WATER USE IN THE ST. JONES RIVER BASIN, KENT COUNTY, DELAWARE, 1983-86

By Daniel J. Phelan

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CONVERSION FACTORS AND ABBREVIATIONS

For those readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, the following conversion factors may be used:

Multiply inch-pound unit	*By*	*To obtain metric unit*
	Length	
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.189	meter per kilometer (m/km)
	Area	
acre	4,047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-inch (acre-in)	102.75	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per year (Mgal/yr)	0.000120	cubic meter per second (m^3/s)

SELECTED EQUIVALENTS (APPROXIMATIONS)

1 gallon	=	8.34 pounds
1 cubic foot	=	62.4 pounds
	=	7.48 gallons
1 acre-foot [1]	=	325,851 gallons
	=	43,560 cubic feet
1 acre-inch	=	27,154 gallons
	=	3,630 cubic feet
1 inch of rain	=	17.4 million gallons per square mile
1 million gallons	=	3.07 acre-feet
1 million gallons per year	=	2,740 gallons per day

[1] One acre covered uniformly by 1 foot of water.

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

$$°C = 0.555 (°F - 32)$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "*Sea Level Datum of 1929.*"

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ABSTRACT

The U.S. Geological Survey, in cooperation with the Delaware Department of Natural Resources and Environmental Control (DNREC), investigated water use in the St. Jones River basin, Kent County, Delaware, from 1983 through 1986. The DNREC presently requires water-use reports from users or suppliers of more than 50,000 gallons per day. Quantities of water withdrawn in Delaware by users of less than 50,000 gallons per day and quantities of consumptive use are not well known. This report presents information on total water use in the St. Jones River basin in central Delaware, so that water managers can develop better estimates of nonreported and consumptive water use in similar areas of the State.

The largest public suppliers of water in the St. Jones River basin are the city of Dover, Dover Air Force Base, and the towns of Camden, Wyoming, and Magnolia. Public-supplied water use in 1985 accounted for 54 percent (2,363 million gallons) of all water use in the basin. Self-supplied water use accounted for the remaining 46 percent (1,987 million gallons). In 1985, 93 percent of the total amount of water used was ground water, and 7 percent was surface water used for irrigation. Irrigation from both ground- and surface-water sources accounted for 24 percent (1,058 million gallons) of all water use in the basin.

In 1985, the total amount of water that was available for eventual discharge to the county wastewater system was about 3,130 million gallons per year. From 1983 through 1986, wastewater flow from the St. Jones basin averaged 2,147 million gallons per year. About 46 percent (1,430 million gallons per year) of the water supplied to systems discharging to the county wastewater system was lost to consumptive uses.

Agriculture accounts for the largest consumptive use of water in the basin. Thirty-nine percent of consumptive use in the basin is from agriculture, while power generation and public supply account for 25 and 22 percent of the total amount of water consumed, respectively. The remaining consumptive water use is by self-supplied commercial users (6 percent), industrial (6 percent), and domestic self-supplied (2 percent).

INTRODUCTION

The Delaware Department of Natural Resources and Environmental Control (DNREC) is responsible for allocating water resources in the State. Water managers need accurate and reliable estimates of current water withdrawals, return flows, and consumptive use to make equitable water-resource-allocation decisions. The DNREC presently requires water-use reports from users or suppliers of more than 50,000 gal/d (gallons per day). Although most reported public and industrial water withdrawals are metered by the users, some usage, particularly irrigation, is estimated. The quantities of consumptive water use (that part of water withdrawn that is evaporated, transpired, incorporated into products or crops, or otherwise removed from the immediate water environment) and self-supplied water use in Delaware are not well known.

Prior to this report, total water use in Delaware has been estimated by integrating quantities reported by large users with estimates based on national averages for various categories of small users. As the margin between water availability and water use decreases, broad estimates based on national averages will become inadequate for making local water-management decisions. For this reason, techniques for estimating withdrawals need to be improved. Furthermore, if withdrawal measurements are made in representative areas, then the data collected can be used to develop better estimates of water use in other similar localities throughout the State.

In 1983, as a result of this need, the U.S. Geological Survey, in cooperation with the DNREC, selected the St. Jones River basin in central Delaware as a representative area for conducting a detailed water-use study. The St. Jones basin was selected because all types of water use that are practiced throughout Delaware are represented in this one area.

Purpose and Scope

This report presents information on total water use in a representative area in central Delaware so that water managers can develop better estimates of nonreported water use in similar areas in the State. Water-use data were collected from 1983 through 1986 in the St. Jones River basin. Data are most complete for 1985 and are the basis for most of the analyses in this report. Pumpage data were collected for all reporting users in the basin. These users included public suppliers, industrial, commercial, institutional, and power-generation sources. Selected water-use data for the city of Dover, located near the center of the basin, were compiled from city records to determine water use for residential, commercial, industrial, and power-generation purposes.

Data on wastewater retum flows in the basin are collected by the Kent County Engineer's Office. Consumptive use is estimated from water-delivery data and reported wastewater flows. In this report, summaries of water-use and consumptive-use data are presented primarily in graphs and tables.

This report does not address the amount of freshwater available for use in the basin, but rather describes water-use patterns and trends from 1983 to 1986.

Previous Investigations

The first comprehensive inventory of water use in Delaware was done by Robertson (1975). Other water-use reports for Delaware include summaries for the years 1979 and 1982, prepared by the Department of Natural Resources and Environmental Control (1981; 1983). Analyses of wastewater systems and infiltration/inflow for the city of Dover were conducted by Betz Environmental Engineers, Inc. (1975), and Whitman, Requardt and Associates (1987).

Data-Collection Methods

Data used to prepare this report were obtained from many sources. Reported withdrawals in the St. Jones River basin were obtained from DNREC's Delaware Water Use Data System. Records showing the distribution of water to users served by the city of Dover were supplied by the city's Finance Office.

Estimates of self-supplied domestic, irrigation, and non-irrigation agricultural withdrawals were made by measuring pump-running time and discharge rate. Pump-running time was measured with time totalizing meters installed on pumping equipment. Pumping rates were determined with a Doppler-effect flow meter. Six irrigation wells and wells at two schools, four residences, and two chickenhouses were instrumented. Additional data on irrigation use were obtained from farmers who kept accurate records of the number of acre-inches of water applied during various growing seasons. Return-flow data for the Kent County sewer system were supplied by the Kent County Engineer's Office. Consumptive use was estimated based on water use and measured or estimated return flows.

Description of Study Area

The St. Jones River basin (fig. 1) drains 86 mi^2 (square miles) of central Kent County, Delaware, and extends 28.6 mi (miles) from northwest to southeast. The basin is bounded on the west by the Choptank River basin, on the north by the Little River and Leipsic River basins, and on the south by the Murderkill River basin (fig. 2). The Choptank River flows southwest to the Chesapeake Bay, and the St. Jones, Leipsic, and Murderkill Rivers flow into the Delaware Bay. Maximum land-surface elevations in the basin are about 75 ft (feet) along the western edge of the basin. Dover is the largest city in the St. Jones River basin.

Population and Land Use

In 1985, the population in the St. Jones basin was about 47,900. This estimate is based on population of census tracts entirely within the basin, and percentages of tracts not entirely within the basin. Average population density in the basin was 560 persons per square mile. Population densities ranged from 2,540 persons per square mile in parts of Dover, to 196 persons per square mile in rural areas in the northwestern part of the basin. The population of Kent County increased about 7 percent between 1980 and 1986 (C. C. Holland, Kent County Planning Office, written commun., 1987)

Fifty-six percent of the study area is cropland. Sixty-eight percent of the cropland is categorized as well-drained and moderately well-drained prime farmland. The remaining part of the study area is 19 percent woodland, 19 percent urbanized, and 6 percent tidal marsh (Richard Hall, U.S. Soil Conservation Service, oral commun., 1987).

