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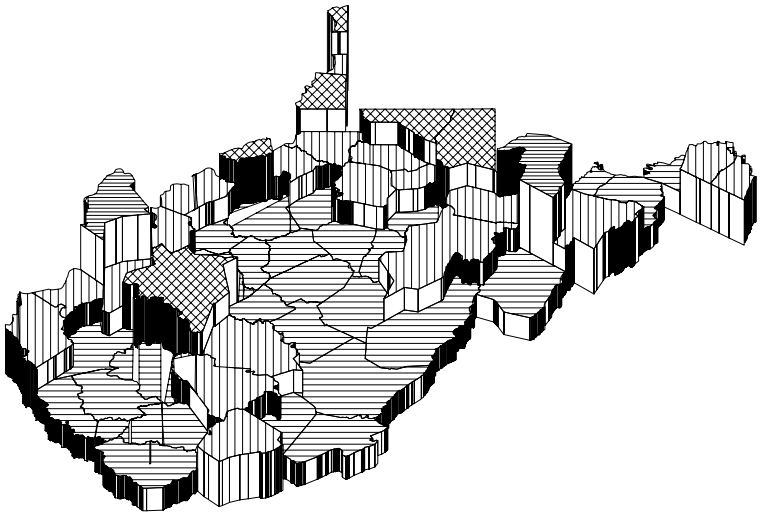
**In cooperation with West Virginia Department of Environmental Protection, Division of Water and Waste Management**

# Water-Use Estimates for West Virginia, 2004



Open-File Report 2007–1038

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

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By John T. Atkins, Jr.

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

**U.S. Department of the Interior**
DIRK KEMPTHORNE, Secretary

**U.S. Geological Survey**
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

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# Contents



# Figures



# Tables

# Conversion Factors

## Inch/Pound to SI

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeter (mm) |
| acre | 0.4047 | hectare (ha) |
| acre | 0.004047 | square kilometer ($km^2$) |
| square mile ($mi^2$) | 259.0 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| gallon (gal) | 3.785 | liter (L) |
| gallon (gal) | 0.003785 | cubic meter ($m^3$) |
| million gallons (Mgal) | 3,785 | cubic meter ($m^3$) |
| acre-foot (acre-ft) | 1,233 | cubic meter ($m^3$) |
| acre-foot per year (acre-ft/yr) | 1,233 | cubic meter per year ($m^3$/yr) |
| 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 acre [(gal/d)/acre] | 1.069 | 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) |
| inch per year (in./yr) | 25.4 | millimeter per year (mm/yr) |
| kilowatthour (kWh) | 3,600,000 | joule (J) |
| gigawatthour (gWh) | 3,600,000,000,000 | joule (J) |

# Water-Use Estimates for West Virginia, 2004

By John T. Atkins, Jr.

## Abstract

This study estimates the quantity of surface water and ground water used within West Virginia. About 4,787 million gallons per day (Mgal/d) of water were withdrawn from West Virginia surface-water and ground-water sources in 2004, with about 4,641 Mgal/d (97 percent) from surface-water sources and about 146 Mgal/d (3 percent) from ground water sources. The largest surface-water withdrawals were in Grant and Mason Counties and were about 1,156 and 1,090 Mgal/d, respectively. The largest ground-water withdrawals were in Berkeley and Wood Counties and were about 12.0 and 12.8 Mgal/d, respectively.

Estimates were determined for surface-water and ground-water withdrawals in seven water-use categories: public supply, domestic, thermoelectric power, industrial, irrigation, commercial, and mining. Instream water uses, including hydroelectric power generation, were not considered. Total withdrawals for public supply were 189 Mgal/d, of which 152 Mgal/d were from surface-water sources and 37 Mgal/d were from ground-water sources. Kanawha County withdrew 34 Mgal/d of surface water for public supply, which is more than any other county in the state. Wood County withdrew more ground water for public supply than any other county in the state, about 7.59 Mgal/d. The total domestic (non-publicly supplied) water withdrawal was estimated at 33.5 Mgal/d, with 98 percent from ground water and 2 percent from surface water. There were 17 fossil-fuel, steam-generating thermoelectric power plants operated in the state, 10 plants with once-through cooling systems and 7 plants with recirculation cooling systems. Thermoelectric power used the greatest amount of water compared to the other water-use categories, and water withdrawal from surface-water sources was about 3,406 Mgal/d for plants with once-through cooling systems and about 145 Mgal/d for plants with recirculation cooling systems. Only a trace of water was withdrawn from ground-water sources for plants with once-through cooling systems and about 0.20 Mgal/d for plants with recirculation cooling systems. Water withdrawal by industries was about 911 Mgal/d from surface-water sources and about 54 Mgal/d from ground-water sources. West Virginia had the lowest estimated irrigation of any state or territory of the United States, with only about 0.036 Mgal/d withdrawn from surface-water sources and 0.036 Mgal/d withdrawn from ground-water sources. Water withdrawal for commercial use was about 16.7 Mgal/d from surface-water sources and about 16.0 Mgal/d from ground-water sources. Water withdrawal for mining was about 9.78 Mgal/d from surface-water sources and about 4.89 Mgal/d from ground-water sources.

The proportions of surface-water and ground-water withdrawals were similar in 1995 and 2004 (at about 3 percent ground water). Public-supply withdrawal for 2004 was about the same as for 2000 and 7 percent greater than the 1995 estimate. Domestic withdrawal for 2004 was about 18 percent less than the 1995 estimate. Withdrawal for thermoelectric power for 2004 was about 10 percent less than the 2000 estimate and about 18 percent greater than the 1995 estimate. Industrial withdrawal for 2004 was about 27 percent less than the estimate for 1995 and about the same as the estimate for 2000. Irrigation withdrawal for 2004 was about double that estimated for 2000.

Commercial withdrawal for 2004 was down 28 percent from 1995. Mining withdrawals for 2004 were about 31 and 32 percent greater for surface and ground water, respectively, than estimates for 1995.

## Introduction

West Virginia has an annual average precipitation of about 45 in. (National Oceanic and Atmospheric Administration, 2006) and has abundant surface-water resources despite having only 163 $mi^2$, less than 0.7 percent of the total area of the state, covered by water (U.S. Census Bureau, 2006; West Virginia Department of Environmental Protection, 2006). Only Delaware and Hawaii have smaller percentages of inland water (U.S. Census Bureau, 2006). West Virginia surface waters are distributed among reservoirs, lakes, impoundments, and ponds that comprise about 0.16 percent of the total area of the state, and in rivers and streams that comprise of about 0.5 percent of the total area (West Virginia Department of Environmental Protection, 2006).

West Virginia has a plentiful supply of clean water; however, increased demands and development threaten this valuable resource. Recent droughts in West Virginia and rapid economic and population growth in urban counties of the state have made it increasingly important for West Virginia to maintain an inventory of its water use.

Water use, in the broadest sense, pertains to the interaction of human activity with and its influence on the hydrologic cycle and includes elements such as self-supplied withdrawals, public-supply delivery, consumptive use, wastewater release, reclaimed wastewater, return flow, and in-stream use. This study investigates a more restrictive aspect of water use in that it refers to water withdrawals that are actually used for specific purposes, such as for domestic use, irrigation, or industrial processing. Instream water uses, including hydroelectric power generation, were not considered.

In 2004, the West Virginia Legislature passed Senate Bill 163, the Water Resources Protection Act, which tasked the West Virginia Department of Environmental Protection (WVDEP) to gather information regarding the quantity and use of surface water and ground water in the state. The WVDEP collected information from questionnaires completed by private and public water users and cooperated with the USGS to conduct this water-use study. This information, which remains the property of WVDEP, was used to improve the water-use estimates in this study. WVDEP will provide their findings to the legislature in a separate report.

This study provides estimates of the quantity of surface water and ground water used for specific purposes within West Virginia. The information presented describes how the 2004 estimates were computed and compares them to previous estimates to provide information for future water-use studies. Estimates are made for the entire state and for each county for seven water-use categories: public supply, domestic, thermoelectric power, industrial (excluding mining), irrigation (excluding livestock operations and domestic applications), commercial, and mining. Water-use estimates in this study are limited to freshwater sources.

## Water-Use Estimates

The U.S. Geological Survey (USGS) has collected and compiled water-use data for the United States for every 5-year period beginning in 1950, and for about one-third of that time the USGS West Virginia Water Science Center has participated in this national water-use compilation by collecting water-use data for West Virginia. The reporting requirements, data elements, and categories of use have varied for each 5-year compilation. The most recent water-use data collected by the USGS for West Virginia was for the 2000 national compilation (Hutson and others, 2004),

which estimated water use by county and major aquifer for four categories for West Virginia: public supply, irrigation, thermoelectric power, and industrial. The seven categories estimated in this study were last estimated by the USGS for West Virginia in the 1995 national compilation (Solley and others, 1998). The 1995 and 2000 estimates are the primary sources for comparisons to estimates made in this 2004 water-use study.

## State and County Totals

Total surface- and ground-water withdrawals were estimated for seven water-use categories, for the entire state and for each county, and the estimates were compared to previous totals and population estimates (figs. 1-5, table 1). Population and water withdrawals do not show a direct correspondence (fig. 1). Population decreased from 1995 to 2000 but withdrawals increased, and population remained fairly stable or slightly increased from 2000 to 2004 but withdrawals decreased. About 4,787 Mgal/d of water was withdrawn from surface- and ground-water sources in 2004 (fig. 2, table 1), about 4 percent more than that estimated in 1995 (Solley and others, 1998). About 4,641 Mgal/d (97 percent) of water withdrawn in 2004 was from surface-water sources, and about 146 Mgal/d (3 percent) was from ground-water sources. The proportions of surface-water and ground-water withdrawals were similar in 1995 and 2004. The largest 2004 surface-water withdrawals were in Grant and Mason Counties of about 1,156 Mgal/d and 1,090 Mgal/d, respectively (fig. 3, and table 1). The largest ground-water withdrawals were in Berkeley and Wood Counties of about 12.0 and 12.8 Mgal/d, respectively (fig. 4, table 1). Total withdrawal for irrigation was the lowest and total withdrawal for thermoelectric power was the greatest among the seven water-use categories (fig. 5).

