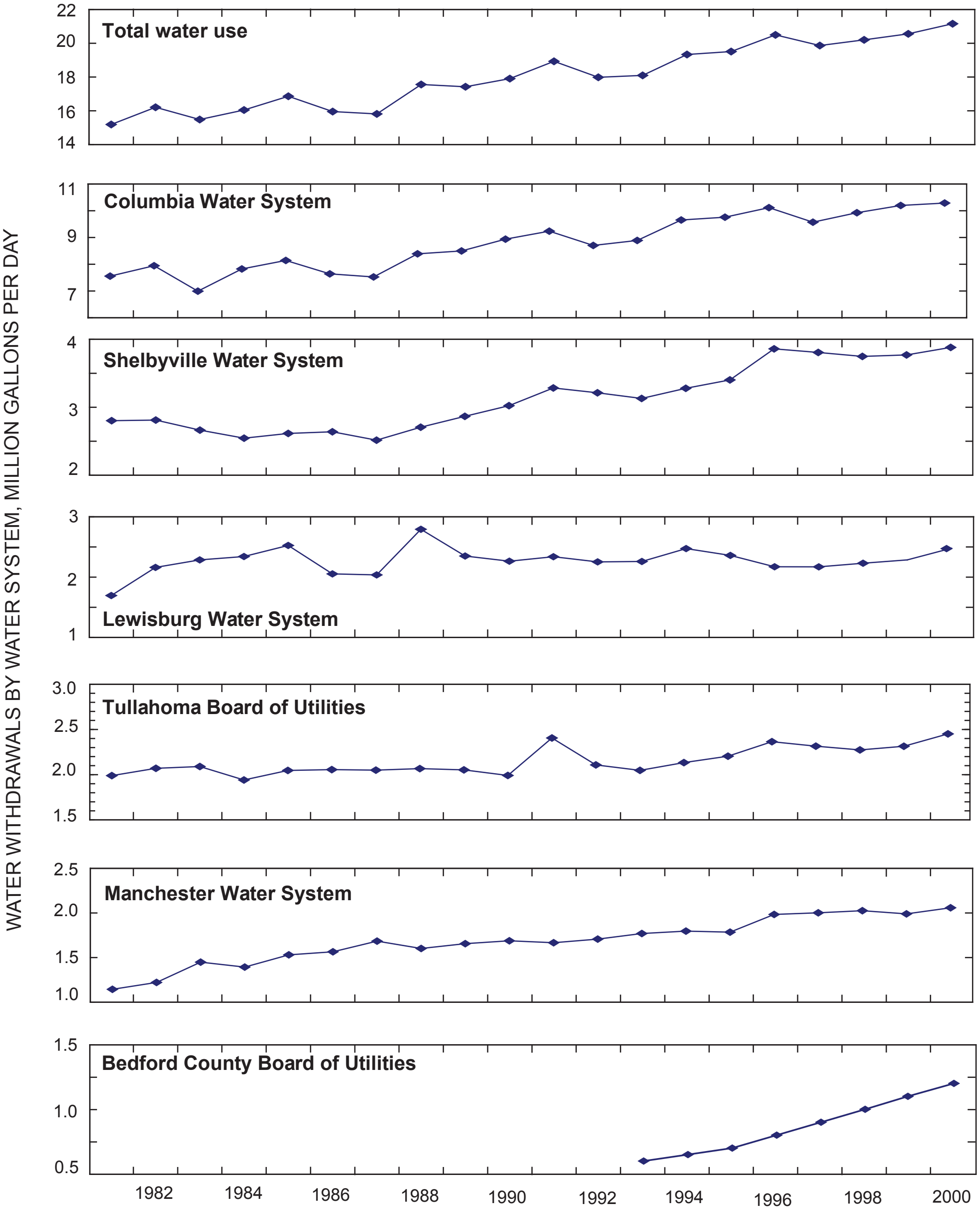


Figure 3. Historic water withdrawals for Columbia Water System, Shelbyville Water System, Lewisburg Water System, Tullahoma Board of Utilities, Manchester Water System, and Bedford County Board of Utilities, Tennessee, 1981–2000.