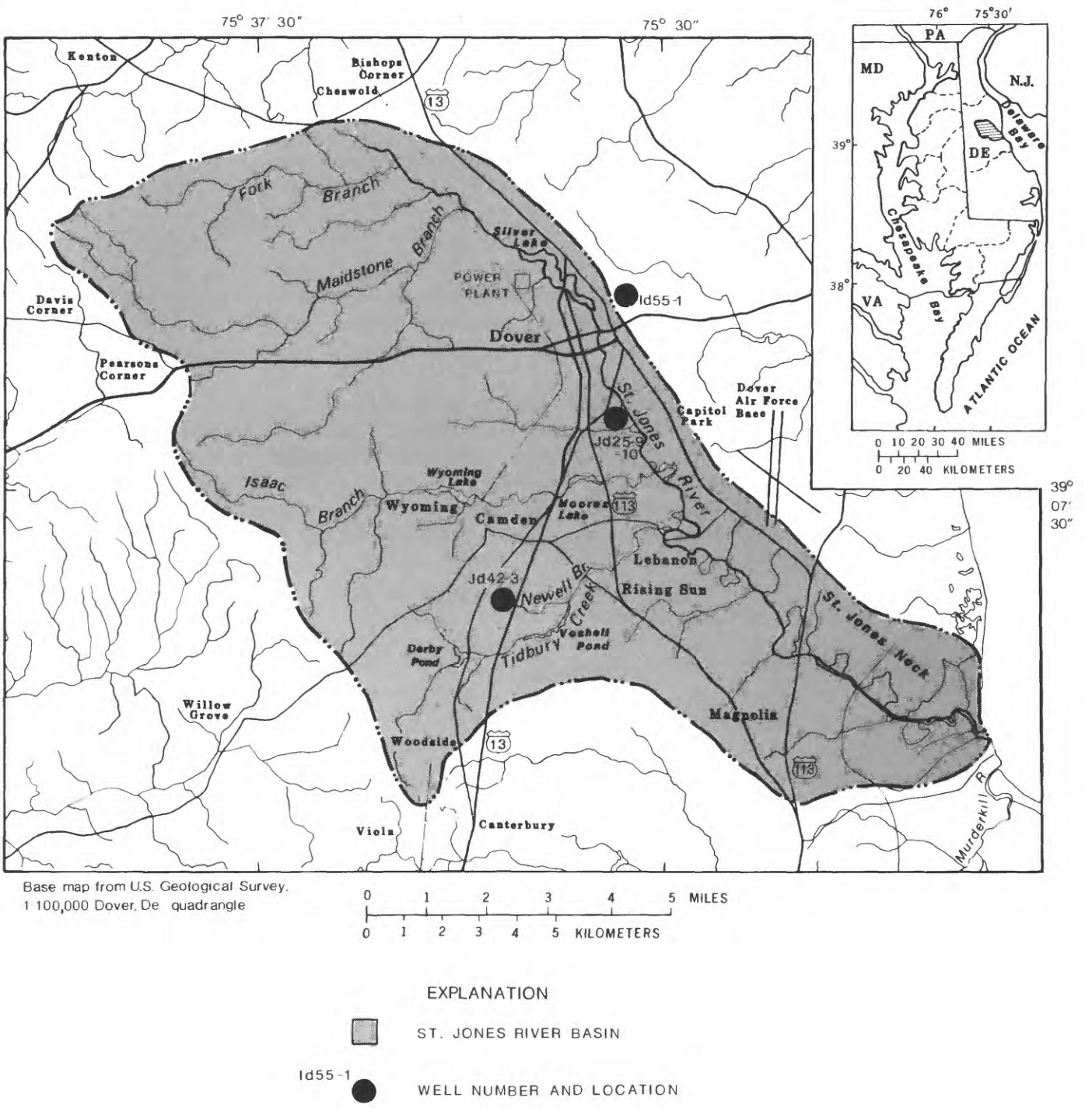


Figure 1.-- Location of study area and selected observation wells.

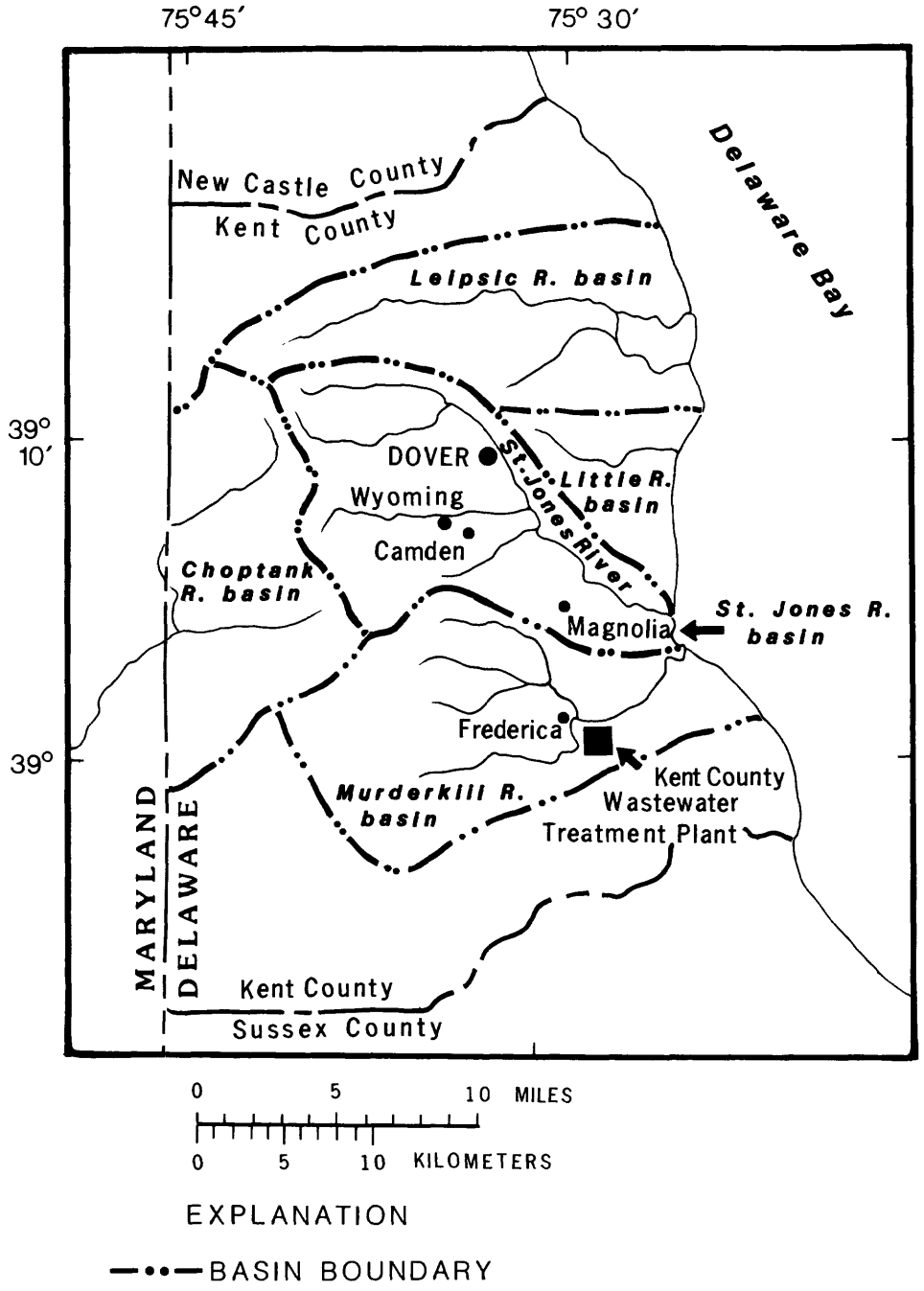


Figure 2.-- Location of the Kent County Wastewater Treatment Plant, the St. Jones River basin, and surrounding basins.

Climate

Delaware has a humid, continental climate with well-defined seasons. The Delaware and Chesapeake Bays and the Atlantic Ocean have considerable influence on the climate, as winds from the bays and ocean tend to moderate temperatures. Maximum afternoon summer temperatures average 89 °F (degrees Fahrenheit). Extremes of 100 °F or more can be expected once every 4 years. The coldest period is late January and early February when early morning temperatures average 24 °F. At Dover, the period between the last freezing temperature in the spring and the first freezing temperature in the fall averages 199 days (Matthews and Ireland, 1971, p. 2). The average annual temperature at Dover is 56 °F, and ranges from about -4 to 101 °F (U.S. National Oceanic and Atmospheric Administration, 1986).

Precipitation in the St. Jones River basin averages about 44 in. (inches) per year, varying monthly from an average minimum of less than 3 in. in February, to an average maximum of more than 5 in. in August (U.S. National Oceanic and Atmospheric Administration, 1986). Annual evapotranspiration losses in central Delaware were estimated by Mather (1969) to be about 25 in.

Hydrologic Setting

Ground-Water System

The St. Jones River basin is entirely within the Atlantic Coastal Plain, and is underlain by unconsolidated deposits of clay, silt, sand, and gravel. The sediments range in age from Early Cretaceous to Holocene and lie unconformably on crystalline basement rock. The principal water-bearing units in the study area are, in descending order, (1) the unconfined aquifer--chiefly sand units of the Columbia Group, (2) the Cheswold and Frederica aquifers of the Chesapeake Group, and (3) the sand units of the Magothy and Piney Point Formations (Leahy, 1982).