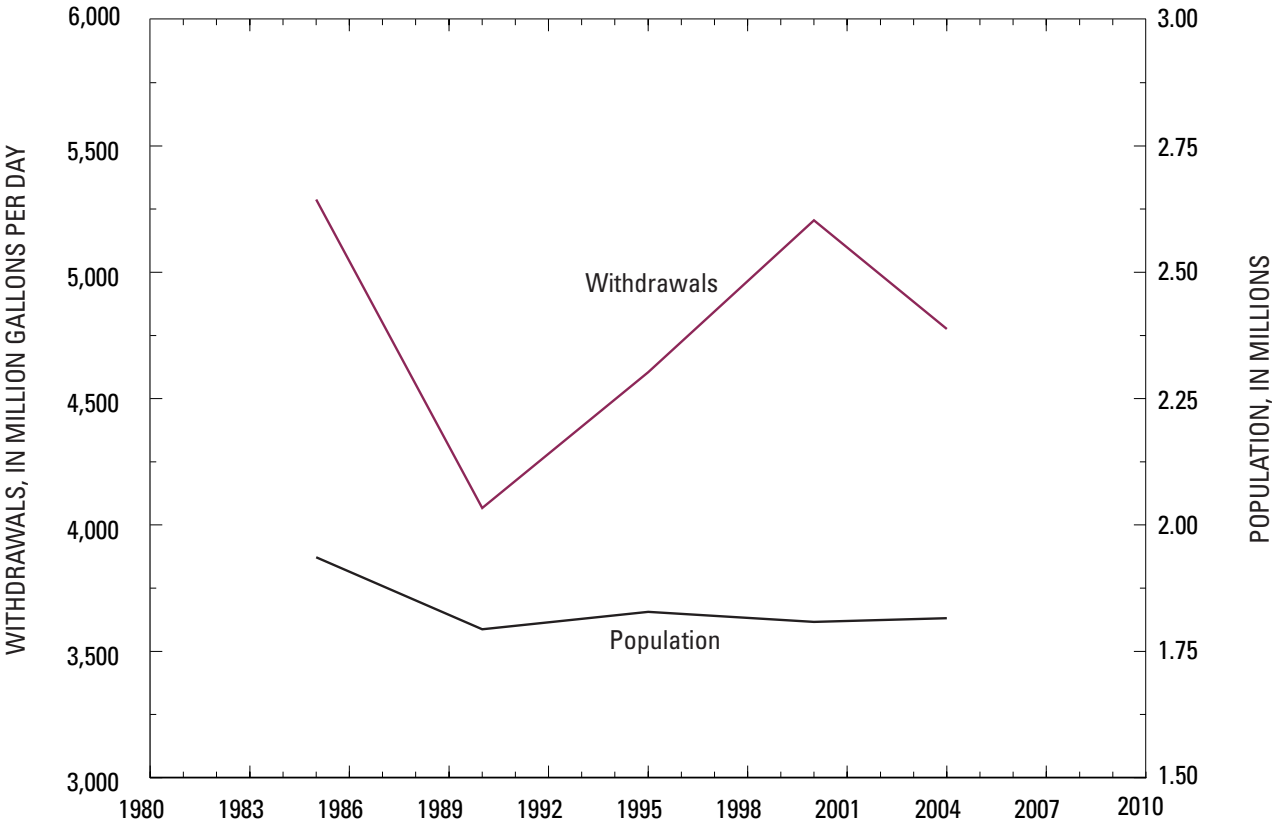


**Figure 1.** West Virginia population and total water withdrawals, 1985-2004 (Solley and others, 1988, 1993, and 1998; Hutson and others, 2004).

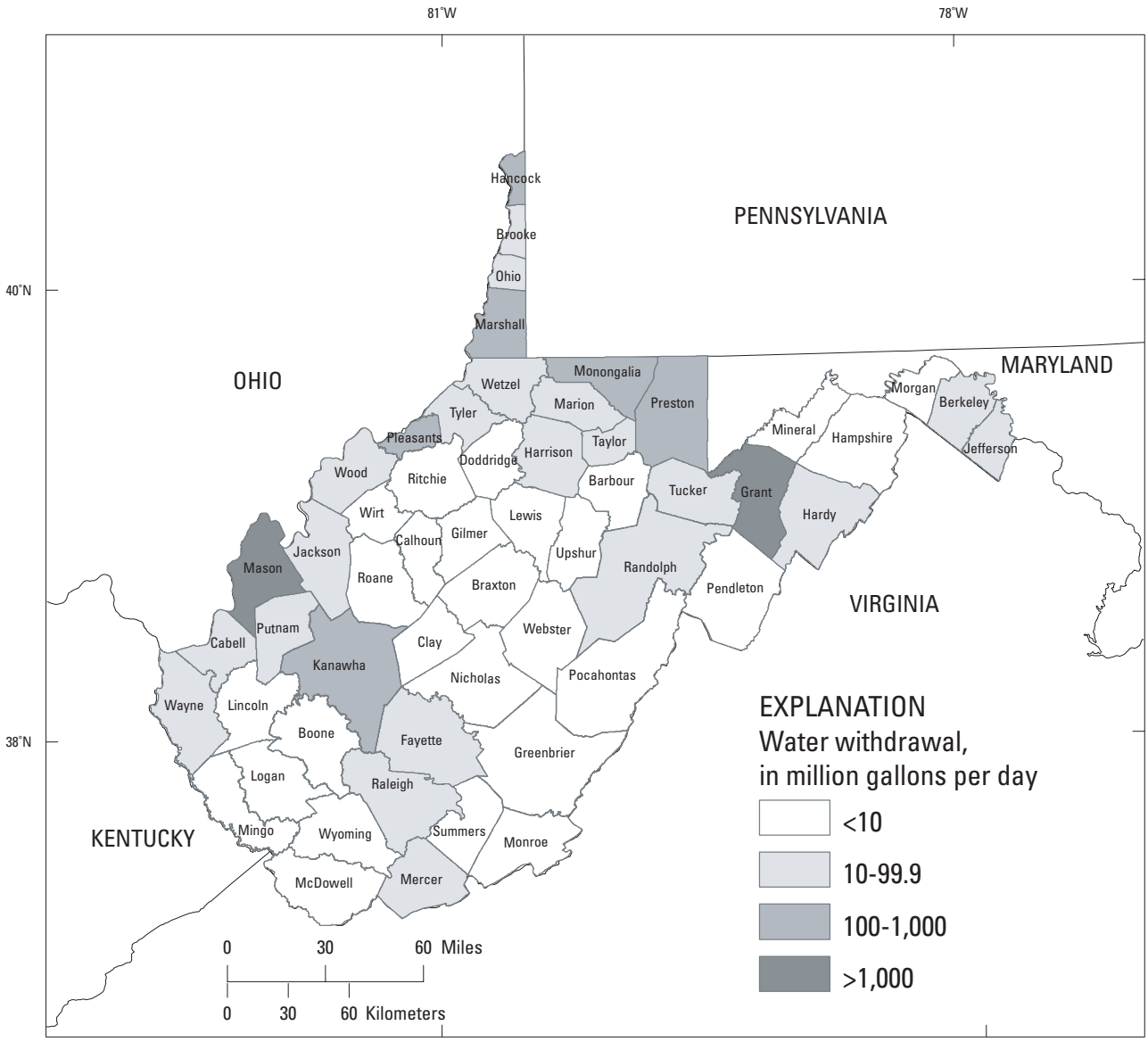


**Figure 2.** Total water withdrawals in West Virginia by county during 2004.

## Estimates by Water-Use Category

Surface- and ground-water withdrawal estimates were determined for seven water-use categories statewide and for each county. The water-use categories estimated in this study included public supply, domestic, thermoelectric power, industrial, irrigation, commercial, and mining. In 1995, the total water withdrawal for these seven categories accounted for more than 99.6 percent of the total withdrawal in the state. Methods of estimating the 2004 water use in each of these water-use categories are described in the following sections.

### Public Supply

Public supply refers to water withdrawn by public and private water suppliers and delivered to multiple users for domestic, commercial, industrial, and other uses. In 2004, there were 534 public water-supply systems that provided water to about 1.396 million people in the state (table 2)

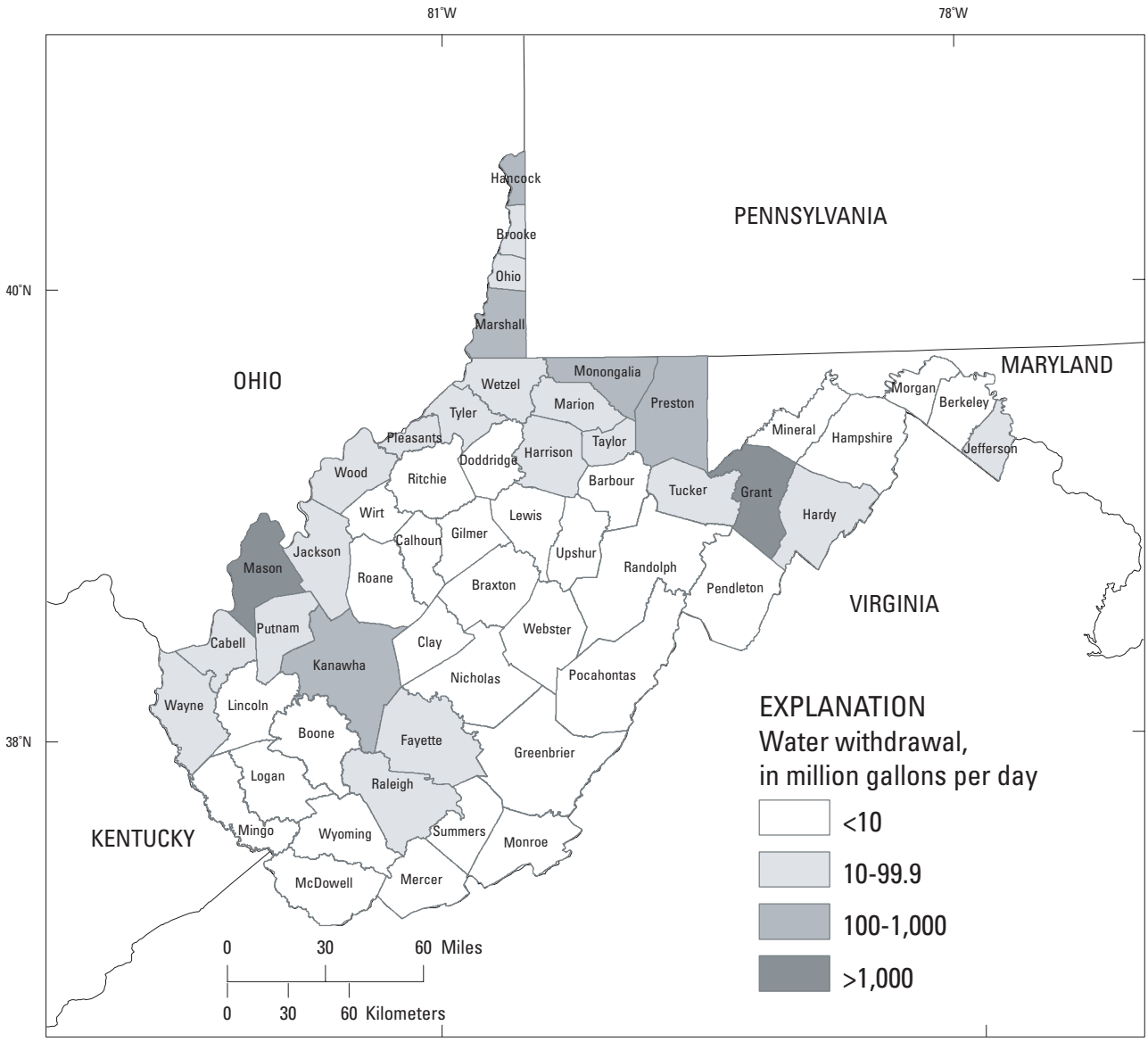


**Figure 3.** Surface-water withdrawals in West Virginia by county during 2004.

(see section on domestic water use for discussion on estimate of persons served by public suppliers). This is about 77 percent of the 2004 total state population, and is 5 percent greater than that estimated in both 1995 and 2000.

Ground water is available throughout the state. Spring water is tallied with ground water herein. There are more than 190 public-water systems withdrawing ground water (U.S. Environmental Protection Agency, 2006).