Modeling Scenarios

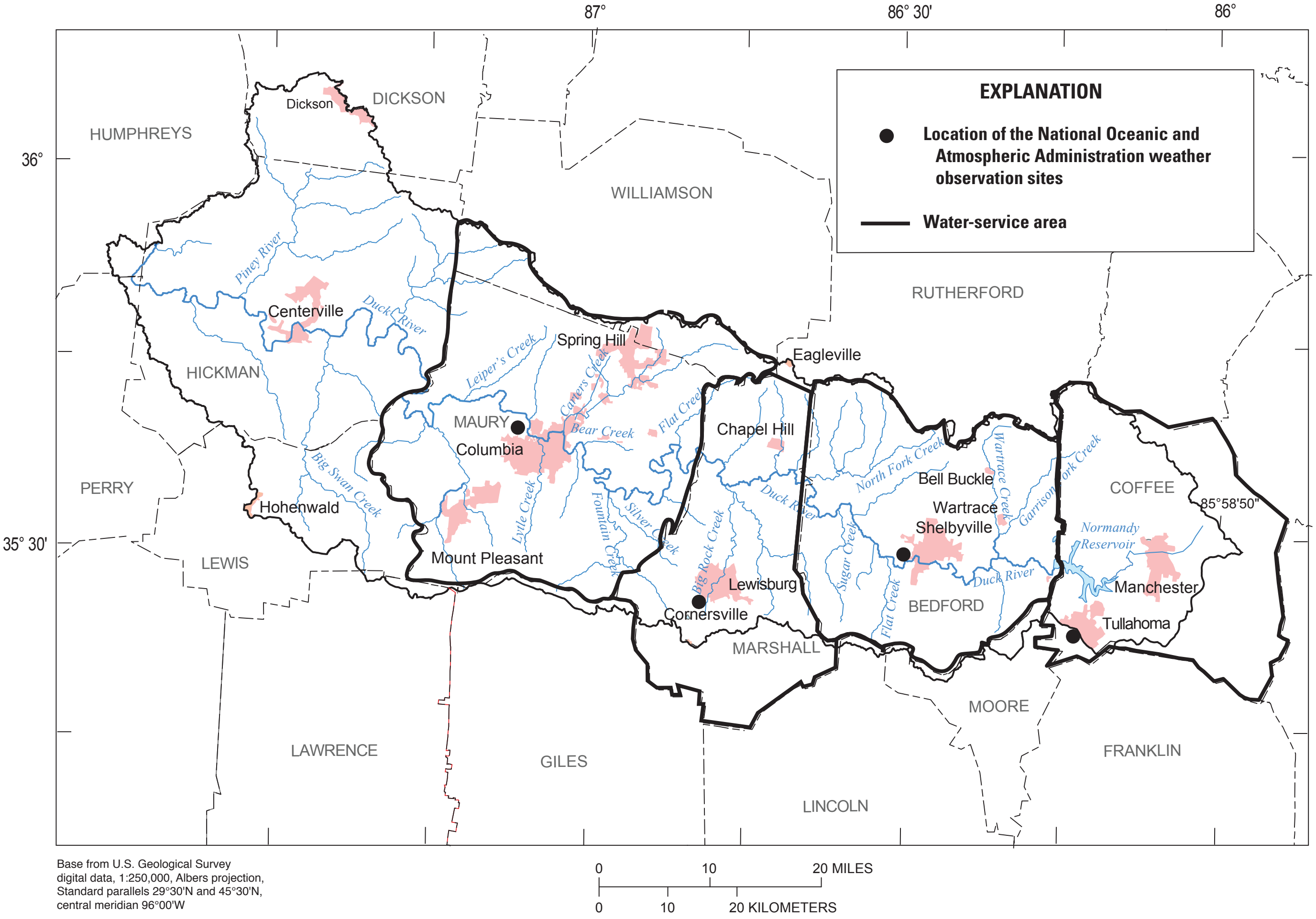
Water use is the expression of the cumulative effect of several factors on customer decision-making. A minimum amount of water is required each day (water requirement) to meet basic household needs for drinking water, food preparation, washing clothes and dishes, and sanitary purposes (U.S. Army Corps of Engineers, 1988). Likewise, commercial and industrial facilities have basic process and technological water requirements. The behavior of water users also responds to changes in the price of water, income, water conservation initiatives, and such physical factors as increases in temperature and decreases in precipitation (Sellers and North, 1990; U.S. Army Corps of Engineers, 1988). Several studies describe how water-demand patterns, like weather patterns, are cyclic, usually with greater **outdoor water use** occurring during the summer season and that the duration of extremes (hot-dry or wet-cold) can amplify the seasonal change in water demand (Linaweaver, 1965; Maidment and others, 1985; Dietemann, 1998; Vickers, 2001; Dziegielewski and others, 2004; and Kiefer, 2006).

To represent the variability in water use across the study area, two base years were selected to cover the range of water-use values experienced over past years. Recent years were selected because they already encompass the results of past trends, and would, therefore, provide more accurate values. The years 2000 and 2003 were found to be representative of drought and typical **weather** conditions and, therefore, were selected to represent base-year conditions for the modeling scenarios. The year 2000 was warmer and drier than **normal climatological conditions** for the period 1971 to 2000. The **mean monthly maximum temperature** (MMMT) was 9.57 °F above normal, and the **departure from normal precipitation** (DP) was 6.39 inches below normal at the Columbia site (fig. 4 and table 3). At the Tullahoma site, the MMMT was 7.49 °F above normal, and DP was 1.93 inches below normal. Year 2003 was cooler and wetter than normal. The MMMT was 3.14 °F below normal and DP was 5.81 inches above normal at the Columbia site; MMMT was 3.48 °F below normal and DP was 12.3 inches above normal at the Tullahoma site.

The most pronounced rainfall deficit in the watershed occurred from 1985 to 1988 (Blaise L. Merchlewitz, National Forecast Office, Memphis, Tennessee, written commun., April 2004). Cumulatively, DP was –52.8 inches for the Columbia site and –50.8 inches for the Tullahoma site for this period. For comparison to 2000 and 2003, in 1988, DP deviated –14.6 inches at the Columbia site (table 3) and per capita use averaged 193 gallons per person per day (James Clark, General Manager, Columbia Water System, written commun., April 2004).