Water from the unconfined aquifer is used primarily by self-supplied residences and farms in the basin. Locally, elevated concentrations of iron and nitrate in the unconfined aquifer have resulted in limited use of the aquifer. The Dover power plant used water from the unconfined aquifer for cooling purposes from 1977 to 1987, until excessive iron concentrations forced the plant to discontinue its use.

The Piney Point and Cheswold aquifers provide most of the water used for all purposes in the St. Jones River basin. Increased pumpage from these aquifers has caused a significant decline of ground-water levels. Water levels in well Id55-1 in east Dover (fig. 1), which is screened in the Piney Point aquifer 329-349 ft below land surface, declined from about 70 ft below land surface in 1970 to nearly 165 ft below land surface in 1987 (fig. 3). Drawdowns of approximately 130 ft were observed in the Piney Point aquifer at the Dover Air Force Base (fig. 1) from 1952 to 1977 (Leahy, 1982, p. 2). Water levels in wells Jd25-9 and Jd25-10 in the Piney Point and Cheswold aquifers, respectively, south of Dover, are shown in figure 4. Water levels in well Jd25-9 have been declining since 1986, whereas water levels in well Jd25-10 have stabilized between 70 to 90 ft below land surface, considerably below prepumping levels. All of Dover's water is withdrawn from the Cheswold and Piney Point aquifers. Five production wells are screened in the Piney Point aquifer and eight are screened in the Cheswold aquifer. The Dover Air Force Base uses three wells in the Cheswold aquifer and two wells in the Piney Point aquifer for its water supply. The towns of Camden and Wyoming use one well in the Cheswold aquifer and one well in the Piney Point aquifer for a combined water supply.

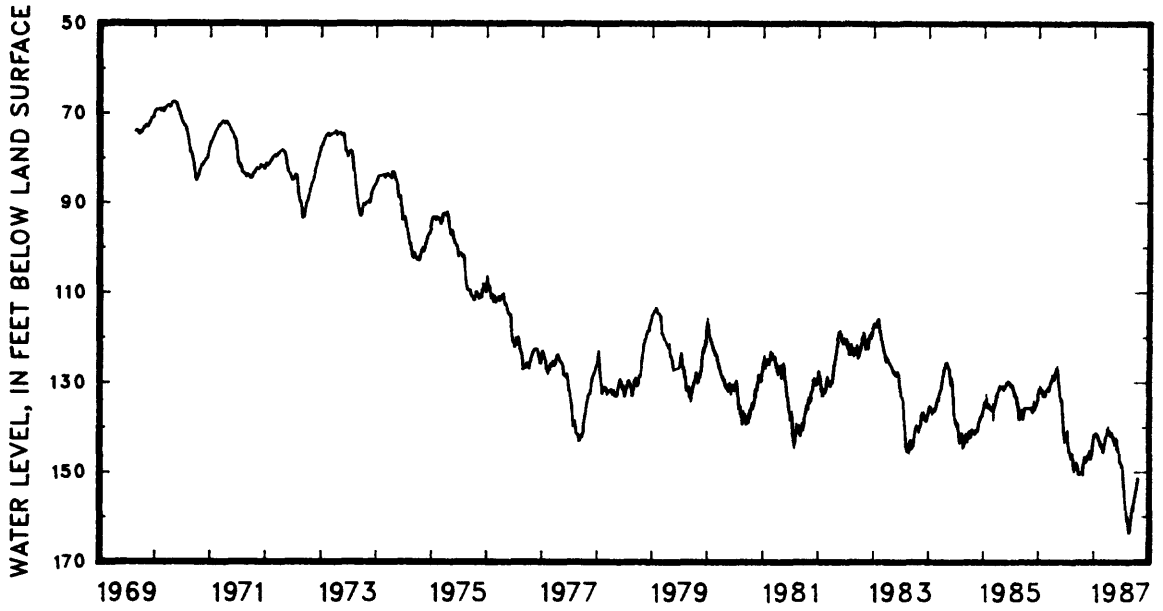


Figure 3.-- Water levels in well Id55-1 in the Piney Point aquifer at Dover, Delaware, 1969-87. (Elevation of land surface datum is 20 feet above sea level).

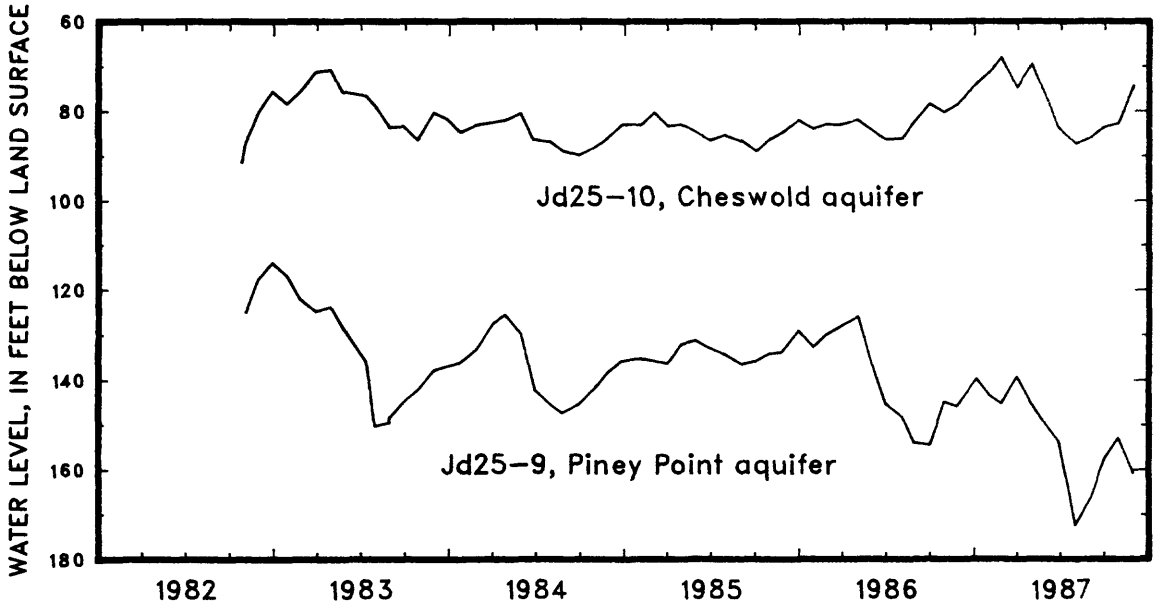


Figure 4.-- Water levels in wells Jd25-9 and Jd25-10 in the Piney Point and Cheswold aquifers at Dover, Delaware, 1982-87. (Elevation of land surface datum is 26 feet above sea level).

Reports that describe the hydrology of these aquifers in more detail include Johnston (1973), which describes the Columbia aquifer of Delaware, and Leahy (1976; 1978; 1979; and 1982), which describes the Cheswold and Piney Point aquifers in Kent County, Delaware.

Surface-Water System

The St. Jones River is tidal for approximately half its length, from the river's mouth at the Delaware Bay, upstream to Dover, 14 mi away (fig. 1). Discharge of the St. Jones River has been measured at Dover since 1958. Average discharge for the 28 years of record is 36.6 ft^3/s (cubic feet per second), or 23.7 Mgal/d (million gallons per day) from the 31.9-mi^2 drainage basin above the gaging station. This is equivalent to 15.58 $(in/yr)/mi^2$ (inches per year per square mile) of drainage area. Extreme flows for the period of record range from a maximum of 1,900 ft^3/s on September 13, 1960, to periods of no flow at times in 1959, 1961, and 1962. The average stream gradient of the St. Jones River upstream of the gage at Dover is 7.5 ft/mi.

The five largest manmade lakes and ponds in the basin are: Silver, Wyoming, and Moores Lakes, and Voshell and Derby Ponds (fig. 1). These lakes and ponds are used primarily for recreation. Wyoming Lake and Voshell and Derby Ponds are used periodically for irrigation by adjoining farms. Small privately owned farm ponds are scattered throughout the basin and several are used for irrigation.

Acknowledgments

The author is grateful to Arthur L. Hodges, Jr., retired from the U.S. Geological Survey, and Andrea Putcher and Caroline Webber, both formerly of the Department of Natural Resources and Environmental Control, for planning and conducting the early phases of this study. Stewart E. Lovell, Robert B. Dundas, and Judith H. Jordan of the Department of Natural Resources and Environmental Control assisted in collecting water-use data.

Thanks are given to George Inverso and Gregory Jackson of the Kent County Engineer's Office for their effort in compiling the wastewater-flow data used in this study. Appreciation is expressed to Constance Holland of the Kent County Planning Office for estimating basin population, and Michael Karia of the city of Dover for his help in determining water-use distribution in Dover. Acknowledgment is made of the many homeowners, farmers, and businesses that assisted in collecting water-use data from previously unmetered sources, and of water-department representatives who helped determine the local distribution of water use. Estimates of livestock populations in the St. Jones River basin are based on interviews with Robert Hockmuth and Richard Barczewski of the Delaware Cooperative Extension Service, and Gerald Truitt of the Delmarva Poultry Institute.