Total withdrawals for public supply were about 189 Mgal/d, of which 152 Mgal/d were from surface-water sources and 37 Mgal/d were from ground-water sources (table 2). For public supply, this was an 11 percent decrease in ground-water use and a 1.9 percent increase in surface-water use since 2000. Nearly 34 Mgal/d of surface water for public supply was withdrawn in Kanawha County, more than any other county in the state. McDowell, Mason, and Pleasants

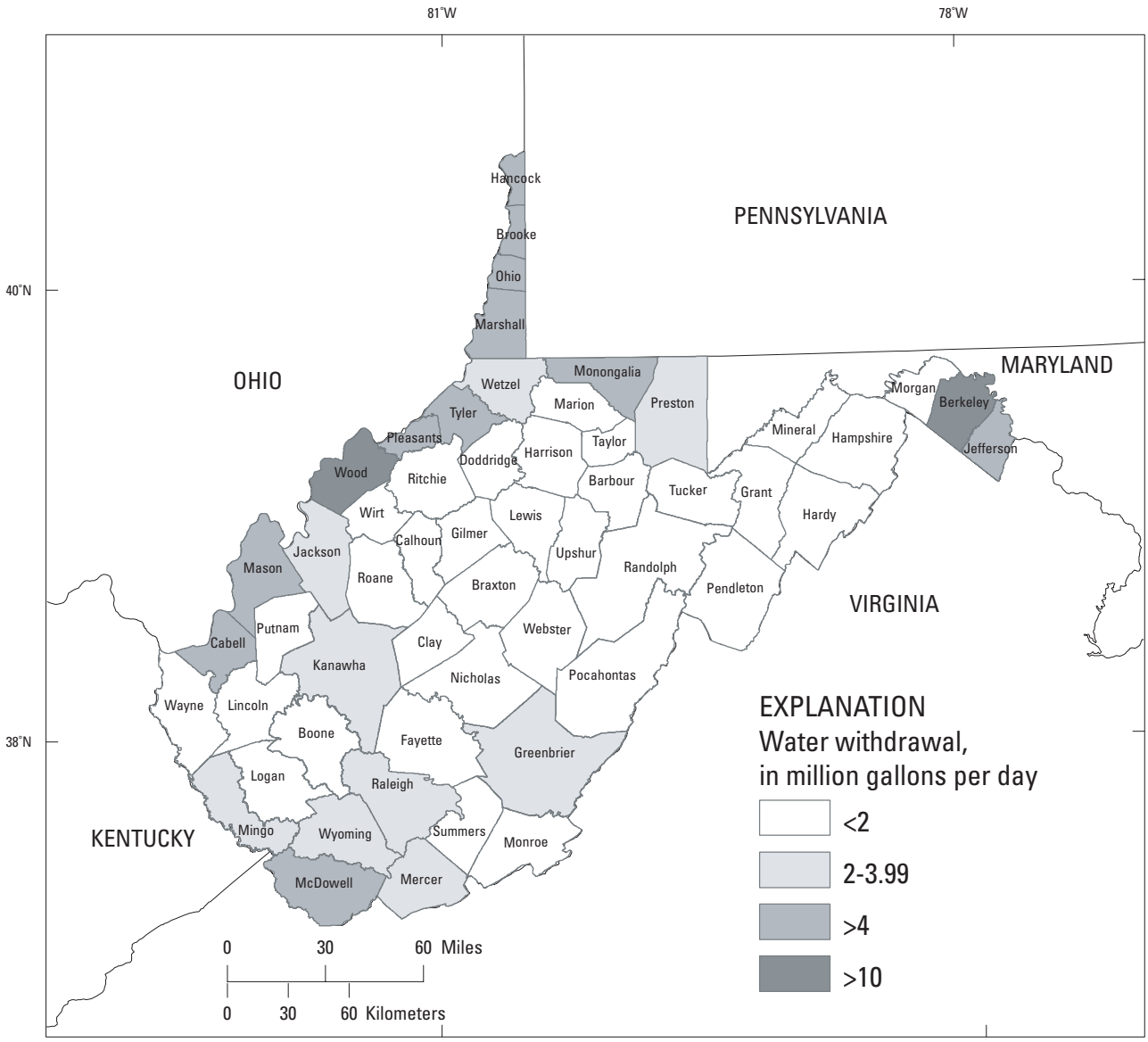


**Figure 4.** Ground-water withdrawals in West Virginia by county during 2004.

Counties withdrew no surface water for public supply. Wood County withdrew more ground water for public supply than any other county in the state (7.59 Mgal/d). Public-supply withdrawal for 2004 was about the same as the estimate for 2000 and 7 percent greater than the estimate for 1995.

*Estimating Method.* —The 2004 estimates for public supply relied principally on an internal database of about 540 public-supply systems compiled and maintained by WVDEP from information provided by the West Virginia Office of Environmental Health Services, Bureau for Public Heath (L. Keller, West Virginia Department of Environmental Protection, personal comm., February 22, 2006). This database contains information on the monthly water withdrawn by each system, an estimate of the number of persons served, and the number of residential and commercial connections in the system. This WVDEP database was augmented with information on public-water systems from the U.S. Environmental Protection Agency Safe Drinking Water Information System (SDWIS) database (U.S. Environmental Protection Agency, 2006). The SDWIS database

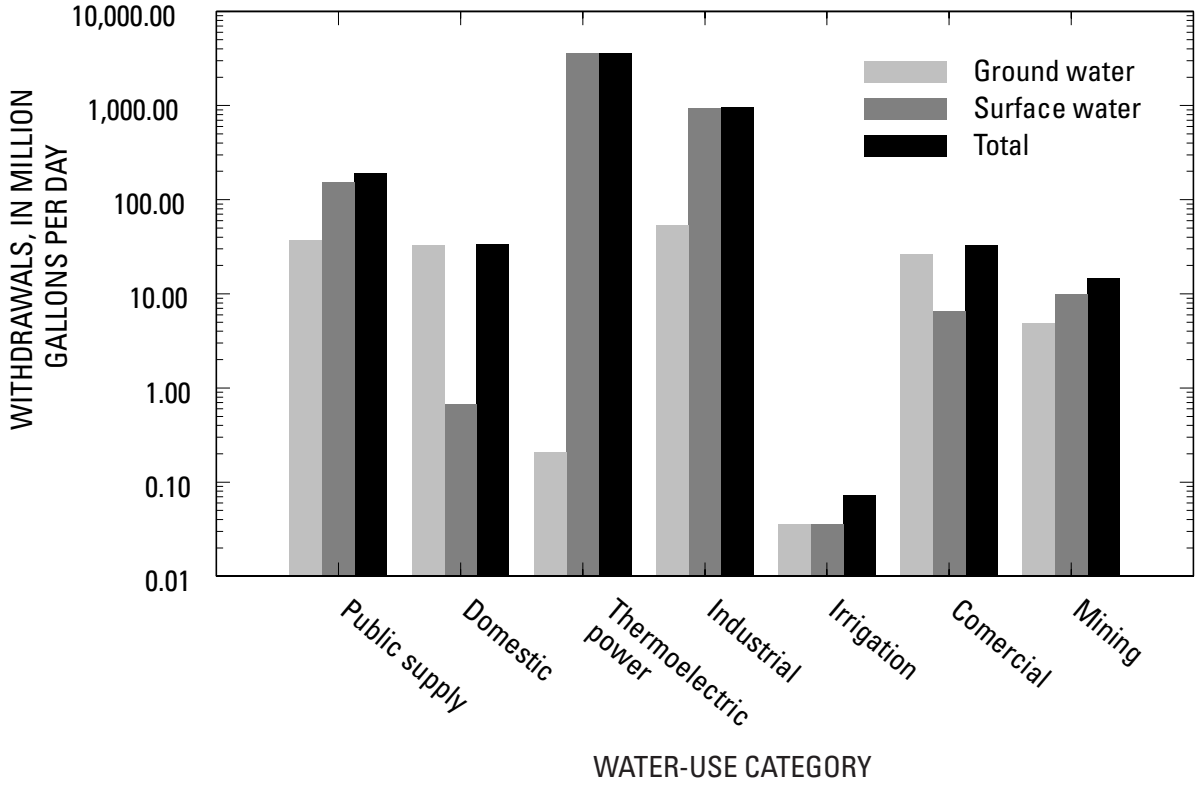


**Figure 5.** Ground-water, surface-water, and total water withdrawals in West Virginia for seven water-use categories during 2004. (Note the log scale on the y axis.)

**Table 1.** Summary of 2004 West Virginia population and water withdrawals.

[GW, Ground water; SW, Surface water; Mgal/d, million gallons per day; Co., County]

| Political boundary | Total population | Withdrawal | | |
|---|---|---|---|---|
| | | GW, in Mgal/d[1] | SW, in Mgal/d[1] | Total, in Mgal/d[1] |
| West Virginia | 1,815,354 | 145.544 | 4,641.252 | 4,786.797 |
| Barbour Co. | 15,476 | 0.347 | 1.570 | 1.918 |
| Berkeley Co. | 89,362 | 12.053 | 8.713 | 20.766 |
| Boone Co. | 25,721 | 1.561 | 1.426 | 2.986 |
| Braxton Co. | 14,950 | 1.148 | 7.572 | 8.720 |
| Brooke Co. | 24,785 | 7.363 | 74.262 | 81.625 |
| Cabell Co. | 94,801 | 5.468 | 55.750 | 61.218 |
| Calhoun Co. | 7,415 | 0.385 | 0.397 | 0.782 |
| Clay Co. | 10,424 | 0.722 | 0.813 | 1.535 |
| Doddridge Co. | 7,418 | 0.439 | 0.298 | 0.737 |
| Fayette Co. | 47,049 | 1.691 | 38.924 | 40.615 |
| Gilmer Co. | 6,982 | 0.442 | 1.077 | 1.519 |
| Grant Co. | 11,537 | 0.466 | 1,156.434 | 1,156.900 |
| Greenbrier Co. | 34,886 | 3.091 | 5.255 | 8.346 |
| Hampshire Co. | 21,542 | 1.322 | 1.442 | 2.764 |
| Hancock Co. | 31,507 | 4.313 | 181.746 | 186.059 |
| Hardy Co. | 13,209 | 0.834 | 19.511 | 20.345 |
| Harrison Co. | 68,303 | 0.659 | 57.019 | 57.679 |

**Table 1.** Summary of 2004 West Virginia population and water withdrawals.

[GW, Ground water; SW, Surface water; Mgal/d, million gallons per day; Co., County]

| Political boundary | Total population | Withdrawal | | |
|---|---|---|---|---|
| | | GW, in Mgal/d[1] | SW, in Mgal/d[1] | Total, in Mgal/d[1] |
| Jackson Co. | 28,477 | 3.796 | 28.131 | 31.927 |
| Jefferson Co. | 47,663 | 4.014 | 10.958 | 14.972 |
| Kanawha Co. | 195,218 | 2.919 | 504.818 | 507.737 |
| Lewis Co. | 17,132 | 0.495 | 3.897 | 4.392 |
| Lincoln Co. | 22,564 | 1.016 | 0.892 | 1.909 |
| Logan Co. | 36,502 | 1.940 | 4.979 | 6.919 |
| McDowell Co. | 24,726 | 4.425 | 1.326 | 5.751 |
| Marion Co. | 56,453 | 1.808 | 45.433 | 47.241 |
| Marshall Co. | 34,722 | 9.326 | 714.167 | 723.493 |
| Mason Co. | 25,941 | 4.365 | 1,089.697 | 1,094.062 |
| Mercer Co. | 62,070 | 3.536 | 8.288 | 11.825 |
| Mineral Co. | 27,145 | 0.735 | 3.823 | 4.558 |
| Mingo Co. | 27,389 | 2.165 | 5.364 | 7.529 |
| Monongalia Co. | 83,918 | 6.385 | 159.738 | 166.124 |
| Monroe Co. | 13,568 | 0.948 | 0.738 | 1.686 |
| Morgan Co. | 15,810 | 1.819 | 0.954 | 2.773 |
| Nicholas Co. | 26,276 | 1.231 | 4.105 | 5.336 |
| Ohio Co. | 45,410 | 4.267 | 16.558 | 20.825 |
| Pendleton Co. | 7,897 | 0.863 | 0.352 | 1.215 |
| Pleasants Co. | 7,441 | 7.312 | 93.403 | 100.715 |
| Pocahontas Co. | 8,995 | 0.626 | 1.695 | 2.322 |
| Preston Co. | 29,856 | 2.085 | 107.988 | 110.073 |
| Putnam Co. | 53,836 | 0.994 | 56.636 | 57.630 |
| Raleigh Co. | 79,175 | 2.097 | 14.981 | 17.077 |
| Randolph Co. | 28,495 | 1.762 | 9.544 | 11.306 |
| Ritchie Co. | 10,486 | 0.585 | 1.975 | 2.560 |
| Roane Co. | 15,359 | 0.796 | 1.536 | 2.331 |
| Summers Co. | 13,809 | 0.687 | 3.219 | 3.906 |
| Taylor Co. | 16,202 | 0.894 | 10.244 | 11.138 |
| Tucker Co. | 7,046 | 0.453 | 17.269 | 17.722 |
| Tyler Co. | 9,365 | 6.716 | 13.352 | 20.068 |
| Upshur Co. | 23,996 | 1.088 | 5.700 | 6.788 |
| Wayne Co. | 42,515 | 1.218 | 19.029 | 20.248 |
| Webster Co. | 9,849 | 0.569 | 1.135 | 1.704 |
| Wetzel Co. | 17,048 | 3.863 | 21.948 | 25.812 |
| Wirt Co. | 5,835 | 0.286 | 0.470 | 0.757 |
| Wood Co. | 87,100 | 12.793 | 40.999 | 53.792 |
| Wyoming Co. | 24,698 | 2.360 | 3.701 | 6.060 |