Scenario 1 (base year 2003) incorporates the trend in recent growth (1999 to 2003) in customer accounts and reflects typical weather conditions with relatively low per household water use. Scenario 2 (base year 2000) considers drier and warmer weather (drought) conditions with relatively high per household water use and either incorporates the recent growth in customer accounts or, for some water-supply systems, an increasing rate of growth. The range of values for household use varies monthly and annually according to the water-use patterns characteristic of each of the modeled public-supply systems.

Municipal water demand in the upper Duck River watershed study area was estimated through 2030 for residential, nonresidential, and public use and losses for two scenarios for each of the 14 water-supply systems that depend on water from the upper Duck River (table 4). The years 2010 and 2020



Base from U.S. Geological Survey digital data, 1:250,000, Albers projection, Standard parallels 29°30'N and 45°30'N, central meridian 96°00'W

Figure 4. Location of the four National Oceanic and Atmospheric Administration cooperative weather observation sites in the upper Duck River watershed.

Table 3. Normal climatological conditions (based on climatological records from National Oceanic and Atmospheric Administration [NOAA] from 1971 to 2000) and mean monthly maximum air temperature and monthly rainfall for 1988, 2000, and 2003 for Columbia and Tullahoma NOAA cooperative weather-observation sites.

[Above normal mean maximum air temperature and below normal rainfall values are in bold text. Air temperature is in Fahrenheit degrees, precipitation is in inches; Jan, January; Feb, February; Mar, March; Apr, April; Aug, August; Sept, September; Oct, October; Nov, November; Dec, December]

Month	Normal		1988		2000		2003	
	Maximum air temperature	Precipitation	Mean maximum air temperature	Departure from normal precipitation	Mean maximum air temperature	Departure from normal precipitation	Mean maximum air temperature	Departure from normal precipitation
			Columbia NOAA cooperative weather-observation site					
Jan	46.1	4.66	42.6	**–0.13**	**48.2**	**–1.23**	42.0	**–3.04**
Feb	51.4	4.35	50.1	**–1.55**	**57.4**	.80	46.9	6.39
Mar	60.3	6.25	**60.8**	**–3.93**	**65.5**	**–.99**	**62.0**	**–3.75**
Apr	69.4	4.85	**71.4**	**–.20**	66.6	1.66	**72.7**	.05
May	77.1	5.57	**79.4**	**–4.06**	**79.3**	**–.79**	76.7	3.97
June	84.8	4.14	**90.5**	**–3.48**	**85.2**	**–.38**	82.6	1.43
July	88.5	5.03	**89.1**	.25	**89.0**	**–1.83**	87.3	1.40
Aug	88.1	3.48	**92.1**	**–1.04**	**89.5**	**–1.18**	**89.0**	**–.03**
Sept	81.8	3.94	81.2	1.26	**84.0**	**–.40**	81.7	2.79
Oct	71.5	3.55	66.0	**–2.16**	**75.8**	**–3.45**	71.3	**–2.05**
Nov	60.1	4.85	**63.4**	1.30	58.4	1.90	**64.1**	1.04
Dec	50.1	5.46	**51.4**	**–.83**	40.3	**–.50**	49.6	**–2.39**
Departure from normal			8.86	–14.6	9.57	–6.39	–3.14	5.81
			Tullahoma NOAA cooperative weather-observation site					
Jan	46.2	5.51	43.7	–0.28	**47.7**	**–0.92**	41.8	**–2.90**
Feb	50.9	4.86	50.9	–1.35	**58.4**	**–1.27**	48.3	5.72
Mar	60.0	6.73	**62.2**	–4.01	**64.8**	.21	**62.5**	**–3.06**
Apr	69.0	4.94	**70.6**	.62	66.3	3.89	**70.7**	.50
May	76.2	5.28	**79.1**	–4.23	**79.4**	**–.55**	75.2	7.99
June	83.9	4.74	**89.2**	–3.71	**83.9**	2.31	80.9	1.69
July	87.1	4.8	**89.0**	–.30	**88.2**	**–2.53**	84.9	3.29
Aug	86.6	3.52	**90.3**	–1.36	**88.2**	**–1.57**	**87.2**	**1.14**
Sept	80.8	4.33	80.2	1.01	79.1	.8	80.2	1.32
Oct	70.8	3.89	67.1	–1.3	**74.6**	**–3.39**	**71.2**	**–2.37**
Nov	59.3	5.47	**62.7**	3.64	56.6	.63	**65.1**	.48
Dec	49.8	5.97	**52.9**	–.057	40.6	.46	49.1	**–1.48**
Departure from normal			17.4	–11.8	7.49	–1.93	–3.48	12.3

Table 4. Water-supply systems and sources of supply in the upper Duck River watershed, 2000 and 2003.