PUBLIC-SUPPLIED WATER USE

Public-supplied water is water withdrawn for all uses by public and private water suppliers and delivered to users that do not supply their own water (Solley, 1983). Figure 5 shows general areas served by public water supplies. The city of Dover operates the largest public-water system in the St. Jones River basin. Public water supplied by Dover to all categories of water users in 1985 totaled about 1,890 Mgal, or about 5.2 Mgal/d (M. Karia, city of Dover Finance Office, written commun., 1986). Thirty-three percent of the water was for domestic use, 32 percent for commercial use, 22 percent for industrial use, and 13 percent for thermoelectric power generation. In Dover, domestic water use in 1985 averaged 63 gal/d (gallons per day) per capita, based on a service population of 25,500. Table 1 shows quarterly and yearly totals of water use by category in the city of Dover service area during 1983-86.

Dover Air Force Base, which extends across the eastern boundary of the St. Jones River basin, operates its own water-supply system. Although more than half of the facility is outside the basin, almost all water use is within the basin because all buildings are inside the basin and the runways are outside the basin. In 1985, the base used 418 Mgal (1.14 Mgal/d) of water for all purposes. No estimates are available for the amount of water supplied for various use categories, except for the base-housing annex. In 1985, about 1,200 residents in the annex area, located west of Lebanon (fig. 5), used about 117 gal/d per capita, totaling 51.3 Mgal/yr. This figure is high for residential use perhaps because lawn watering is encouraged by the base-housing authority (Joseph Dietz, Dover Air Force Base Housing Office, oral commun., 1986).

The towns of Camden and Wyoming (fig. 5) use a combined system to supply about 3,600 residents with water. Water use in the service area averaged 97.6 Mgal/yr from 1983 through 1985. Per capita water use in Camden and Wyoming cannot be computed accurately because separate records of quantities used by commercial and residential accounts are not available.

The town of Magnolia (fig. 5) has a central water-supply system, but individual users are not metered. Ground-water withdrawals are metered at the supply wells. About 1,000 customers used 53 gal/d per capita in 1985, totaling about 19.4 Mgal/yr.

Industrial

Industrial water use is for purposes such as fabrication, processing, washing, and cooling, and includes use by industries such as steel, chemical, paper, mining, and petroleum refining (Solley and others, 1983, p. V). Three large industrial users of public-supplied water in the basin are in the city of Dover. Combined use of public-supplied water for these industries averaged 20 percent (369 Mgal/yr) of the total water supplied by the Dover system from 1983 through 1986 (table 1). Two of the three users withdraw additional water from on-site wells to augment the public supply. A garment-manufacturing plant is about 70 percent self-supplied, and a food-processing company is about 25 percent self-supplied. A paper-manufacturing plant is entirely supplied by the city of Dover. Average use of public-supplied water from 1983 through 1986 was 246 Mgal/yr for the food-processing company, 98 Mgal/yr for the paper plant, and 25 Mgal/yr for the garment plant.

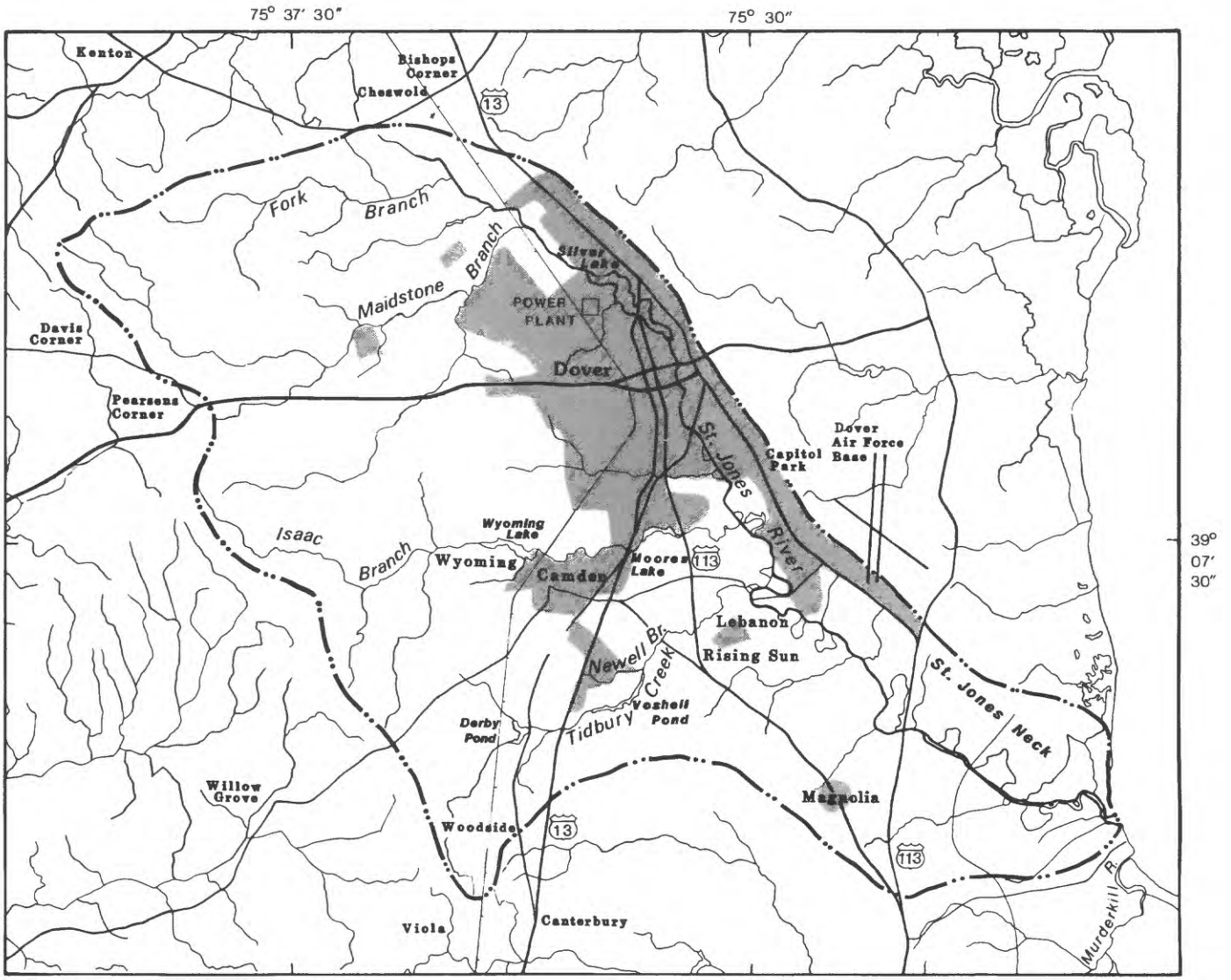


Figure 5.-- Areas served by public water supplies in the St. Jones River basin, Kent County, Delaware.

Table 1.--Water-use distribution in the city of Dover, Delaware, 1983-86

(Quantities are in million gallons)

Quarter years	Within city limits					Outside city limits			Total water use
	Residential	Commercial	Industrial	Power plant	Total	Residential	Commercial[1]	Total	
1983									
Jan-Mar	129.0	123.2	71.7	72.9	396.8	12.4	5.1	17.5	414.3
Apr-Jun	129.1	174.7	78.7	104.5	487.0	11.9	4.7	16.6	503.6
Jul-Sep	155.1	94.8	90.6	159.1	499.6	14.9	6.0	20.9	520.5
Oct-Dec	140.0	83.6	85.3	130.0	438.9	13.5	5.9	19.4	458.3
Total	553.2	476.3	326.3	466.5	1,822.3	52.7	21.7	74.4	1,896.7
1984									
Jan-Mar	133.3	302.0	88.1	116.7	640.1	13.5	5.8	19.3	659.4
Apr-Jun	128.0	133.7	88.1	95.8	445.6	11.4	4.3	15.7	461.3
Jul-Sep	143.2	26.0	90.4	109.6	369.2	12.6	6.8	19.4	388.6
Oct-Dec	139.0	68.2	96.6	136.9	440.7	13.5	6.2	19.7	460.4
Total	543.5	529.9	363.2	459.0	1,895.6	51.0	23.1	74.1	1,969.7
1985									
Jan-Mar	139.1	133.8	105.8	93.7	472.4	12.7	5.8	18.5	490.9
Apr-Jun	143.4	147.9	106.9	22.0	420.2	13.0	6.2	19.2	439.4
Jul-Sep	150.8	144.0	102.0	79.1	475.9	14.7	7.1	21.8	497.7
Oct-Dec	143.2	145.1	103.5	51.6	443.4	13.3	5.7	19.0	462.4
Total	576.5	570.8	418.2	246.4	1,811.9	53.7	24.8	78.5	1,890.4
1986									
Jan-Mar	135.1	134.7	84.3	82.5	436.6	12.6	5.9	18.5	455.1
Apr-Jun [2]	101.8	82.3	90.8	87.3	362.2	8.0	3.8	11.8	374.0
Jul-Sep [2]	117.6	131.8	95.1	133.0	477.5	9.9	4.7	14.6	492.1
Oct-Dec [2]	119.9	135.4	98.0	82.4	435.7	10.2	4.8	15.0	450.7
Total	474.4	484.2	368.2	385.2	1,712.0	40.7	19.2	59.9	1,771.9

[1] Commercial use includes institutional use.