[1] Numeric values having greater than three significant figures are for accounting purposes only.

identified 536 active public-water suppliers in West Virginia, of which 340 are self-supplied but may also purchase water. The other 196 suppliers purchase water for distribution but do not withdraw. The SDWIS database contains information on the numbers of persons served by each system and identifies the source as ground or surface water.

Monthly water-withdrawal information from the WVDEP internal database was incomplete for some sites but the water source (either ground or surface water) was known from SDWIS. The annual withdrawal of a public-water system that had any monthly information was estimated as the sum of the monthly withdrawals, with the missing monthly withdrawals as the average of available

**Table 2.** Public-supply and domestic water withdrawals, and population served in West Virginia during 2004.

[GW, Ground water; SW, Surface water; Mgal/d, million gallons per day; Co., County; - -, no withdrawal]

| Political boundary | Public supply | | | | | Domestic | | |
|---|---|---|---|---|---|---|---|---|
| | Withdrawal | | Population served | | | Withdrawal | | Total |
| | GW, in Mgal/d[1] | SW, in Mgal/d[1] | GW | SW | Total | GW, in Mgal/d[1] | SW, in Mgal/d[1] | population served |
| West Virginia | 37.195 | 151.622 | 340,331 | 1,056,160 | 1,396,491 | 32.83882 | 0.67018 | 418,863 |
| Barbour Co. | - - | 1.112 | - - | 11,279 | 11,279 | .32928 | .00672 | 4,197 |
| Berkeley Co. | 4.949 | 3.494 | 38,366 | 25,666 | 64,032 | 1.98548 | .04052 | 25,330 |
| Boone Co. | 0.024 | 0.163 | 2,106 | 12,826 | 14,932 | .84574 | .01726 | 10,789 |
| Braxton Co. | - - | 0.938 | - - | 8,079 | 8,079 | .53900 | .01100 | 6,871 |
| Brooke Co. | 1.839 | 3.259 | 10,271 | 12,605 | 22,876 | .14994 | .00306 | 1,909 |
| Cabell Co. | - - | 14.181 | - - | 87,578 | 87,578 | .56644 | .01156 | 7,223 |
| Calhoun Co. | - - | 0.309 | - - | 3,175 | 3,175 | .33222 | .00678 | 4,240 |
| Clay Co. | 0.058 | 0.362 | 488 | 3,659 | 4,147 | .49196 | .01004 | 6,277 |
| Doddridge Co. | - - | 0.156 | - - | 2,429 | 2,429 | .39102 | .00798 | 4,989 |
| Fayette Co. | 0.668 | 4.649 | 7,723 | 31,117 | 38,839 | .64386 | .01314 | 8,210 |
| Gilmer Co. | - - | 0.507 | - - | 2,738 | 2,738 | .33320 | .00680 | 4,244 |
| Grant Co. | - - | 1.057 | - - | 8,531 | 8,531 | .23520 | .00480 | 3,006 |
| Greenbrier Co. | 2.004 | 1.933 | 10,618 | 11,436 | 22,054 | 1.00646 | .02054 | 12,832 |
| Hampshire Co. | 0.165 | 0.427 | 2,641 | 6,353 | 8,994 | .98392 | .02008 | 12,548 |
| Hancock Co. | 0.923 | 0.333 | 13,102 | 16,004 | 29,107 | .18816 | .00384 | 2,400 |
| Hardy Co. | 0.099 | 3.573 | 801 | 5,093 | 5,894 | .57330 | .01170 | 7,315 |
| Harrison Co. | 0.002 | 8.717 | 65 | 61,691 | 61,756 | .51352 | .01048 | 6,547 |
| Jackson Co. | 0.768 | 0.821 | 8,367 | 9,169 | 17,536 | .85750 | .01750 | 10,941 |
| Jefferson Co. | 1.043 | 1.654 | 10,734 | 17,639 | 28,374 | 1.51214 | .03086 | 19,289 |
| Kanawha Co. | 0.023 | 33.893 | 113 | 181,031 | 181,144 | 1.10348 | .02252 | 14,074 |
| Lewis Co. | - - | 1.353 | - - | 11,490 | 11,490 | .44198 | .00902 | 5,642 |
| Lincoln Co. | - - | 0.751 | - - | 11,140 | 11,140 | .89572 | .01828 | 11,424 |
| Logan Co. | 0.406 | 3.261 | 3,473 | 23,819 | 27,292 | .72226 | .01474 | 9,210 |
| McDowell Co. | 3.111 | - - | 16,441 | - - | 16,441 | .64974 | .01326 | 8,285 |
| Marion Co. | 0.059 | 6.474 | 833 | 52,614 | 53,447 | .23520 | .00480 | 3,006 |
| Marshall Co. | 2.843 | 0.118 | 23,192 | 7,036 | 30,228 | .35280 | .00720 | 4,494 |
| Mason Co. | 2.275 | - - | 18,337 | 1,930 | 20,267 | .44492 | .00908 | 5,674 |
| Mercer Co. | 0.903 | 3.181 | 19,782 | 28,558 | 48,341 | 1.07604 | .02196 | 13,729 |
| Mineral Co. | 0.109 | 1.645 | 4,772 | 14,790 | 19,562 | .59486 | .01214 | 7,583 |
| Mingo Co. | 0.236 | 3.756 | 573 | 12,591 | 13,163 | 1.11524 | .02276 | 14,226 |
| Monongalia Co. | - - | 9.980 | - - | 78,899 | 78,899 | .39298 | .00802 | 5,019 |
| Monroe Co. | 0.321 | 0.652 | 3,256 | 2,787 | 6,043 | .58996 | .01204 | 7,525 |
| Morgan Co. | 0.195 | 0.536 | 3,207 | 3,018 | 6,225 | .75166 | .01534 | 9,585 |
| Nicholas Co. | 0.008 | 2.290 | 115 | 17,917 | 18,031 | .64680 | .01320 | 8,245 |
| Ohio Co. | 1.307 | 5.228 | 18,131 | 25,642 | 43,773 | .12838 | .00262 | 1,637 |
| Pendleton Co. | 0.380 | 0.057 | 2,296 | 872 | 3,168 | .37044 | .00756 | 4,729 |
| Pleasants Co. | 0.676 | - - | 4,055 | 1,106 | 5,161 | .17836 | .00364 | 2,280 |
| Pocahontas Co. | 0.165 | 0.647 | 801 | 2,675 | 3,476 | .43316 | .00884 | 5,519 |
| Preston Co. | 0.678 | 1.043 | 6,845 | 9,632 | 16,477 | 1.04860 | .02140 | 13,379 |
| Putnam Co. | - - | 2.184 | - - | 43,030 | 43,030 | .84672 | .01728 | 10,806 |
| Raleigh Co. | 0.422 | 8.923 | 23,028 | 49,661 | 72,689 | .50862 | .01038 | 6,486 |
| Randolph Co. | 0.207 | 2.795 | 2,461 | 16,907 | 19,367 | .71540 | .01460 | 9,128 |
| Ritchie Co. | - - | 0.439 | - - | 5,177 | 5,177 | .41650 | .00850 | 5,309 |

**Table 2.** Public-supply and domestic water withdrawals, and population served in West Virginia during 2004.

[GW, Ground water; SW, Surface water; Mgal/d, million gallons per day; Co., County; - -, no withdrawal]

| Political boundary | Public supply | | | | | Domestic | | |
|---|---|---|---|---|---|---|---|---|
| | Withdrawal | | Population served | | | Withdrawal | | Total population served |
| | GW, in Mgal/d[1] | SW, in Mgal/d[1] | GW | SW | Total | GW, in Mgal/d[1] | SW, in Mgal/d[1] | |
| Roane Co. | - - | 0.679 | - - | 7,369 | 7,369 | .62622 | .01278 | 7,990 |
| Summers Co. | - - | 3.138 | - - | 6,919 | 6,919 | .53998 | .01102 | 6,890 |
| Taylor Co. | - - | 1.941 | - - | 13,494 | 13,494 | .21266 | .00434 | 2,708 |
| Tucker Co. | 0.049 | 0.544 | 632 | 3,799 | 4,431 | .20482 | .00418 | 2,615 |
| Tyler Co. | 0.048 | 0.392 | 651 | 4,740 | 5,391 | .31164 | .00636 | 3,974 |
| Upshur Co. | - - | 2.097 | - - | 16,742 | 16,742 | .56840 | .01160 | 7,254 |
| Wayne Co. | - - | 3.229 | - - | 32,031 | 32,031 | .82222 | .01678 | 10,484 |
| Webster Co. | - - | 0.433 | - - | 5,250 | 5,250 | .36064 | .00736 | 4,599 |
| Wetzel Co. | 1.706 | 0.069 | 10,408 | 1,291 | 11,699 | .41944 | .00856 | 5,349 |
| Wirt Co. | - - | 0.107 | - - | 2,647 | 2,647 | .24990 | .00510 | 3,188 |
| Wood Co. | 7.596 | 1.204 | 65,852 | 13,541 | 79,394 | .60466 | .01234 | 7,706 |
| Wyoming Co. | 0.930 | 0.938 | 5,795 | 8,948 | 14,743 | .78008 | .01592 | 9,955 |

[1] Numeric values having greater than three significant figures are for accounting purposes only.

monthly withdrawals. The annual withdrawal for 31 systems in the database that had no monthly withdrawal information was estimated from records used in the USGS 2000 compilation (Hutson and others, 2004). For 64 public-water systems that had no monthly withdrawal information and for which previous compilation data were not available, missing withdrawals were estimated by use of one of two regression models. A regression model with monthly withdrawal as the dependent variable and with residential and commercial connections as the independent variables (based on 4,556 data pairs) was forced through the origin:

$$Gm = 13{,}987Cr - 7{,}816Cc\ , \qquad \text{(eqn 1)}$$

where

Gm is the water withdrawal, in gallons per month,

Cr is the number of residential connections, and

Cc is the number of commercial connections.