[Water-demand projections were determined for the water-supply systems indicated in bold type. West Warren–Viola distributes water to customers in Coffee County, but withdraws water from the Barren Fork River. Mgal/d, million gallons per day; WSA, water-service area; —, no transaction; do., ditto; WS, Water System; BU, Board of Utilities; gw, ground water; CUD, County Utility District; UC, Utility Commission; WD, Water Department; MHP, Mobile Home Park; MCBPU, Marshall County Board of Public Utilities; MCWS, Maury County Water System; UD, Utility District; 0.000, line connection but no transaction]

Water-supply system	Source of supply	2000		2003	
		Withdrawals	Purchased water	Withdrawals	Purchased water
		Million gallons per day			
Bedford WSA					
Shelbyville Water System	Duck River	4.44	—	4.45	—
Bedford County Utility District	Duck River	1.30	—	1.41	—
do.	Shelbyville WS	—	0.000	—	0.001
do.	Tullahoma BU	—	.052	—	.001
Wartrace Water System	Cascade Spring (gw)	.830	—	.812	—
Bell Buckle Water System	Bedford CUD	—	.031	—	.035
do.	Wartrace WS	—	.112	—	.172
Flat Creek Cooperative	Shelbyville WS	—	.163	—	.162
do.	Tullahoma BU	—	.001	—	.002
Jarrell Mobile Home Park	well	.004	—	.004	—
Coffee WSA					
Manchester Water Department	Duck River UC	—	2.41	—	2.22
Tullahoma Board of Utilities	Duck River UC	—	2.76	—	2.81
Duck River Utility Commission	Duck River	5.20	—	5.04	—
Hillsville Utility District	Manchester WD	—	.596	—	.549
Stacy Anne's MHP	well	.009	—	.020	—
West Warren–Viola Utility District	Barren Fork River	1.27	—	1.54	—
Marshall WSA					
Chapel Hill Water System	MCBPU		0.017	—	0.003
do.	Town Well	0.152	—	0.154	—
Marshall County BPU	Lewisburg WS	—	.496	—	.526
do.	Cornersville WD	—	.016	—	.012
do.	Chapel Hill WS	—	.058	—	.051
Cornersville Water Department	Lewisburg WS	—	.121	—	.164
Petersburg Water System	Fayetteville WS	—	.065	—	.061
Lewisburg Water System	Duck River	2.76	—	2.80	—
Maury-southern Williamson WSA					
Columbia Water Department	Duck River	10.6	—	9.57	—
Mount Pleasant Water System	Springs	1.03	—	1.01	—
do.	Columbia WS	.000	—	—	0.03
Spring Hill Water Department	Duck River	—	—	.48	—
do.	Columbia WS	—	1.30	—	.96
do.	MCWS	—	.000	—	.08
Maury County Water System	Columbia WS	—	1.05	—	1.07
do.	Spring Hill WD	—	—	—	.102
HB & TS Utility District	Spring Hill WD	—	.406	—	.137
do.	Harpeth Valley UD	—	.913	—	1.24

are intermediate modeling intervals that capture short-term changes in the rate of growth for some water-supply systems. Projected water demand for a WSA is the sum of the municipal water demand for the individual systems. The projected water demand for the study area is the sum of the municipal water demand for the Bedford, Coffee, Marshall, and Maury-southern Williamson WSAs.

Water-Use Projections

Water-use projections for the upper Duck River watershed study area were determined using a constant-rate method based on the average monthly water use per account and the estimated number of accounts per water-supply system projected through 2030. The base-year (2000 or 2003) rate of use per account (q in equation 1) was determined from base-year monthly water use and the number of monthly residential accounts. The quantity of water use in the sector, month, and forecast year was calculated as follows and is expressed in million gallons per day for this study:

$$Q_{s,m,y} = N_{s,m,y} \times q_{s,m,b} \times d_{m}, \qquad (1)$$

where,

Q is gallons of water used in sector (s) in month (m) in year (y),

N is the number of accounts in sector (s) in month (m) in year (y),

q is the average daily water-use rate per account in sector (s) in month (m) in base year (b), and

d is the number of days in month (m).

For each residential modeling scenario, the water use per residential account for 2000 and for 2003 remained constant for all of the forecast years. The change in number of residential accounts (N in equation 1) explains the change in forecast from year to year. The rate of change in residential accounts rather than in county or WSA population or in population served by water-supply systems was used as the factor determining N in equation 1 (U.S. Army Corps of Engineers, 1988). In addition to accounting for population growth, the number of residential records also included new connections to water lines by residences previously supplied by individual wells or springs. The recent rate of increase in the customer accounts in each of the WSAs has been greater than the rate of increase in county population projected by the University of Tennessee, Center for Business and Economic Research (Tennessee Advisory Commission on Intergovernmental Relations and The University of Tennessee, 2003). Local officials, local and regional development agencies, and water-supply system managers also provided guidance in developing residential and nonresidential rates of growth for estimating N for the model for 2010, 2020, and 2030.