[2] April to December 1986 figures were estimated from reported total city pumpage.

Commercial

Commercial water use in this report includes that used by motels, hotels, restaurants, office buildings, schools, public buildings, health-care facilities, churches and other commercial facilities. Most water for commercial use in the basin is supplied by the Dover system. Commercial use represents about 32 percent (596 Mgal/yr) of the total water supplied by the city of Dover. In 1985, about 960 commercial accounts were supplied by the Dover system. Average commercial water use in Dover in 1985, excluding industrial and thermoelectric users, was about 0.62 Mgal/yr per account (1,700 gal/d per account). Although the precise number of commercial establishments in the St. Jones River basin was not known, it was estimated that about 90 percent were supplied by the Dover water system. About 5 percent, or 53 of the establishments in the basin, received water from other public suppliers. Thus, about 1,013 of the estimated 1,066 commercial water users in the basin received public-supplied water, totaling about 629 Mgal/yr.

Domestic

In 1985, about 90 percent of the population (42,440 residents) in the St. Jones River basin was served by public water-supply systems. In 1985, the city of Dover supplied water to about 25,500 people in 6,300 residential units within and outside of the city. The estimated number of residents served by municipal or community water supplies in the St. Jones River basin in 1985 are listed in table 2 (Jeff Beaman, Delaware Division of Public Health, written commun., 1986).

Average domestic water use in Dover was about 63 gal/d per capita. Using that figure, the average domestic use of public-supplied water use in the St. Jones River basin was about 976 Mgal/yr (2.67 Mgal/d). Average domestic water use in urbanized areas of New Castle County, Del. (fig. 2), was 71 gal/d per capita (Water Resources Agency for New Castle County, 1981, p. 24), which was consistent with the national average of 78 gal/d per capita (Solley, 1988). Residential usage of 56 gal/d per capita in rural areas of southern New Castle County was less than the usage in urbanized areas.

Domestic per-capita water-use figures from different sources are not always comparable. Some sources may estimate per-capita use as the total quantity of water supplied to a system, divided by the population. This method does not account for industrial, commercial, institutional, and other nondomestic amounts, and consequently, domestic per-capita water-use estimates are three or four times larger than the actual amount. For example, unadjusted water use for the city of Dover in 1986 was 180 gal/d per capita, but this figure does not represent actual domestic per-capita water use because of the industrial, commercial, and institutional quantities included.

Power Generation

The city of Dover generates electricity at the McKee Run power plant in northwest Dover (fig. 1). The plant serves an 88-mi^2 area with two 16-megawatt (MW) and one 110-MW generating units.

The major uses of water in power plants are for cooling and for generating steam to drive turbine generators. Table 1 shows quarterly water use by the Dover power plant from 1983 through 1986. Water use averaged 0.87 gallons per kilowatt hour or 389 Mgal/yr (1.07 Mgal/d) during 1983-86. About 69 Mgal/yr of cooling water is discharged from the power plant to a tributary of Silver Lake (fig. 1) in Dover (Phillip Kosek, McKee Run Power Plant, oral commun.,

Table 2.--Estimated number of residents served by municipal or community water-supply systems in the St. Jones River basin, Delaware, 1985

Water-supply systems	*Number of residents*
Municipalities	
Dover	25,500
Magnolia	1,000
Camden-Wyoming	3,600
Total, municipalities	30,100
Other housing developments	
Burrwood Farms	80
Camden Park	1,200
Carlisle Village	110
Dover Air Force Base Annex [1]	1,200
Dover Air Force Base [2]	8,000
Generals' Green	480
King's Cliff [3]	353
Lakeland [3]	557
Park View [3]	120
Voshell's Cove	240
Total, other housing developments	12,340
Grand total, municipalities and other housing developments	42,440

[1] Off-base housing near Lebanon.
[2] Housing in and adjacent to the base.
[3] Mobile-home park.

1989). About 82 percent of the water that enters the plant is eventually evaporated from the cooling towers; less than 1 percent of the water is used for other purposes.

Miscellaneous Uses

The sum of unaccounted water and revenue-producing water should equal the total amount of water produced from all sources in a municipal water system. The unaccounted water includes water withdrawn from hydrants for firefighting, line flushing and cleaning, and exfiltration (water that leaks from the distribution system). Estimates of the quantity of water used for firefighting are not available. About 250,000 gallons per month (3 Mgal/yr) are used by the city of Dover for line flushing and cleaning. This accounts for less than 0.2 percent of the total public-supplied water. The Dover Water Department estimates 10- to 12-percent (about 200 Mgal/yr) unaccounted water for the entire system (A. Gersitz, city of Dover Water Department, oral commun., 1987). This is consistent with the median value of 11 percent unaccounted water from public-owned utilities that serve more than 10,000 people, according to a nationwide survey of 1,397 utilities taken in 1980 (Seidel, 1985, p. 34). Estimates of unaccounted water for other distribution systems in the St. Jones River basin are not available.

SELF-SUPPLIED WATER USE

Industrial

Major self-supplied industrial water users in the St. Jones River basin include a garment company and a food company in Dover, and a chemical manufacturing plant north of Dover. The garment company uses ground water for manufacturing purposes and the food company uses ground water for cooling purposes; both use municipal water for all other purposes. The chemical company uses ground water and is entirely self-supplied. Annual amounts of self-supplied water for industrial use for 1980-86 are given in the following table.

Self-supplied industrial water use in the St. Jones River basin

[*Units are in million gallons per year*]

	Type of industry			
Year	*Garment*	*Food*	*Chemical*	*Total*
1980	[1] 71.2	48.2	143.6	263.0
1981	[1] 71.2	50.0	140.5	261.7
1982	[1] 71.2	46.9	116.3	234.4
1983	[1] 71.2	43.3	134.7	249.2
1984	71.2	42.6	142.4	256.2
1985	58.2	[2] 102.5	183.3	344.0
1986	59.4	[2] 122.2	124.2	305.8

[1] Estimates based on 1984 sewer-meter readings.
[2] Includes about 80 Mgal/yr for self-supplied power generation.

Because the garment company does not meter ground-water withdrawals, estimates of water use were based on sewer-meter readings for a plant in Dover that uses only self-supplied water. Sewer-meter readings are estimated to be 1 percent less than ground-water pumpage because of evaporation during the manufacturing process (Brian Huntington, Playtex, oral commun., 1988). About 70 percent of the water used by the company is self-supplied; the rest is supplied by the city of Dover.

The large increase in water use in 1985 by the food company was caused by the completion of a new power-generating station for the plant. In 1985, 80.3 Mgal (0.22 Mgal/d) of the 102 Mgal used at the plant was for power generation.

A concrete-mixing plant near the Dover Air Force Base uses about 4.7 Mgal/yr of ground water for washing operations and mixing concrete (James White, Capital Concrete, oral commun., 1986). A sand and gravel mining operation at the same location uses water in dredging and washing operations, but recirculates all water. Excluding water used for power generation at the food company, about 42 percent (269 Mgal/yr) of all industrial water use in the basin was self-supplied in 1985.

Commercial

As stated previously, about 90 percent (960 users) of commercial accounts in the basin were supplied by the city of Dover water system. About 5 percent (53 users) of commercial accounts were served by other public water systems, and the remaining 5 percent (53 users) were self-supplied. Using the average commercial water-use figure of 0.62 Mgal/yr per account, as determined from public-supply data, about 33 Mgal/yr (0.09 Mgal/d) of water use were by self-supplied commercial users in the St. Jones River basin. Additionally, two elementary schools in Rising Sun (fig. 1) used approximately 1.8 Mgal/yr of water during 1985-86, raising the total self-supplied commercial water use in the basin to about 35 Mgal/yr.

Water use by the Dover Air Force Base is not included in the above accounting of commercial use. Military water use is generally considered to be commercial, but is reported separately here because of its large magnitude. Reported water use at the Air Force Base during 1983-86 is given in the following table.