The F-value for this equation was 21,598 and the adjusted $r^2$ value was 0.90; this model was used to estimate monthly withdrawals for only 33 public suppliers. This equation was not applied for estimates for 10 public suppliers because the negative term resulted in estimates that were considered unreasonable.

For the 10 public suppliers for which the two-variable equation could not be used, and 21 additional suppliers, a simple one-variable regression model was developed using average monthly withdrawal as the dependent variable and population served as the independent variable. Public suppliers that sell to other water companies and outliers were removed from the regression, but suppliers that purchase water were kept to represent small suppliers. Data for systems that supply

less than 1,000 gallons per month per customer were not included in the analysis. Based on 415 pairs of average withdrawal (or purchase) and population served, a simple regression was forced through the origin:

$$Gm = 3{,}436Pr\ , \qquad \text{(eqn 2)}$$

where

Gm is the water withdrawal in gallons per month, and

Pr is the number of persons served.

The F-value for this equation was 4,991 and the adjusted $r^2$ value was 0.92.

The F-test probabilities for both regression equations described above were less than 0.0001, which is very unfavorable for the null hypothesis of no correlation. In spite of these good correlations, applying the equations was the last resort, and these estimates are considered poor. In all, water-use estimates using the described regression equations involved only 64 public-supply systems out of 534 that were considered in this study, and the total water use estimated for these 64 systems was less than 5 percent of the total public-supply withdrawal.

## Domestic

Domestic water use includes water for normal household purposes by homes relying on self-supplied water from wells, streams, or springs. The total domestic water withdrawal was estimated at 33.5 Mgal/d. About 418,863 West Virginians, 23 percent of the state's population, relied on self-supplied water for domestic use (table 2). The self-supplied sources for domestic withdrawals in West Virginia were estimated to be 98 percent from ground water and 2 percent from surface water. Total domestic water use estimated in previous studies was 40.7 and 40.4 Mgal/d for 1995 and 2000, respectively. The approximately 18-percent decrease in the estimate of domestic water use since 1995 is probably due to population movement, development of public supplies, and extension of distribution systems.

*Estimating Method.* —The domestic water withdrawals were estimated by multiplying the domestic self-supplied population by a domestic self-supplied per capita coefficient. The self-supplied per capita coefficient of 80 gal/d per person was used in the 1995 and 2000 studies and continued for this study. Domestic self-supplied population is calculated by subtracting total population served by any public supply in a county, referred to as the retail population, from the total census population in the county. The reliability of the estimate of domestic self-supplied population depends on the reliability of the estimate for the retail population (Hutson and others, 2004).

Public suppliers estimate the retail population by multiplying the number of connections, which is well known, by the number of persons per retail connection, which is not well known. The public-supplier estimates are considered unreliable because the estimated number of persons per retail connection (persons per household) decreased from 2.55 on July 1, 1990, to 2.48 in July 1998, and to 2.40 in 2001 (U.S. Bureau of the Census, 1999 and 2004a). There were 866,944 housing units and a population of 1,815,354 estimated for July 1, 2004 (U.S. Bureau of the Census, 2005), which is 2.09 persons per retail connection. Since 1995, another method was used to estimate the retail population of each county because the number of persons per retail connection appeared to be changing and was therefore not well known.

For the USGS 1995 and 2000 estimates, the 1990 U.S. Census estimate of the percentage of the retail population for a county (U.S. Bureau of the Census, 1992) was multiplied by the

population for a county. The 1990 U.S. Census estimate of the percentage of retail population was used for the 1995 and 2000 water-use estimates because the 2000 Census did not acquire information sufficient to make an estimate of the percentage of the retail population. For 2000, the retail population reported by the public suppliers for the state was 1,400,968; this was adjusted to 1,303,454 using the 55 county-population-served factors.

For 2004, the retail population reported by public suppliers (without adjustment) was 1,493,390, an increase of 92,422 from 2000. The 2004 estimates of retail population were calculated in a manner similar to the 2000 study except that the 1990 U.S. Census estimates of the percentage of the retail population for a county were increased to account for the statewide increase of 92,422 customers by using the following equation for each county:

$$F_{2004} = 1 - 0.819\ (1 - F_{1990})\ , \qquad \text{(eqn 3)}$$

where

$F_{2004}$ is the 2004 county-population-served factor, and

$F_{1990}$ is the 1990 county-population-served factor (U.S. Bureau of the Census, 1992).

## Thermoelectric Power

Thermoelectric power includes water used for the generation of electricity in West Virginia by steam-powered plants fueled by conventional fuels (there were no nuclear facilities in the state). More than 99 percent of all thermoelectrically generated power in West Virginia was from burning coal, with minimal power generated from burning petroleum and natural gas (U.S. Department of Energy, 2005a). There were 17 fossil-fuel, steam-generating thermoelectric power plants operated in the state; 14 were public utilities and 3 were industrial plants. There were 10 plants with once-through cooling systems and 7 plants with recirculation (closed-loop) cooling systems.

Water withdrawn during 2004 from surface-water sources was about 3,406 Mgal/d for plants with once-through cooling systems and about 145 Mgal/d for plants with recirculation cooling systems (table 3). Only a trace of water was withdrawn from ground-water sources for plants with once-through cooling systems and about 0.2 Mgal/d for plants with recirculation cooling systems. The power generated was about 25,134 gigawatt hours per year (gWh/yr) for plants with once-through cooling systems and about 61,698 gWh/yr for plants with recirculation cooling systems (U.S. Department of Energy, 2005b). The total water withdrawn for thermoelectric power use was 3,551 Mgal/d, which was greater than that of any other water-use category for West Virginia in 2004 (fig. 5). The 2004 estimate was about 10 percent (400 Mgal/d) less than that estimated for 2000 and about 18 percent (540 Mgal/d) greater than that estimated for 1995 (table 4). Thermoelectric power is probably the most accurately estimated category of water use because of the significant engineering and maintenance required to attain the necessary pumping rates, and strong regulatory oversight.

**Table 3.** Thermoelectric-power water withdrawals and power generated in West Virginia during 2004.

[GW, Ground water; SW, Surface water; Mgal/d, million gallons per day; hr, hour; Co., County; - -, no withdrawal. Power generation figures from Steam-Electric Plant Operation Report (U.S. Department of Energy, 2005b). Numeric values having greater than three significant figures are for accounting purposes only.]

| Political boundary | Withdrawal | | | | Power generated | |
|---|---|---|---|---|---|---|
| | GW source | | SW source | | | |
| | Recirculation cooling, in Mgal/d | Once-through cooling, in Mgal/d | Recirculation cooling, in Mgal/d | Once-through cooling, in Mgal/d | Recirculation cooling, in gigawatt-hr | Once-through cooling, in gigawatt-hr |
| West Virginia | 0.205 | 0.001 | 145.28 | 3,405.912 | 61,698 | 25,134 |
| Barbour Co. | - - | - - | - - | - - | - - | - - |
| Berkeley Co. | - - | - - | - - | - - | - - | - - |
| Boone Co. | - - | - - | - - | - - | - - | - - |
| Braxton Co. | - - | - - | - - | - - | - - | - - |
| Brooke Co. | - - | - - | - - | - - | - - | - - |
| Cabell Co. | - - | - - | - - | - - | - - | - - |
| Calhoun Co. | - - | - - | - - | - - | - - | - - |
| Clay Co. | - - | - - | - - | - - | - - | - - |
| Doddridge Co. | - - | - - | - - | - - | - - | - - |
| Fayette Co. | - - | - - | - - | 33.429 | - - | 97 |
| Gilmer Co. | - - | - - | - - | - - | - - | - - |
| Grant Co. | - - | - - | - - | 1,153.769 | - - | 11,632 |
| Greenbrier Co. | - - | - - | - - | - - | - - | - - |
| Hampshire Co. | - - | - - | - - | - - | - - | - - |
| Hancock Co. | - - | - - | | 0.055 | | 170 |
| Hardy Co. | - - | - - | - - | - - | - - | - - |
| Harrison Co. | - - | - - | 39.525 | - - | 13,584 | - - |
| Jackson Co. | - - | - - | - - | - - | - - | - - |
| Jefferson Co. | - - | - - | - - | - - | - - | - - |
| Kanawha Co. | - - | - - | - - | 343.855 | - - | 1,975 |
| Lewis Co. | - - | - - | - - | - - | - - | - - |
| Lincoln Co. | - - | - - | - - | - - | - - | - - |
| Logan Co. | - - | - - | - - | - - | - - | - - |
| McDowell Co. | - - | - - | - - | - - | - - | - - |
| Marion Co. | - - | - - | 1.916 | 26.350 | 653 | 172 |
| Marshall Co. | - - | - - | 21.380 | 537.358 | 9,101 | 3,511 |
| Mason Co. | .205 | .001 | 11.380 | 1,060.197 | 8,268 | 5,661 |
| Mercer Co. | - - | - - | - - | - - | - - | - - |
| Mineral Co. | - - | - - | - - | - - | - - | - - |
| Mingo Co. | - - | - - | - - | - - | - - | - - |
| Monongalia Co. | - - | - - | 18.250 | 75.052 | 7,669 | 420 |
| Monroe Co. | - - | - - | - - | - - | - - | - - |
| Morgan Co. | - - | - - | - - | - - | - - | - - |
| Nicholas Co. | - - | - - | - - | - - | - - | - - |
| Ohio Co. | - - | - - | - - | - - | - - | - - |
| Pendleton Co. | - - | - - | - - | - - | - - | - - |
| Pleasants Co. | - - | - - | 11.906 | 70.736 | 6,043 | 517 |
| Pocahontas Co. | - - | - - | - - | - - | - - | - - |

**Table 3.** Thermoelectric-power water withdrawals and power generated in West Virginia during 2004.

[GW, Ground water; SW, Surface water; Mgal/d, million gallons per day; hr, hour; Co., County; - -, no withdrawal. Power generation figures from Steam-Electric Plant Operation Report (U.S. Department of Energy, 2005b). Numeric values having greater than three significant figures are for accounting purposes only.]

| Political boundary | Withdrawal | | | | Power generated | |
|---|---|---|---|---|---|---|
| | GW source | | SW source | | | |
| | Recirculation cooling, in Mgal/d | Once-through cooling, in Mgal/d | Recirculation cooling, in Mgal/d | Once-through cooling, in Mgal/d | Recirculation cooling, in gigawatt-hr | Once-through cooling, in gigawatt-hr |
| Preston Co. | - - | - - | - - | 105.111 | - - | 979 |
| Putnam Co. | - - | - - | 40.923 | - - | 16,380 | - - |
| Raleigh Co. | - - | - - | - - | - - | - - | - - |
| Randolph Co. | - - | - - | - - | - - | - - | - - |
| Ritchie Co. | - - | - - | - - | - - | - - | - - |
| Roane Co. | - - | - - | - - | - - | - - | - - |
| Summers Co. | - - | - - | - - | - - | - - | - - |
| Taylor Co. | - - | - - | - - | - - | - - | - - |
| Tucker Co. | - - | - - | - - | - - | - - | - - |
| Tyler Co. | - - | - - | - - | - - | - - | - - |
| Upshur Co. | - - | - - | - - | - - | - - | - - |
| Wayne Co. | - - | - - | - - | - - | - - | - - |
| Webster Co. | - - | - - | - - | - - | - - | - - |
| Wetzel Co. | - - | - - | - - | - - | - - | - - |
| Wirt Co. | - - | - - | - - | - - | - - | - - |
| Wood Co. | - - | - - | - - | - - | - - | - - |
| Wyoming Co. | - - | - - | - - | - - | - - | - - |

**Table 4.** Estimated thermoelectric power generated, water withdrawals, and water consumed in West Virginia, 1985-2004.