For nonresidential water-use projections, future changes in water use per account in the commercial and industrial subsectors could not be determined. Therefore, water use per account for 2000 and for 2003 remained constant for the forecast years for each subsector. The projected change in the number of commercial or industrial accounts (N in equation 1) determines the change in the water-use forecast from year to year. The number of commercial accounts for the nonresidential model in future years was determined by applying recent or expected future rates of growth to the baseline year accounts. The number of industrial accounts was estimated differently. Baseline conditions for industrial accounts generally were kept constant through 2030 except for the addition of water needed for newly built or planned industrial parks—likely locations of new industry in the study area—in the Coffee and Marshall WSAs.

Public use and losses were estimated as a percentage of the total municipal use for each water-supply system. For the base year of 2000 or 2003, the percentage varied among systems and often reflected different operational, maintenance, and community needs. The base-year percentages were used in each of the forecast years for each of the systems. Across the 14 water-supply systems, percentages of public use and losses ranged from about 8 to 39 percent.

Data Preparation/Model Input

Residential, commercial, and industrial billing account data and percentages of public use and losses were prepared as input to the water-use models contained in IWR-MAIN for 2010, 2020, and 2030 for the water-supply systems that depend on the upper Duck River. Water-supply systems that withdrew ground water were not modeled. Base-year data were prepared for 2000 (drought year) and 2003 (typical year) to calibrate two water-demand scenarios.

For this study, **monthly summary billing account records** were used to determine per account water use, in gallons per account per month (converted by the IWR-MAIN software to gallons per account per day). Although the level of detail of billing varied among the water-supply systems—primarily related to size of water-supply system and the choice of financial accounting system format—water use generally could be characterized for the water-supply systems as inside the city or outside the city for the residential, commercial, and industrial customer classes. The terms *urban* and *rural* are used in this report to simplify the terminology. Urban refers to the area inside the corporate boundaries of a city, and rural refers to the areas outside the corporate boundaries and may include subdivisions and farms. Estimates of water use per account are based on metered data and are considered reliable. Although length of billing cycle per account generally varies from month to month, the total number of billed days over the year for each account approximated 1 year and is not considered problematic. For data analysis and modeling purposes, sales to a water-supply system were assigned to the water-supply system purchasing the water and were modeled separately.

A smaller subset of customer billing record data was selected for analysis for this study partly because the data for each water-supply system are extensive and sometimes difficult to access. Historical data most often were maintained as paper files—often archived, sometimes not readily available, and sometimes not available at all. At a minimum, readily available monthly data were collected for each system for 1999 through 2003 (the period of increasing residential and commercial growth in the study area). More complete records were analyzed for the Columbia Water System (billing records from 1980 to 2003) and the Duck River Utility Commission (water-withdrawal records, August 1981 to 2003). For some water-supply systems, only annual summary data were readily available and, therefore, were used to calibrate the models for those systems.

Some general characteristics of sector water use were examined from customer accounts for 2000 to 2003 using Columbia Water System, Lewisburg Water System, Shelbyville Water System, and Tullahoma Utility Board data (table 5). These four water-supply systems serve both urban and rural residential, commercial, and industrial customers and are representative of the other water-supply systems in the study area. As indicated in table 5, most of the residential accounts are

Table 5. Average per account use for selected water-supply systems in the upper Duck River watershed study area and billing account sectors for 2000 and 2003.

[gal/d, gallons per day; Mgal/d, million gallons per day]

Columbia Water System								
	Residential				Commercial		Industrial	
	Urban		Rural		Urban	Rural	2000	2003
	2000	2003	2000	2003	2000	2003		
Per account use, in gal/d	180	165	227	209	861[a]	812[a]	66,692[a]	61,684[a]
Accounts	11,182	11,548	4,430	4,722	2,027[a]	2,105[a]	28[a]	25[a]
Sector use, in Mgal/d	2.01	1.91	1.00	.99	1.75	1.71	1.87	1.54

Lewisburg Water System						
	Residential				Commercial	
	Urban		Rural		2000	2003
	2000	2003	2000	2003		
Per account use, in gal/d	140	132	193	182	1,161[b]	817[b]
Accounts	3,595	3,603	957	984	634[b]	641[b]
Sector use, in Mgal/d	.503	.475	.185	.179	.736	.524

Shelbyville Water System								
	Residential				Commercial		Industrial	
	Urban		Rural		2000	2003	2000	2003
	2000	2003	2000	2003				
Per account use, in gal/d	141	139	195	173	585[a]	571[a]	29,479[a]	31,095[a]
Accounts	6,114	6,346	396	421	884[a]	939[a]	49[a]	49[a]
Sector use, in Mgal/d	.862	.882	.077	.073	.517	.536	1.45	1.52

Tullahoma Utility Board								
	Residential				Commercial			
	Urban		Rural		Urban		Rural	
	2000	2003	2000	2003	2000	2003	2000	2003
Per account use, in gal/d	161	154	170	167	759[b]	767[b]	588[b]	666[b]
Accounts	6,684	6,891	881	1,025	950[b]	997[b]	48[b]	50[b]
Sector use, in Mgal/d	1.08	1.06	.150	.171	.721	.765	.028	.033

[a] Urban and rural accounts are combined

[b] Commercial and industrial facilities are classified as commercial

urban, and these households consistently use less water than rural households. For 2003, the percentage of urban residential customers for the four water-supply systems ranged from 71 to 94 percent, and water use ranged from 132 to 165 gallons per household per day. Rural water use for 2003 ranged from 167 to 209 gallons per household per day. For modeling purposes, the percentage of urban households relative to rural households was held constant for the forecast years.