Year	Water use (Mgal/yr)
1983	481.4
1984	491.5
1985	417.7
1986	492.1

The average water use for 1983-86 was 470.7 Mgal/yr (1.29 Mgal/d).

Because Dover Air Force Base does not keep records of distribution, the water supplied to an adjacent section of base housing and some commercial users adjacent to the base system is not known.

Domestic

Four rural self-supplied residences in the St. Jones River basin were equipped with flow-measuring devices to help estimate domestic water use. Instruments at two of the original four residences provided acceptable data and showed water use of 49 and 66 gal/d per capita (averaging about 58 gal/d per capita). Assuming this figure is representative of rural domestic water use in the area, the 5,460 self-supplied residents in the basin used slightly more than 116 Mgal/yr (0.32 Mgal/d) of water. Reliability of this estimate is low because of the small sample size.

Power Generation

The only self-supplied power generation system in the basin is at the food plant in west Dover. Since 1985, about 80.3 Mgal/yr (0.22 Mgal/d) of water has been used to cool the 16-MW unit. The amount of water used for power generation at the plant before 1985 was not significant and was included with self-supplied industrial water use.

Agricultural

Agricultural water use includes primarily irrigation and livestock watering. Values for domestic self-supplied water use on farms were included in the self-supplied domestic water-use values.

Irrigation

In 1985, 31 wells and 21 surface-water sites in the St. Jones River basin were permitted by the DNREC for withdrawals for irrigation. According to DNREC withdrawal-allocation data, about 7,500 acres in the basin are irrigated. Water for irrigation for 71 percent of this acreage (5,325 acres) was supplied by wells, and water for the remaining 29 percent (2,175 acres) was supplied by ponds and streams.

From 1984 to 1987, the two largest irrigators by area watered a total of 2,530 acres and used an average of 354 Mgal/yr, or 0.14 Mgal/yr per irrigated acre. Digital-vibration-time totalizers (DVTT's) were installed on four production wells, two at each of the largest farms, to estimate irrigation pump-running time. Discharge from the wells was measured with an ultrasonic flowmeter. Irrigation rates on one farm averaged 88 Mgal/yr for 460 acres (one-third of the acres irrigated), or approximately 260 Mgal/yr (6.9 in/acre) for the entire 1,380 acres. The irrigation rate on the other farm averaged 3 in/acre per year, or about 94 Mgal/yr for the 1,150 irrigated acres. Combining irrigation rates for the two farms yields 354 Mgal/yr for 2,530 acres, or an average of 0.14 Mgal/yr per irrigated acre (5.1 in/acre per year).

Other irrigators in the basin watered similar types of crops in areas with similar soil characteristics. Given the average application rate of 0.14 Mgal/yr per acre, the 7,500 irrigated acres in the basin used an estimated 1,050 Mgal/yr. Given that 29 percent of the irrigated acreage is supplied by surface water, about 305 Mgal/yr of surface water is used for irrigation.

Two golf courses in the basin are irrigated for grounds maintenance. Although water-use data for the golf courses are not available, a golf course near Annapolis, Md., with similar climate, size, and soil characteristics, used 4.2 Mgal for irrigation in 1986 (J.C. Wheeler, U.S. Geological Survey, oral commun., 1988). Because irrigation techniques at the golf courses are similar, an irrigation rate of 8.4 Mgal/yr is estimated for the two golf courses in the St. Jones River basin, yielding a total irrigation rate in the basin of about 1,058 Mgal/yr.

Livestock Watering

The U.S. Army Corps of Engineers (1978) estimated water demand for livestock in the Chesapeake Bay area. Water demand for broiler chickens was also determined during this study by monitoring water use at two poultry houses in the St. Jones River basin. Water use at the two poultry houses was 37.2 and 38.6 gal/d per 1,000 broilers, or an average of about 38 gal/d per 1,000 broilers during 1986-87. An average daily population of 270,000 broilers is estimated in the St. Jones River basin, given five flocks per year per poultry house. Estimated water use by livestock in the St. Jones River basin is listed in table 3.

Although livestock populations vary, the figures reported in table 3 probably are representative for the period of this study. About 1 percent (11 Mgal/yr) of agricultural water use in the basin is for purposes other than irrigation, and 99 percent (1,058 Mgal/yr) is for irrigation.

Table 3.--Livestock water use in the St. Jones River basin, Delaware, 1985

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

Animal	*Estimated population* [1]	*Average daily water use per animal* [2] *(gal/d)*	*Total annual water use (Mgal/yr)*
Broilers [3]	270,000	0.038	3.74
Chickens [4]	2,000	.040	.03
Sheep	250	2	.18
Dairy cows	400	35	5.11
Beef cattle	100	12	.44
Horses	200	12	.88
Pigs and hogs	200	4	.29
		Total	10.67

[1] Source: Discussions between author and the University of Delaware Cooperative Extension Service, Dover, Del.

[2] Source: U.S. Army Corps of Engineers (1978), except water-use rate for broilers which was determined during this study.

[3] Broilers are chickens raised only for meat.

[4] Chickens are raised only for commercial egg production.

COMPILATION OF WATER-USE DATA

About 4,350 Mgal of water were used for all purposes in the St. Jones River basin in 1985. Approximately 93 percent (4,045 Mgal) of the water used was ground water, given that 7 percent (305 Mgal) was surface water used solely for irrigation. Public-supplied water use accounted for 54 percent (2,363 Mgal) of the total water use in the basin and self-supplied sources accounted for the remaining 46 percent (1,987 Mgal). Self-supplied industries accounted for 6 percent (269 Mgal), self-supplied commercial and institutions accounted for 10 percent (453 Mgal), self-supplied power generation accounted for 2 percent (80 Mgal), self-supplied domestic accounted for 3 percent (116 Mgal), and self-supplied agriculture accounted for 24 percent (1,069 Mgal) of the total water use in the basin. (Percentages do not add to 100 because of independent rounding.)

In 1985, public supplies distributed 41 percent (976 Mgal) to domestic use, 27 percent (629 Mgal) to commercial and institutional use, 16 percent (389 Mgal) to power generation, and 16 percent (369 Mgal) to industrial use. Figure 6 shows the distribution of water use by water-use category and figure 7 shows distribution by source. Distribution by water-use category in the basin for combined public- and self-supplied sources are given in the following table.

Distribution for combined public- and self-supplied sources, by water-use category

[*Mgal, million gallons*]

Category	*Public-supplied (Mgal)*	*Self-supplied (Mgal)*	*Total (Mgal)*	*Percentage of total*
Domestic	976	116	1,092	25
Commercial and institutional	629	453	1,082	25
Agricultural	0	1,069	1,069	24
Industrial	369	269	638	15
Power generation	389	80	469	11
Total	2,363	1,987	4,350	