[Mgal/d, million gallons per day; gWh/yr; gigawatthour per year; - -, no value; tabulated data from Solley and others, 1988, 1993, and 1998; Hutson and others, 2004; U.S. Department of Energy, 205b]

| Year | Power generated, in gWh/yr | Water withdrawals, in Mgal/d | Consumptive water use, in Mgal/d |
|---|---|---|---|
| 1985 | 80,231 | 4,207 | 658 |
| 1990 | 84,560 | 3,709 | 99 |
| 1995 | 79,068 | 3,010 | 122 |
| 2000 | 92,359 | 3,949 | -- |
| 2004 | 86,832 | 3,551 | -- |

*Estimating Method.* —Thermoelectric power generation is estimated for two categories based on cooling method: once-through cooling, and recirculation cooling that uses cooling ponds or towers. Estimates for water withdrawn for 2004 relied on data compiled by WVDEP from water-use questionnaires; only aggregates of estimates made or improved by use of that information are presented here.

## Industrial

Industrial water users are factories and other business that construct or fabricate products including assembly, chemical products, and steel (excluding mining). This category consists of industries with Standard Industrial Classification (SIC) codes between 1500 and 3999 (Office of Management and Budget, 1987). Surface-water withdrawn by industries in 2004 was estimated to be about 911 Mgal/d (table 5) and was used mostly for cooling. This is a 30-percent decrease from the 1995 estimate of 1,303 Mgal/d and a 5-percent decrease from the 2000 estimate of 958 Mgal/d. Ground-water withdrawn by industries in 2004 was estimated to be about 54 Mgal/d, which is about 4 times greater than estimated in 1995 or 2000. Industrial withdrawal for 2004 (965 Mgal/d) was about 27 percent less than the estimate for 1995 (1,316 Mgal/d) and about the same as the estimate for 2000 (968 Mgal/d).

**Table 5.** Industrial, irrigation, commercial, and mining water withdrawals in West Virginia during 2004.

[GW, Ground water; SW, Surface water; Mgal/d, million gallons per day; Co., County; - -, no withdrawal]

| Political boundary | Industrial | | Irrigation | | Commercial | | Mining | |
|---|---|---|---|---|---|---|---|---|
| | GW, in Mgal/d[1] | SW, in Mgal/d[1] | GW, in Mgal/d[1] | SW, in Mgal/d[1] | GW, in Mgal/d[1] | SW, in Mgal/d[1] | GW, in Mgal/d[1] | SW, in Mgal/d[1] |
| West Virginia | 54.360 | 911.276 | 0.036295 | 0.036295 | 16.019 | 16.670 | 4.89267 | 9.78533 |
| Barbour Co. | 0.003 | 0.276 | 0.000497 | 0.000497 | 0.002 | 0.149 | 0.01333 | 0.02667 |
| Berkeley Co. | 4.411 | 4.411 | 0.003612 | 0.003612 | 0.644 | 0.644 | 0.06000 | 0.12000 |
| Boone Co. | 0.007 | 0.099 | 0.000097 | 0.000097 | 0.127 | 0.032 | 0.55733 | 1.11467 |
| Braxton Co. | 0.469 | 6.573 | 0.000028 | 0.000028 | 0.131 | 0.033 | 0.00867 | 0.01733 |
| Brooke Co. | 5.065 | 70.922 | 0.000490 | 0.000490 | 0.310 | 0.077 | - - | - - |
| Cabell Co. | 2.932 | 41.06 | 0.001964 | 0.001964 | 1.965 | 0.491 | 0.00233 | 0.00467 |
| Calhoun Co. | 0.004 | 0.049 | 0.000035 | 0.000035 | 0.038 | 0.010 | 0.01133 | 0.02267 |
| Clay Co. | 0.011 | 0.158 | 0.000083 | 0.000083 | 0.022 | 0.006 | 0.13867 | 0.27733 |
| Doddridge Co. | 0.006 | 0.077 | 0.000577 | 0.000577 | 0.015 | 0.004 | 0.02633 | 0.05267 |
| Fayette Co. | 0.050 | 0.697 | 0.000454 | 0.000454 | 0.299 | 0.075 | 0.03033 | 0.06067 |
| Gilmer Co. | 0.037 | 0.512 | 0.000014 | 0.000014 | 0.054 | 0.013 | 0.01867 | 0.03733 |
| Grant Co. | 0.109 | 1.522 | 0.000442 | 0.000442 | 0.093 | 0.023 | 0.02867 | 0.05733 |
| Greenbrier Co. | 0.024 | 2.328 | 0.000776 | 0.000776 | 0.009 | 0.879 | 0.04733 | 0.09467 |
| Hampshire Co. | 0.069 | 0.969 | 0.000517 | 0.000517 | 0.103 | 0.026 | - - | - - |
| Hancock Co. | 2.587 | 181.2 | 0.000283 | 0.000283 | 0.615 | 0.154 | - - | - - |
| Hardy Co. | 0.160 | 15.816 | 0.001220 | 0.001220 | 0.001 | 0.109 | - - | - - |
| Harrison Co. | 0.074 | 7.329 | 0.000558 | 0.000558 | 0.013 | 1.325 | 0.05600 | 0.11200 |
| Jackson Co. | 1.944 | 27.217 | 0.000430 | 0.000430 | 0.216 | 0.054 | 0.01067 | 0.02133 |
| Jefferson Co. | 1.265 | 8.478 | 0.006360 | 0.006360 | 0.088 | 0.589 | 0.10000 | 0.20000 |
| Kanawha Co. | 1.217 | 120.502 | 0.000566 | 0.000566 | 0.056 | 5.508 | 0.51867 | 1.03733 |
| Lewis Co. | 0.022 | 2.134 | 0.000350 | 0.000350 | 0.004 | 0.345 | 0.02767 | 0.05533 |
| Lincoln Co. | 0.003 | 0.042 | 0.000109 | 0.000109 | 0.088 | 0.022 | 0.02933 | 0.05867 |
| Logan Co. | 0.056 | 0.784 | 0.000076 | 0.000076 | 0.338 | 0.085 | 0.41733 | 0.83467 |

**Table 5.** Industrial, irrigation, commercial, and mining water withdrawals in West Virginia during 2004.

[GW, Ground water; SW, Surface water; Mgal/d, million gallons per day; Co., County; - -, no withdrawal]

| Political boundary | Industrial | | Irrigation | | Commercial | | Mining | |
|---|---|---|---|---|---|---|---|---|
| | GW, in Mgal/d[1] | SW, in Mgal/d[1] | GW, in Mgal/d[1] | SW, in Mgal/d[1] | GW, in Mgal/d[1] | SW, in Mgal/d[1] | GW, in Mgal/d[1] | SW, in Mgal/d[1] |
| McDowell Co. | 0.019 | 0.266 | 0.000042 | 0.000042 | 0.751 | 0.188 | 0.50567 | 1.01133 |
| Marion Co. | 0.748 | 10.471 | 0.000750 | 0.000750 | 0.290 | 0.073 | 0.01433 | 0.02867 |
| Marshall Co. | 5.716 | 154.984 | 0.000456 | 0.000456 | 0.147 | 0.037 | 0.12333 | 0.24667 |
| Mason Co. | 1.291 | 18.072 | 0.000965 | 0.000965 | 0.140 | 0.035 | 0.00033 | 0.00067 |
| Mercer Co. | 0.336 | 4.704 | 0.000272 | 0.000272 | 1.178 | 0.295 | 0.04333 | 0.08667 |
| Mineral Co. | 0.019 | 1.906 | 0.002203 | 0.002203 | 0.002 | 0.242 | 0.00767 | 0.01533 |
| Mingo Co. | 0.062 | 0.873 | 0.000146 | 0.000146 | 0.451 | 0.113 | 0.29967 | 0.59933 |
| Monongalia Co. | 3.965 | 55.528 | 0.000693 | 0.000693 | 1.791 | 0.448 | 0.23600 | 0.47200 |
| Monroe Co. | 0.005 | 0.066 | 0.000546 | 0.000546 | 0.032 | 0.008 | - - | - - |
| Morgan Co. | 0.646 | 0.207 | 0.000042 | 0.000042 | 0.153 | 0.049 | 0.07333 | 0.14667 |
| Nicholas Co. | 0.089 | 1.239 | 0.000123 | 0.000123 | 0.235 | 0.059 | 0.25200 | 0.50400 |
| Ohio Co. | 0.758 | 10.618 | 0.000199 | 0.000199 | 1.964 | 0.491 | 0.10900 | 0.21800 |
| Pendleton Co. | 0.015 | 0.216 | 0.000075 | 0.000075 | 0.071 | 0.018 | 0.02667 | 0.05333 |
| Pleasants Co. | 6.423 | 10.698 | 0.000038 | 0.000038 | 0.033 | 0.055 | 0.00200 | 0.00400 |
| Pocahontas Co. | 0.007 | 0.495 | 0.000193 | 0.000193 | 0.007 | 0.517 | 0.01367 | 0.02733 |
| Preston Co. | 0.118 | 1.656 | 0.000627 | 0.000627 | 0.185 | 0.046 | 0.05500 | 0.11000 |
| Putnam Co. | 0.129 | 12.784 | 0.003681 | 0.003681 | 0.007 | 0.710 | 0.00700 | 0.01400 |
| Raleigh Co. | 0.810 | 4.44 | 0.000492 | 0.000492 | 0.257 | 1.411 | 0.09800 | 0.19600 |
| Randolph Co. | 0.469 | 6.56 | 0.000087 | 0.000087 | 0.324 | 0.081 | 0.04667 | 0.09333 |
| Ritchie Co. | 0.104 | 1.452 | 0.000934 | 0.000934 | 0.030 | 0.008 | 0.03333 | 0.06667 |
| Roane Co. | 0.057 | 0.798 | 0.000151 | 0.000151 | 0.102 | 0.026 | 0.01000 | 0.02000 |
| Summers Co. | 0.002 | 0.033 | 0.000648 | 0.000648 | 0.144 | 0.036 | - - | - - |
| Taylor Co. | 0.590 | 8.268 | 0.000338 | 0.000338 | 0.086 | 0.022 | 0.00433 | 0.00867 |
| Tucker Co. | 0.167 | 16.518 | 0.000066 | 0.000066 | 0.001 | 0.140 | 0.03133 | 0.06267 |
| Tyler Co. | 6.328 | 12.898 | 0.000106 | 0.000106 | 0.021 | 0.042 | 0.00700 | 0.01400 |
| Upshur Co. | 0.250 | 3.493 | 0.000784 | 0.000784 | 0.252 | 0.063 | 0.01733 | 0.03467 |
| Wayne Co. | 0.152 | 15.024 | 0.000440 | 0.000440 | 0.003 | 0.277 | 0.24100 | 0.48200 |
| Webster Co. | 0.031 | 0.434 | 0.000028 | 0.000028 | 0.054 | 0.014 | 0.12333 | 0.24667 |
| Wetzel Co. | 1.558 | 21.813 | 0.000021 | 0.000021 | 0.173 | 0.043 | 0.00733 | 0.01467 |
| Wirt Co. | 0.025 | 0.353 | 0.000319 | 0.000319 | 0.009 | 0.002 | 0.00133 | 0.00267 |
| Wood Co. | 2.809 | 39.333 | 0.001220 | 0.001220 | 1.781 | 0.445 | 0.00133 | 0.00267 |
| Wyoming Co. | 0.137 | 1.921 | 0.000083 | 0.000083 | 0.114 | 0.028 | 0.39867 | 0.79733 |

[1] Numeric values having greater than three significant figures are for accounting purposes only.