Average annual combined urban and rural household use was different for each water-supply system but consistently greater in 2000 than in 2003 (table 6). Further, a distinct summer season is evident from the monthly water-use data. For example, for the Columbia Water System, household use was above average in June, July, August, and September (peak month). For 2000 (drought conditions), September household usage was 1.26 times greater than the average use for the year; for 2003 (typical weather conditions), September household usage was 1.11 times greater than the average usage. Outdoor usage usually accounts for nearly all the seasonal difference in water use (U.S. Army Corps of Engineers, 1988). This ratio between peak month and average annual use varied only slightly among the water-supply systems for 2000 and 2003. On average, less water is used in March than in the other months for both years, suggesting that March likely represents typical indoor household usage.

Monthly nonresidential use indicated a seasonal pattern similar to residential use. Per account use was above average during the summer season. For the Columbia Water System, combined commercial and industrial use was above average in June, July, August, and September (peak month). For 2000, September nonresidential usage was 1.28 times greater than the average nonresidential use for the year; for 2003, September usage was 1.23 times greater than the average use. Summer seasonal usage may be attributed to water cooling of on-site air conditioning systems and landscape irrigation. Year-to-year variation of nonresidential use, however, is more difficult to assess as water requirements linked to manufacturing processes or manufacturing output may change. Although increased water recycling and reuse were not considered in this study, these activities can significantly reduce water use (Vickers, 2001).

Most of the rapid growth in customer accounts in the watershed from 1999 to 2003 occurred in the residential and commercial sectors. This growth trend is the basis for the estimates of the number of future customer accounts by water-supply systems for scenario 1. For scenario 2, any increase in the number of accounts from the expected trend was considered in consultation with municipal officials, local and regional planning groups, and water-supply managers. The number of industrial accounts or associated water use had either stabilized or declined from 1999 to 2003. For the two scenarios, industrial water use was held constant throughout the modeling years except for the addition of newly built or planned industrial parks. The model input reflects the decision that the industrial parks would be operational by 2020, and the capacity of the pipelines to the industrial parks would be fully utilized. Changes in the assumed patterns of industrial growth in the study area could affect the projected industrial water demand.

Projected Water Demand

Municipal water demand for 2010, 2020, and 2030 for the upper Duck River watershed study area was estimated using the constant-rate models contained in the IWR-MAIN Water Demand Management Suite software. The number of accounts and the associated water use for each water-supply system for 2000 and 2003 were input to the Forecast-Management system to estimate water demand for the residential and nonresidential sectors. Public use and losses were modeled as a percentage of the total water-supply system demand. Results were aggregated to the WSA and then to the study area (table 7). Although 2003 data are used as base-year data for scenario 1,

Table 6. Average modeled household use for selected water-supply systems in the upper Duck River watershed study area for 2000 and 2003.

[Values expressed in gallons per household per day; above annual average household water-use values for year are in bold text; greatest average household water-use values for year are underlined; Jan, January; Feb, February; Mar, March; Apr, April; Aug, August; Sept, September; Oct, October; Nov, November; Dec, December; WS, Water System; UB, Utility Board]

Water system	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual average
Warmer and drier than normal climatological conditions (2000)													
Columbia WS	182	187	164	177	176	**200**	**230**	**215**	**245**	184	183	179	194
Lewisburg WS	141	151	139	135	142	**172**	**153**	**177**	**178**	146	148	133	151
Shelbyville WS	152	151	142	150	144	**170**	**176**	**169**	**182**	142	156	141	156
Tullahoma UB	150	159	144	153	**166**	**173**	**176**	**178**	**177**	**171**	160	152	163
Typical of normal climatological conditions (2003)													
Columbia WS	177	190	154	162	176	**188**	**176**	**194**	**197**	175	179	168	178
Lewisburg WS	143	167	119	137	142	**148**	**153**	**145**	**156**	**144**	133	131	143
Shelbyville WS	147	157	115	141	**145**	**141**	**163**	**147**	**152**	139	138	133	143
Tullahoma UB	158	168	136	143	153	**162**	**168**	**169**	**170**	149	152	152	156

Table 7. Simulated water demand for the upper Duck River watershed study area for the Bedford, Coffee, Marshall, and Maury-southern Williamson water-service areas for 2000, 2010, 2020, and 2030.