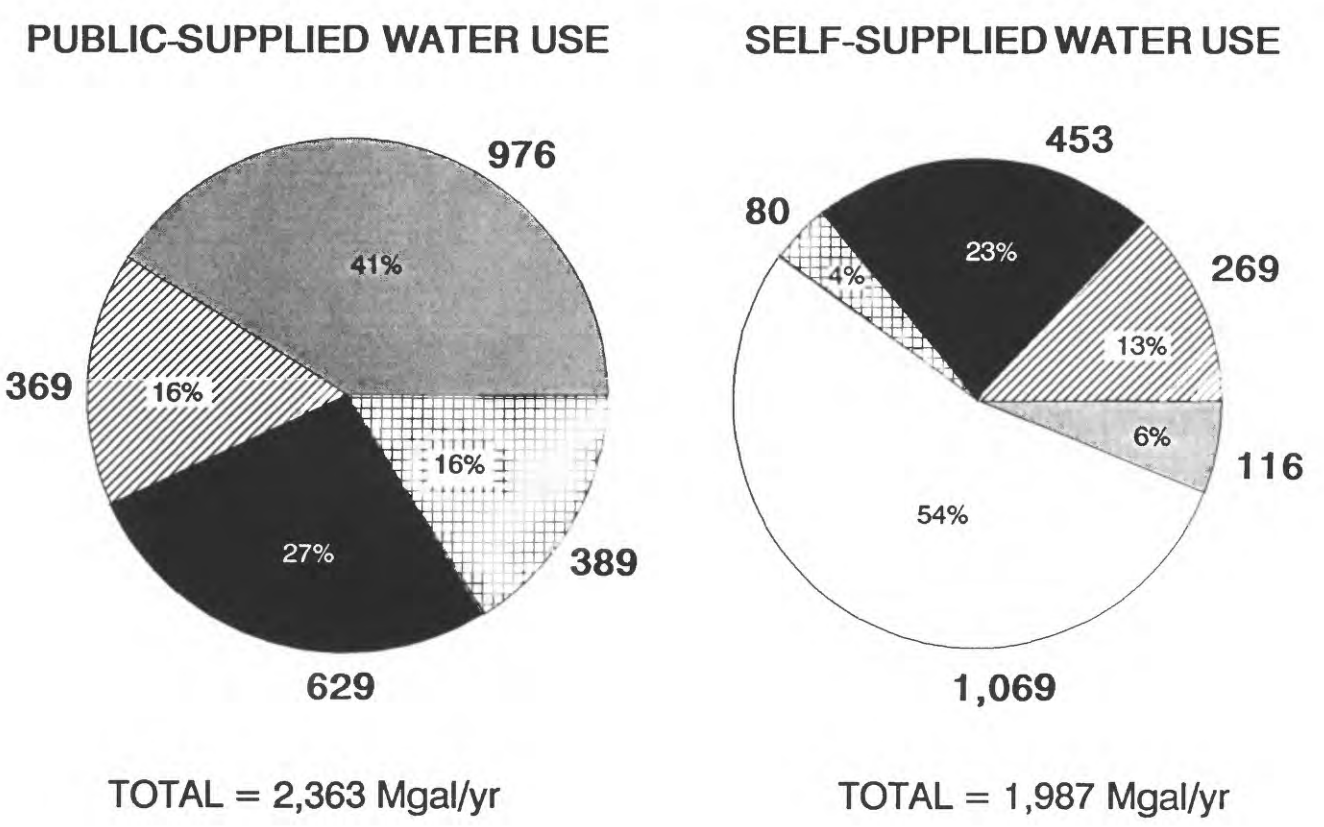


Figure 6.-- Distribution of water use by category, in the St. Jones River basin, Kent County, Delaware, 1985.

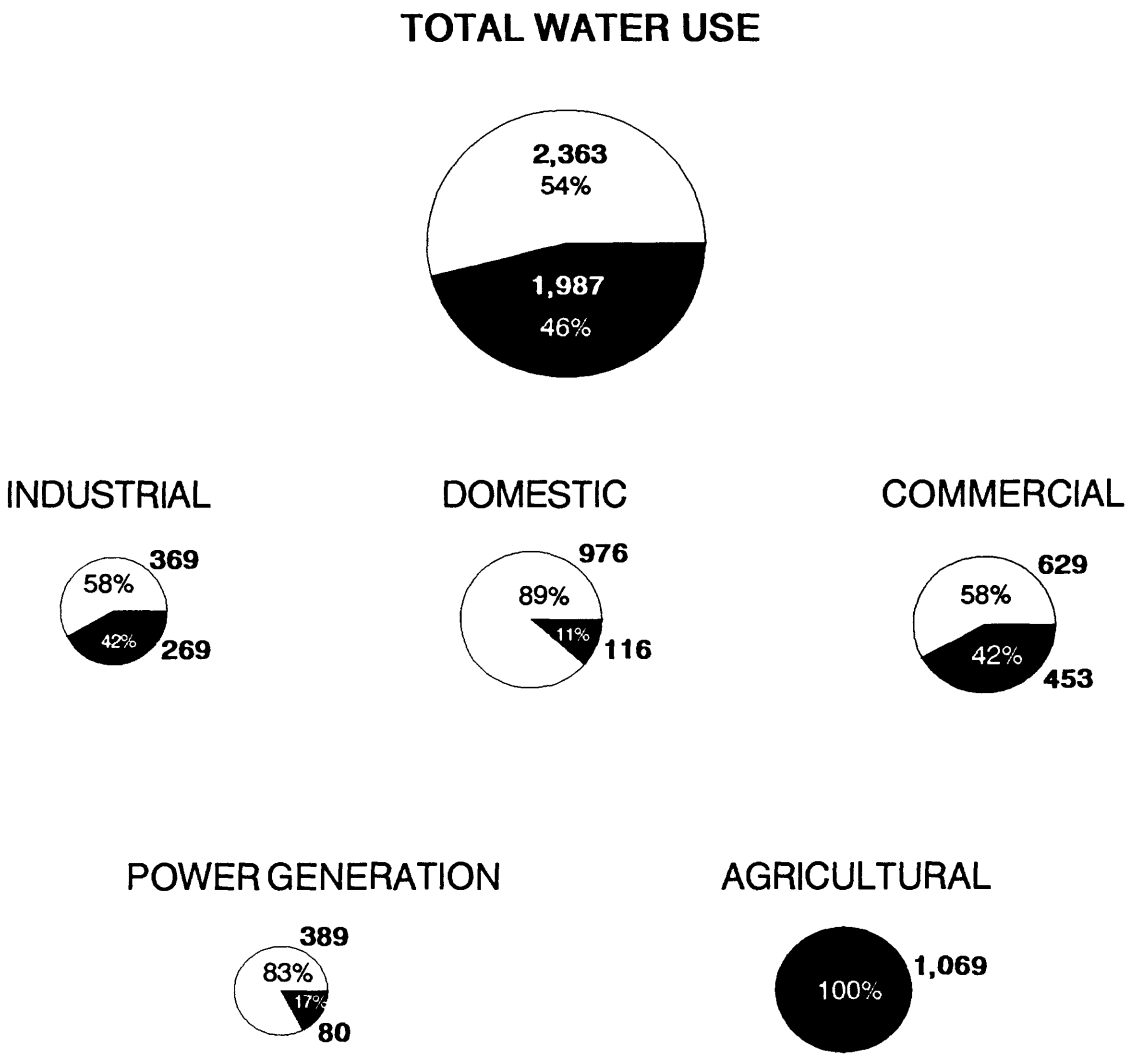


Figure 7.-- Distribution of water use by source, in the St. Jones River basin, Kent County, Delaware, 1985.

CONSUMPTIVE USE

Consumptive use is that part of water withdrawn that has been evaporated, transpired, incorporated into products or crops, or otherwise removed from the immediate water environment. It also is referred to as "water consumption" or "water consumed."

A centralized system conveys wastewater from sewered areas of the St. Jones River basin (fig. 8) to the Kent County Wastewater Treatment Plant near Frederica (fig. 2). Treated effluent is discharged to the Murderkill River.

Return flow is the amount of water that reaches a ground- or surface-water source after release from the point of use and, thus, becomes available for further use (Solley and others, 1983, p. VI). Examples of return flow are discharges from wastewater treatment plants and individual septic systems, and excess irrigation water that infiltrates to the ground-water system or flows overland to streams.

Wastewater in the St. Jones River basin originates from public-supplied sources, self-supplied industries that discharge to the county wastewater system, Dover Air Force Base, infiltration, and inflow. Infiltration is ground water that leaks into sewers through cracks and joints. Inflow primarily is rainwater that is diverted into sewers from sumps, rainspout connections, and other point sources. More than 99 percent of all public-supplied sources discharge wastewater to the county system.

Infiltration and inflow of water to wastewater systems complicates determination of how much supplied water is returned to the wastewater treatment plant. Whitman, Requardt and Associates (1987, p. 17) estimated infiltration and inflow to be 23 percent of Dover's wastewater flow in 1985 when precipitation was 46.77 in., and 16 percent in 1986 when precipitation was 37.33 in. Given an average of 44.44-in. precipitation at Dover, linear regression techniques predict mean infiltration and inflow values to be approximately 21 percent of the total flows for the Dover system. Infiltration and inflow values are largest in the older sections of the city of Dover (Whitman, Requardt and Associates, 1987). Exfiltration from wastewater pipes is not considered a factor by the Kent County Engineer's Office because leaks from the system are easily detected by pressure meters at pumping stations, and are quickly repaired. Because there are no official estimates available for the amount of infiltration and inflow into the overall county wastewater system, this study will use the average figure of 21 percent previously calculated for the Dover system as the basis for basinwide consumptive use calculations.

Ground-water fluctuations also affect infiltration into gravity-flow wastewater systems. Figure 9 shows water levels in well Jd42-3 near Camden, and the monthly wastewater flow measured at the city of Dover pumping station 3 from 1978 through 1986. Ground-water levels from 1978 to 1983 closely resemble return-flow amounts at Dover. In 1983, another pumping station diverted return flow from sections of Dover, causing a reduction in flow, but not changing the general relation between ground-water levels and wastewater flow.