*Estimating Method.* — Specific site data were used for two high-use sites. Otherwise, industrial water use for each county was estimated by multiplying the number of employees working in industrial facilities times a water-use coefficient for each type of industrial operation. A Harris InfoSource (2004) database on West Virginia businesses was used as the primary source of information for the 2004 industrial water-use estimates. This database contained information on individual facility locations, SIC codes, and employment per facility for the third quarter of 2004. Data on employment-per-facility, however, were adjusted by simple proportion to agree with total employment, by SIC code, in each county reported by the West Virginia Department of Commerce (2005). Data on employment reported by the West Virginia

**Table 6.** Water-use coefficients for industrial withdrawals in West Virginia.

[SIC, Standard Industrial Classification; gal/d, gallon per day. See References Cited section for complete reference citation.]

| SIC code (major category) | Description of industry | Withdrawal | |
|---|---|---|---|
| | | Coefficient, in gal/d per employee | Reference |
| 2900 | Petroleum refining and related industries | 163,000 | van der Leeden and others, 1990 |
| 2800 | Chemicals and allied products | 40,300 | van der Leeden and others, 1990 |
| 2600 | Paper and allied products | 38,900 | van der Leeden and others, 1990 |
| 3300 | Primary metal industries | 21,200 | van der Leeden and others, 1990 |
| 2100 | Tobacco products | 6,100 | van der Leeden and others, 1990 |
| 3700 | Transportation equipment | 4,600 | van der Leeden and others, 1990 |
| 2000 | Food and kindred products | 4,200 | van der Leeden and others, 1990 |
| 3200 | Stone, clay, glass, and concrete products | 3,100 | van der Leeden and others, 1990 |
| 3000 | Rubber and miscellaneous plastics products | 2,900 | van der Leeden and others, 1990 |
| 3600 | Electronic and other electrical equipment and components, except computer equipment | 2,500 | van der Leeden and others, 1990 |
| 2200 | Textile mill products | 1,800 | van der Leeden and others, 1990 |
| 2400 | Lumber and wood products, except furniture | 1,600 | van der Leeden and others, 1990 |
| 3800 | Measuring, analyzing, and controlling instruments; photographic, medical and optical goods; watches and clocks | 1,200 | van der Leeden and others, 1990 |
| 3500 | Industrial and commercial machinery and computer | 1,000 | van der Leeden and others, 1990 |
| 3400 | Fabricated metal products, except machinery and transportation equipment | 800 | van der Leeden and others, 1990 |
| 3900 | Miscellaneous manufacturing industries | 300 | van der Leeden and others, 1990 |
| 3100 | Leather and leather products | 200 | van der Leeden and others, 1990 |
| 2500 | Furniture and fixtures | 120 | van der Leeden and others, 1990 |
| 2300 | Apparel and other finished products made from fabrics and similar materials | 100 | van der Leeden and others, 1990 |
| 1500 | Building construction general contractors and operative builders | 54.2 | Planning and Management Consultants, Ltd., 1995; viewable at Horne, 1999 |
| 1700 | Construction special trade contractors | 24.8 | Planning and Management Consultants, Ltd., 1995, viewable at Horne, 1999 |
| 1600 | Heavy construction other than building construction | 20.2 | Planning and Management Consultants, Ltd., 1995, viewable at Horne, 1999 |

Department of Commerce were referenced to the North American Industry Classification System (NAICS), and were converted to the older SIC-code system using corresponding tables from the U.S. Census Bureau (2004b). The adjusted employment data for each SIC code in a county were multiplied by water-use coefficients (table 6) to calculate the industrial water use. These coefficients account for major withdrawals in heavy manufacturing for cooling water, of which only a trace is consumptive use.

## Irrigation

Irrigation water use includes water that is applied by an irrigation system to sustain plant growth in all agricultural and horticultural practices. This category also includes water that is applied for pre-irrigation, frost protection, application of chemicals, weed control, field preparation, crop cooling, harvesting, dust suppression, leaching salts from the root zone, and water lost in conveyance. Irrigation of golf courses, parks, nurseries, turf farms, cemeteries, and other self-supplied landscape-watering uses also are included. Water used for application to domestic lawns and gardens is not included in this category but is included in the domestic water-use category. Golf-course and agricultural uses are the only two forms of irrigation significant enough to measure in West Virginia, and total irrigation was estimated by summing the use for golf courses and agriculture. The estimated golf-course use is much greater than agriculture use and more confidence is given to the golf-course estimates than the agriculture estimates.

West Virginia had the lowest estimated irrigation of any state or territory of the United States in 2000 (Hutson and others, 2004). Only about 0.036 Mgal/d was withdrawn in 2004 for irrigation from surface-water sources and 0.036 Mgal/d was withdrawn from ground-water sources (table 5). Although it is only a small part of statewide water use, irrigation water use in 2004 was almost double that estimated in the USGS 2000 study.

*Estimating Method.* — There were approximately 1,728 golf holes in the state in 2004 (U.S. Golf Course Directory, 2006). In 1990, the West Virginia Geologic and Economic Survey received responses to questionnaires on irrigation from about 60 percent of all golf courses in West Virginia at that time (J.S. McColloch, West Virginia Geologic and Economic Survey, personal comm., April 21, 1998). From the questionnaires, it was determined that an annual average of about 5.37 gal/d per golf hole was applied in West Virginia and that the area irrigated per hole was about 1.71 acres. The value of 5.37 gal/d per hole was used for the 1995, 2000, and 2004 irrigation water-use estimates. It was estimated, therefore, that there were 2,955 golf course acres irrigated in 2004, by multiplying 1,728 golf holes by 1.71 acres per hole.

The irrigation estimates for agricultural water use were computed by multiplying an application rate by the number of agricultural acres irrigated. The values for application rates for agriculture, however, have significant uncertainty. The application rate determined by the 1998 Farm and Ranch Irrigation Survey (U.S. Department of Agriculture, 1999) was 0.5 (acre-ft/acre)/yr (6 in./yr) for West Virginia and Ohio, and increased to 1.1 (acre-ft/acre)/yr (13.2 in./yr) in 2002 (U.S. Department of Agriculture, 2004a). For this 2004 study, the West Virginia agricultural application rates were reduced to 1/3 of the smallest Farm and Ranch Irrigation Survey values (1999) because it was considered that West Virginia has greater annual rainfall and more frequent precipitation events than does Ohio, thus reducing the necessity for irrigation. An application rate of 0.17 (acre-ft/acre)/yr (2 in./yr) was used for the 2004 irrigation water-use estimates.

Estimates of irrigated acres by the USDA and the USGS have varied greatly since 1965 as demonstrated by the variation in number of irrigated farms, withdrawals, and irrigated acres (table 7). The USDA and USGS definition of irrigated acres are related, but the USGS estimates include mostly golf courses and agricultural acres, except for the 1990 estimate when only golf-course acres were used. In addition, it is believed that 20 percent of the most recent USDA total of irrigated agricultural acres is a more reasonable estimate for calculating irrigation water use. The 20-percent estimate was used in the 1995-2004 USGS studies. It is assumed in this report that half of the supply for irrigation was from surface water and half was from ground water.

**Table 7.** Estimated irrigated acres and withdrawals for irrigation in West Virginia, 1965-2004.

[USDA. U.S. Department of Agriculture; USGS, U.S. Geological Survey; acre-ft/yr, acre-foot per year; Mgal/d, million gallon per day. See References Cited section for complete reference citation.]

| Year | Reference | USDA (agriculture only) | | USGS (agricultural and golf courses) | |
|---|---|---|---|---|---|
| | | Number of Irrigated farms | Irrigated acres | Withdrawals in acre-ft/yr and Mgal/d[1] | Irrigated acres |
| 1965 | (USGS) Murray, 1968 | | | 1,500 acre-ft/yr (1.34 Mgal/d) | 2,500 |
| 1969 | USDA, 1994 | 130 | 3,166 | | |
| 1970 | (USGS) Murray and Reeves, 1972 | | | 1,600 acre-ft/yr (1.43 Mgal/d) | 2,600 |
| 1974 | USDA, 1994 | 113 | 1,513 | | |
| 1975 | (USGS) Murray and Reeves, 1977 | | | 1,400 acre-ft/yr (1.25 Mgal/d) | 2,400 |
| 1978 | USDA, 1994 | 116 | 1,236 | | |
| 1980 | (USGS) Solley and others, 1983 | | | 1,500 acre-ft/yr (1.34 Mgal/d) | 2,400 |
| 1982 | USDA, 1994 | 135 | 945 | | |
| 1985 | (USGS) Solley and others, 1988 | | | 4,200 acre-ft/yr (3.74 Mgal/d) | 4,100 |
| 1987 | USDA, 1994 | 255 | 3,132 | | |
| 1990 | (USGS) Solley and others, 1993 | | | 0.007 Mgal/d [2] (7.84 acre-ft/yr) | 2,230 [2] |
| 1992 | USDA, 1994 | 312 | 2,769 | | |
| 1995 | (USGS) Solley and others, 1998 | | | 0.01 Mgal/d [3] (11.2 acre-ft/yr) | 2,820 [3] |
| 1997 | USDA, 2004 | 319 | 3,543 | | |
| 2000 | (USGS) Hutson and others, 2004 | | | 0.04 Mgal/d [3] (44.8 acre-ft/yr) | 3,190 [3] |
| 2002 | USDA, 2004 | 408 | 1,981 | | |
| 2004 | (USGS) This report | | | 0.07 Mgal/d [3] (78.4 acre-ft/yr) | 3,966 [3] |

1 Published values are outside parentheses and converted values are within parentheses.

2 The value 0.007 was published as zero and the estimate was for golf courses only.

3 The estimate was for golf courses plus 20 percent of the agriculture use from the most recent USDA reference.

## Commercial

Commercial use included self-supplied water for businesses such as restaurants, motels, and car washes, but also included use by institutions such as churches and schools. Water withdrawal for commercial use in West Virginia during 2004 was about 16.7 Mgal/d from surface-water sources and about 16.0 Mgal/d from ground-water sources (table 5). Commercial withdrawals for 2004 were down 28 percent from 45.6 Mgal/d in 1995.

*Estimating Method.* — Commercial water use for each county was estimated by multiplying the number of employees working in commercial businesses by a water-use coefficient for each type of commercial operation (table 8). A Harris InfoSource (2004) database on West Virginia businesses was used as the primary source of information for the 2004 commercial water-use estimates. This database contained information on individual facility locations, SIC codes, and employment per facility for the third quarter of 2004. The commercial SIC codes were generally those greater than 4,000 except for the following codes that related to other water uses: 4911 Electric Services, 4941 Water Supply, 4952 Sewerage Systems, 4971 Irrigation Systems, 7992 Public Golf Courses, 7997 Membership Sports and Recreation Clubs, and 8811 Private Households. Data on employment-per-facility were adjusted by simple proportion to agree with total employment, by SIC code, in each county reported by the West Virginia Department of Commerce (2005). Data on employment reported by the West Virginia Department of Commerce were referenced to the North American Industry Classification System (NAICS), and were converted to the older SIC code system using correspondence tables from the U.S. Census Bureau (2004b). The adjusted employment figures for each SIC code in each county were multiplied by water-use coefficients (table 8) and summed to calculate the commercial water use.