[Scenario 1, typical climatological conditions and an expected rate of growth in customer accounts; scenario 2, drought conditions and either an expected rate of growth or an increasing rate of growth in customer accounts. Figures are expressed as two significant figures. Totals may not add to sums because of independent rounding. Percentages are based on the numbers presented in the table. WSA, water-service area]

Sector	Water use, in million gallons per day (Mgal/d)				Change in water use from 2000 to 2030, in Mgal/d	Change in water use from 2000 to 2030, in percent
	2000	2010	2020	2030		
Bedford WSA scenario 1						
Residential	1.9	2.4	3.2	4.2	2.3	121
Nonresidential	2.1	2.4	2.6	2.8	.7	33
Public use/losses	1.7	1.9	2.4	2.9	1.2	71
Total	5.7	6.7	8.1	9.9	4.2	74
Bedford WSA scenario 2						
Residential	1.9	2.5	3.3	4.5	2.6	137
Nonresidential	2.1	2.4	2.6	2.9	.8	38
Public use/losses	1.7	2.1	2.4	3.0	1.3	76
Total	5.7	6.9	8.4	10	4.3	75
Coffee WSA scenario 1						
Residential	2.3	2.8	3.8	5.1	2.8	122
Nonresidential	1.4	1.8	6.9	7.7	6.3	450
Public use/losses	1.3	1.5	2.0	2.7	1.4	108
Total	5.0	6.1	13	16	11	220
Coffee WSA scenario 2						
Residential	2.3	2.9	3.9	5.3	3.0	130
Nonresidential	1.4	1.8	6.9	7.7	6.3	450
Public use/losses	1.3	1.6	2.2	2.9	1.6	123
Total	5.0	6.3	13	16	11	220
Marshall WSA scenario 1						
Residential	1.2	1.3	1.7	2.0	0.8	67
Nonresidential	.8	.6	1.2	1.3	.5	62
Public use/losses	1.1	1.1	1.3	1.5	.4	36
Total	3.0	3.0	4.2	4.8	1.8	60
Marshall WSA scenario 2						
Residential	1.2	1.5	1.9	2.5	1.3	108
Nonresidential	.8	.9	1.5	1.7	.9	112
Public use/losses	1.1	1.3	1.5	1.9	.8	73
Total	3.0	3.6	4.9	6.1	3.1	103
Maury-southern Williamson WSA scenario 1						
Residential	5.1	7.2	10	12	6.9	135
Nonresidential	3.8	3.7	4.3	4.8	1.0	26
Public use/losses	2.0	2.3	2.9	3.5	1.5	75
Total	11	13	17	21	10	91
Maury-southern Williamson WSA scenario 2						
Residential	5.1	7.5	10	13	7.9	155
Nonresidential	3.8	4.2	4.7	5.3	1.5	39
Public use/losses	2.0	2.5	3.1	3.8	1.8	90
Total	11	14	18	22	11	100
Upper Duck River watershed study area scenario 1						
Residential	10	14	19	24	14	140
Nonresidential	8.1	8.5	15	17	8.9	110
Public use/losses	6.0	7.3	8.5	11	5.0	83
Total	25	30	42	51	26	104
Upper Duck River watershed study area scenario 2						
Residential	10	14	19	26	16	160
Nonresidential	8.1	9.2	16	18	9.9	122
Public use/losses	6.0	7.4	9.2	12	6.0	100
Total	25	31	44	55	30	120

the measure of change in water use for scenario 1 is the same as for scenario 2, from 2000 through 2030 (table 7). Projected estimates of water demand for scenario 1 indicate that

- average total municipal water use could increase about 104 percent to 51 Mgal/d by 2030,
- residential water use could increase about 140 percent to 24 Mgal/d,
- nonresidential water use could increase about 110 percent to 17 Mgal/d, and
- public use and losses could increase about 83 percent to 11 Mgal/d.

Projected estimates for scenario 2 indicate that

- average total municipal water use could increase about 120 percent to 55 Mgal/d,
- residential water use could increase about 160 percent to 26 Mgal/d,
- nonresidential water use could increase about 122 percent to 18 Mgal/d, and
- public use and losses could increase 100 percent to 12 Mgal/d.

The water demand forecast outlined in this study can be considered as the most likely of scenarios; however, projections are not absolute. Inconsistencies in the billing account data for the different water-supply systems of different age and design with different mixtures of customer requirements over the same period of time affect the water-demand projections (Kindler and Russell, 1984). The degree of uncertainty increases, as with any model, as the length of time of the projections increases. Projecting water demand through 2030 assumes that many political, environmental, economic, and technical factors will be relatively constant. If the assumptions are changed—fewer or more industrial parks are developed in the study area or a shift to more or less ground water occurs—the water demand will likely change. The water-demand models developed for this study are designed primarily to examine the effects that various assumptions could have on water use rather than as predictive tools to generate absolute values of future water use. The validity of the results of the modeling effort depends on the reliability of the assumptions.

Summary

Water-demand projections through 2030 were developed by the U.S. Geological Survey in cooperation with the Tennessee Duck River Agency during 2004 under the planning process to update water-demand projections once every 5 years as proposed by the Duck River Technical Advisory Committee and the Duck River Water Resources Council and formalized in the Duck River Watershed Comprehensive Water Resources Plan: Part 1 Water Supply Plan—2003. The water-use inventory, which establishes baseline conditions for estimating water demand, indicated that total water withdrawals for the Bedford, Coffee, Marshall, and Maury-southern Williamson water-service areas were 28.6 million gallons per day (Mgal/d) for municipal supply, self-supplied industry, and self-supplied irrigation use during 2000. Water withdrawals from the upper Duck River provided about 92 percent of the total supply; the remaining 2.26 Mgal/d came from springs and wells. About 92 percent or 26.3 Mgal/d of the total withdrawals were for municipal supply. Industrial withdrawals from surface water were 1.44 Mgal/d. Irrigation withdrawals (0.85 Mgal/d) were chiefly from surface water and primarily used for golf courses. The Maury-southern Williamson water-service area accounted for 47 percent of the total withdrawals, 47 percent of the surface-water withdrawals, and 49 percent of the ground-water withdrawals.

Public-supply withdrawals increased 46 percent (from 18.0 to 26.3 Mgal/d) from 1981 to 2000. During the same period, industrial withdrawals decreased from 40.2 to 1.48 Mgal/d. The Columbia Water System increased water withdrawals the most during this period, 3.07 Mgal/d; by percentage, the Bedford County Utility District increased the most, 100 percent from 1993 to 2000 (from 0.60 Mgal/d to 1.20 Mgal/d).

Future water demand was estimated using the Institute of Water Resources–Municipal and Industrial Needs Water Demand Management Suite software. Modeling scenarios were prepared for each water-supply system addressing the short-term variability of weather conditions and the long-term effect of water-supply system expansion. Scenario 1 considered monthly water demand under typical weather conditions as represented by monthly per account use for 2003 and an expected rate of growth in customer accounts. For the upper Duck River watershed study area, total municipal water use could increase about 104 percent to 51 Mgal/d by 2030. Residential water use could increase about 140 percent to 24 Mgal/d, nonresidential water use could increase about 110 percent to 17 Mgal/d, and public use and losses could increase about 83 percent to 11 Mgal/d.

Scenario 2 considered monthly water demand under drought conditions as represented by monthly per account use during 2000 and combined either the expected rate of growth in customer accounts or, for some water-supply systems, a more rapid than expected rate of growth. Simulated water demand indicates that total municipal water use could increase about 120 percent to 55 Mgal/d. Residential water use could increase about 160 percent to 26 Mgal/d, nonresidential water use could increase about 122 percent to 18 Mgal/d, and public use and losses could increase 100 percent to 12 Mgal/d.

For both scenarios, the model assumed that the Duck River would supply all future surface-water needs within the study area, that available ground-water resources would meet the demands of the ground-water-based water-supply systems, and that the sale of supplemental surface-water to ground-water-based water-supply systems in 2000 would remain constant through 2030.

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Glossary

departure from normal precipitation Normal precipitation minus observed precipitation.

mean monthly maximum temperature The average of the daily maximum air temperatures for 1 month.

monthly summary billing account records Total amount of water billed for all customers in a customer class for a billing cycle. Generally, a billing cycle is approximately 1 month for the water-supply systems in the study area. The number of days can vary per customer from month to month because of the number of days in the month, the meter reading schedule, or weather.

municipal water Public-supply water delivered to residential, commercial, and industrial customers and includes public use and losses. *See also* public use and losses.

normal climatological conditions A climate normal is defined as the arithmetic mean of a climatological element computed over 30 consecutive years. Since records are frequently characterized by data inhomogeneities, statistical methods have been developed to identify and account for them. In application of these methods, adjustments are made so that earlier periods in the data record more closely conform to the most recent period. Additionally, methods have been developed to estimate values for missing observations. After such adjustments are made, the climate record is said to be homogeneous and serially complete. This adjusted record is said to be characterized by variations in trends in weather and climate. By using appropriately adjusted data records, the 30-year mean value will more closely reflect the average climatic conditions at a given station with respect to the instrumentation and siting conditions at the end of normal periods (National Climatic Data Center, March 2002).

outdoor water use Water used for lawn, landscape, or garden watering, car washing, maintenance, or other similar activities.

persons per household A measure obtained by dividing the number of people living in owner-occupied units by the total number of owner-occupied housing units (U.S. Census Bureau, 2002).

public use and losses Municipal water other than residential, commercial, or industrial sales that includes such uses as firefighting, pipeline flushing, operational and maintenance needs, conveyance losses and apparent losses caused by cumulative meter misregistration.

water use The terms water use, water demand, and water requirement are commonly interchanged. Technically, the terms are distinct. In a restrictive sense, water use refers to water that is actually used for a specific purpose such as for residential use or industrial processing. More broadly, water use pertains to human interaction with and influence on the hydrologic cycle, and includes elements such as water withdrawal, delivery, consumptive use, wastewater release, reclaimed wastewater, return flow, and instream use. Water demand is the relation between water use and price when all other factors are held constant; however, for this study, the relation is between water use and climate with all other factors being held constant. Water requirement is water use as an absolute requirement unaffected by economic or climatic factors.

weather The condition of atmospheric elements such as temperature and precipitation at a given time and for a specific area. Many observations of the weather of a place over a period of years provide us with a description of climate. Climate describes an area’s average weather, but it also includes those common deviations from the norm or average that are likely to occur, as well as extreme conditions, such as drought. (Gabler and others, 1990). Weather is not the same as climate.

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