## Mining

Mining water use includes water for the extraction of minerals that may be in the form of solids such as coal, iron, sand, and gravel; liquids such as crude petroleum; and gases such as natural gas. The category includes quarrying, milling (crushing, screening, washing, and flotation of mined materials), re-injecting extracted water for secondary oil recovery, and other operations associated with mining activities. Recirculation implies that there is a beneficial use, but withdrawals are a fraction of recirculation rates. All mining withdrawals are considered self-supplied. Dewatering is not reported as a mining withdrawal unless the water was used beneficially, such as dampening roads for dust control. Although dewatering is not considered a water use, the 2004 dewatering estimate was 593 Mgal/d; about 37 percent of this was from surface mines, 61 percent was from deep mines, and 2 percent was from quarries.

Water withdrawal for mining use in West Virginia during 2004 was about 9.78 Mgal/d from surface-water sources and about 4.89 Mgal/d from ground-water sources (table 5). The 2004 estimate of surface-water withdrawals for mining was about 31 percent greater than that estimated in the USGS 1995 study, and the estimate of ground-water withdrawals was about 32 percent greater. About 4 percent of mining ground-water withdrawals in 2004 was saline water withdrawn as a result of oil and gas production.

*Estimating Method.* —The estimated mining water use was calculated by summing the withdrawals for quarrying, oil and gas drilling and production, and coal mining. Coal mining withdrawals (surface, auger, and deep mines) include the use for mining dust suppression on haul roads, coal-mining machines (drills, augers, conveyors, long-wall shearerclearer, etc…) and coal preparation and related facilities (docks, tipples, shower houses, etc…). Water withdrawals for

**Table 8.** Water-use coefficients for commercial withdrawals in West Virginia.
[SIC, Standard Industrial Classification; gal/d, gallon per day. See References Cited section for complete reference citation.]

| SIC code (major category) | Description of business | Withdrawal | |
|---|---|---|---|
| | | Coefficient, in gal/d per employee | Reference |
| 8400 | Museums, art galleries, and botanical and zoological gardens | 343 | Dziegielewski and others, 1990 |
| 6500 | Real estate | 313.2 | Cook and others, 2001 |
| 7200 | Personal services | 276.9 | Davis and others, 1988 |
| 6200 | Security and commodity brokers, dealers, exchanges, and services | 221 | Dziegielewski and others, 2000 |
| 5800 | Eating and drinking places | 186.6 | Davis and others, 1988 |
| 7900 | Amusement and recreation services | 175[1] | Davis and others, 1988 |
| 6400 | Insurance agents, brokers, and service | 162 | Dziegielewski and others, 1990 |
| 6000 | Depository institutions | 107.9 | Cook and others, 2001 |
| 5100 | Wholesale trade-non-durable goods | 77.36 | Cook and others, 2001 |
| 6300 | Insurance carriers | 76.71 | Cook and others, 2001 |
| 8600 | Membership organizations | 72 | Davis and others, 1988 |
| 8000 | Health services | 70 | Davis and others, 1988 |
| 6700 | Holding and other investment offices | 56.51 | Cook and others, 2001 |
| 8200 | Educational services | 55.6 | Davis and others, 1988 |
| 4100 | Local and suburban transit and interurban highway passenger transportation | 47.2 | Davis and others, 1988 |
| 6100 | Non-depository credit institutions | 31.92 | Cook and others, 2001 |
| 5400 | Food stores | 31.3 | Davis and others, 1988 |
| 5000 | Wholesale trade-durable goods | 20.58 | Cook and others, 2001 |
| 5200 | Building materials, hardware, garden supply, and mobile home dealers | 19.3 | Davis and others, 1988 |
| 7500 | Automotive repair, services, and parking | 19.1 | Davis and others, 1988 |
| 4900 | Electric, gas, and sanitary services | 6.7 | Davis and others, 1988 |

[1] Withdrawal coefficient is based on various individual coefficients in this major category (Davis and others, 1988).

mining were estimated to be 1/3 groundwater and 2/3 surface water (J.S. McColloch, West Virginia Geologic and Economic Survey, personal comm., April 21, 1998).

The rate of water withdrawals by quarrying in the 1990 study was about 8.5 Mgal/d per 100 million tons for limestone and 40 Mgal/d per 100 million tons for sand or sand and gravel produced, and these values were used in this study. For the 2004 estimates, the 2002 quarry production per county (West Virginia Office of Miners Health, Safety, and Training, 2004) was multiplied by the rates and summed to compute 2.12 Mgal/d as the water use for quarrying.

State oil and gas drilling and production water use was estimated by multiplying the production by the heating value by a use coefficient for each county, and summing. The county oil and gas drilling production for 2002 was used for 2004, as available from West Virginia Office of Miners' Health Safety and Training (2004) and from the West Virginia Geologic and Economic Survey (2006). The heating values used for this study were 125,000 BTU/Gallon for oil and 900,000 BTU/MCF for gas (Beck, 1931). The use coefficient applied was 3.05 gallons per million BTU (van der Leeden and others, 1990). About 1/3 of the total oil and gas ground-water withdrawal was considered saline (J.S. McColloch, West Virginia Geologic and Economic Survey,

personal comm., April 21, 1998). The total freshwater withdrawal for oil and gas drilling and production was 1.55 Mgal/d.

Withdrawal for coal mining was estimated as the sum of estimates for dust control on haulroads, coal preparation plants, and coal extraction. Water applied for dust suppression on haul roads for each county was estimated by multiplying the area of haul roads by an application rate and then summed. The area of haul roads in each county was determined from a Geographical Information System (GIS) coverage of haul roads for 2004 (West Virginia Department of Environmental Protection, 2005). An application rate of 534.6 gal/acre (about 0.02 in.) was available from dust management studies conducted by Thompson and Visser (2002). This amount per treatment was assumed to be applied for 50 treatments per year in West Virginia. The estimate for dust control on haul roads was 1.03 Mgal/d. From questionnaires, the 2004 total withdrawal for coal preparation plants was estimated to be 9.48 Mgal/d. Coal extraction was estimated to have the smallest withdrawals in coal mining, at 0.50 Mgal/d for the state. The 2004 total estimate for coal mining was 11.0 Mgal/d (1.03 Mgal/d for haulroads, plus 9.48 Mgal/d for coal preparation plants, plus 0.5 Mgal/d for coal extraction), and withdrawals were allocated to counties by coal production (West Virginia Office of Miners' Health Safety and Training, 2006).

The total withdrawal for mining in 2004 was about 14.7 Mgal/d (2.12 Mgal/d for quarrying, plus 1.55 Mgal/d for oil and gas drilling and production, plus 11.0 Mgal/d for coal mining), and was about 4.9 Mgal/d from ground-water sources (1/3 of the total) and about 9.80 Mgal/d from surface-water sources (2/3 of the total). The 9.48 Mgal/d for coal preparation plants accounted for about 65 percent of the total withdrawal for mining. The 14.7 Mgal/d total mining withdrawal represented a 32-percent increase since 1995 (Solley and others, 1998). The total withdrawal for quarrying and coal mining in 1995 of 10.1 Mgal/d (separate estimates were not available from Solley and others, 1998) increased by 30 percent to 13.13 Mgal/d in 2004.

## Summary

The U.S. Geological Survey (USGS), in cooperation with the West Virginia Department of Environmental Protection (WVDEP), estimated the quantity of surface water and ground water used within West Virginia, for the entire state and each county, and for seven water-use categories: public supply, domestic, thermoelectric power, industrial, irrigation, commercial, and mining. Instream water uses, including hydroelectric power generation, were not considered.

About 4,787 Mgal/d of water were withdrawn from surface-water and ground-water sources in 2004, with about 4,641 Mgal/d (97 percent) from surface-water sources and about 146 Mgal/d (3 percent) from ground water. The largest surface-water withdrawals were in Grant and Mason Counties of about 1,156 Mgal/d and 1,090 Mgal/d, respectively. The largest ground-water withdrawals were in Berkeley and Wood Counties of about 12.0 and 12.8 Mgal/d, respectively. The proportions of surface-water and ground-water withdrawals were similar in 1995 and 2004.

Total withdrawals for public supply were 189 Mgal/d, of which 152 Mgal/d were from surface-water sources and 37 Mgal/d were from ground-water sources. Kanawha County withdrew 34 Mgal/d, which was more surface water for public supply than any other county in the state. Wood County withdrew 7.59 Mgal/d, which was more ground water for public supply than any other county in the state. Estimates were made by summing data available in a WVDEP internal database augmented with estimates based on information from USEPA, SDWIS database (U.S. Environmental Protection Agency, 2006). Public-supply withdrawal for 2004 was about the same as the 2000 withdrawal and increased 7 percent from 1995.

The total domestic water withdrawal was estimated at 33.5 Mgal/d, with 98 percent from ground water and 2 percent from surface water. Estimates were made by multiplying domestic self-

supplied population by a domestic self-supplied  per capita coefficient where the domestic self-supplied population equaled the total population minus the retail population. The retail population was estimated as the suppliers' percentage of the total declared retail population for a county multiplied by the 2004-adjusted 1990 U.S. Census percentage of that county on public supply by the population for that county. Domestic withdrawal for 2004 was about 18 percent less than estimates for 1995.

There were 17 fossil-fuel, steam-generating thermoelectric power plants operated in the state in 2004, 10 plants with once-through cooling systems and 7 plants with recirculation cooling systems. Water withdrawal from surface-water sources was about 3,406 Mgal/d for plants with once-through cooling systems and about 145 Mgal/d for plants with recirculation cooling systems. Water withdrawal from ground-water sources was only a trace for plants with once-through cooling systems and about 0.20 Mgal/d for plants with recirculation cooling systems. Thermoelectric power used the greatest amount of water compared to the other water-use categories. Reported flows from WVDEP questionnaires provided the information on total withdrawals for this category. Withdrawals for thermoelectric power for 2004 were about 10 percent less than estimates for 2000 and about 18 percent greater than estimates for 1995.

Water withdrawal by industries was about 911 Mgal/d from surface-water sources, mostly used for cooling, and was about 54 Mgal/d from ground-water sources. Estimates were made by converting employment data organized by NAICS codes into SIC code categories and multiplying by water-use coefficients for SIC code categories. Withdrawals decreased from 1316 Mgal/d in 1995 to 968 Mgal/d in 2000, then to 965 Mgal/d in 2004. Industrial withdrawal for 2004 was about 27 percent less than estimates for 1995 and about the same as the estimate for 2000.

West Virginia has the lowest estimated irrigation of any state or territory of the United States. Only about 0.036 Mgal/d were withdrawn from surface-water sources and 0.036 Mgal/d were withdrawn from ground-water sources for irrigation during 2004. Estimates were made by summing the use for golf courses and agriculture. Golf-course estimates were made based on responses to a 1990 questionnaire. Agriculture estimates were based on an application rate of 33 percent of the Ohio irrigation rate, and were estimated at 0.17 (acre-ft/acre)/yr (2 in./yr). Irrigation withdrawals for 2004 were about double that estimated for 2000.

Water withdrawal for commercial use was about 16.7 Mgal/d from surface-water sources and about 16.0 Mgal/d from ground-water sources. As in the industrial category, estimates were made by multiplying employment data converted from the NAICS to SIC codes by water-use coefficients. Estimated withdrawals decreased about 28 percent from 45.6 Mgal/d in 1995 to 32.7 Mgal/d in 2004. Commercial withdrawals for 2004 were down 28 percent from 1995.

Water withdrawal for mining was about 9.78 Mgal/d from surface-water sources and about 4.89 Mgal/d from ground-water sources. Mining withdrawals for 2004 were about 31 and 32 percent greater for surface- and ground-water, respectively, than estimates for 1995.

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