The Kent County wastewater system receives discharges from all categories of public supply, self-supplied industries, self-supplied power generation, and from 92 percent of the self-supplied commercial use (primarily the Dover Air Force Base). About 90 percent of the population in the basin is served by the county wastewater system. In 1985, total public-supplied water use in the basin was 2,363 Mgal/yr (fig. 6). Self-supplied industrial, power generation, and commercial water systems used about 767 Mgal/yr, increasing the total water

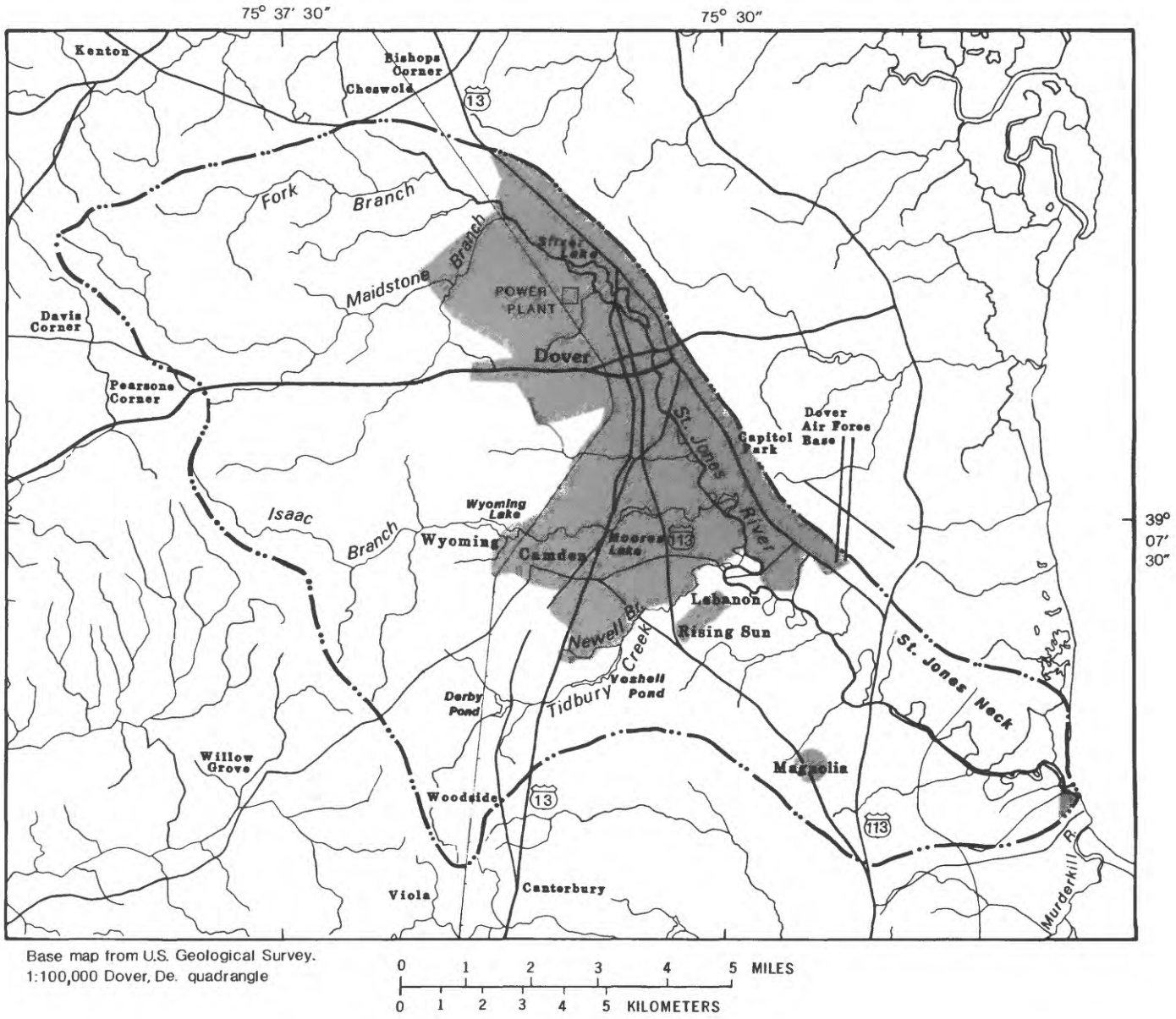


Figure 8.-- Areas served by the Kent County wastewater system in the St. Jones River basin, Kent County, Delaware (Source: Kent County Office of the County Engineer)

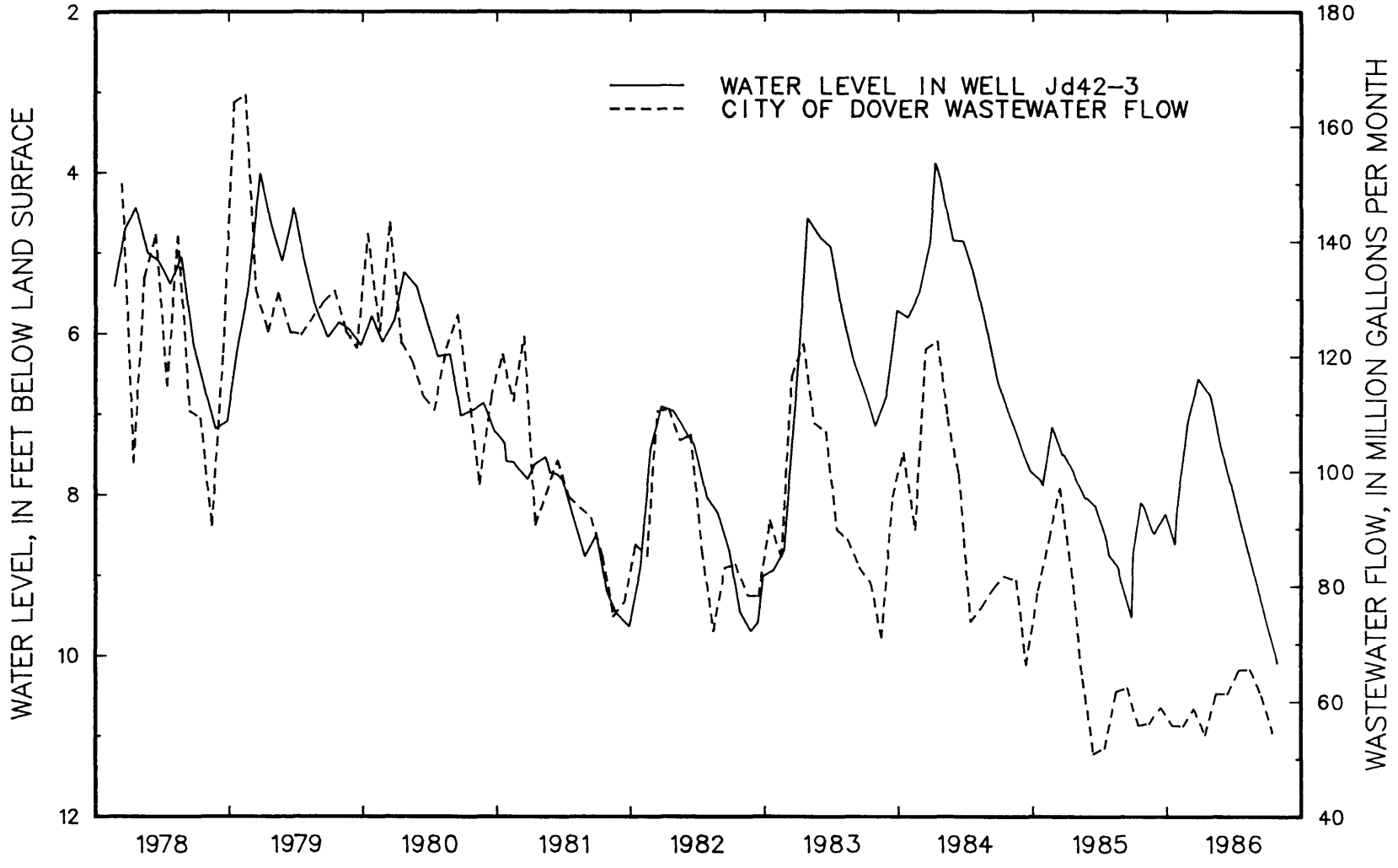


Figure 9.-- Relation between water-table fluctuations and wastewater flow at Dover, Delaware. (Elevation of land surface datum for well Jd42-3 is 44 feet above sea level).

available for eventual discharge to the wastewater system to about 3,130 Mgal/yr. Wastewater flow from the St. Jones basin averaged 2,147 Mgal/yr from 1983 through 1986. Subtracting the estimated 21 percent for infiltration and inflow gives a net return flow of 1,700 Mgal/yr (amount returned from delivered sources). Although this large amount of wastewater leaves the basin each year to the tidal part of the Murderkill River, its loss has a negligible effect on the basin because (1) prior to 1973, Dover discharged wastewater to the tidal part of the St. Jones River, (2) both the Murderkill and the St. Jones Rivers are tidal near the Delaware Bay, and (3) flows in the lower parts of these rivers are exchanged with bay water, keeping any effects from reduced streamflow to the tidal part of the St. Jones River to a minimum.

From 1983 through 1986, about 46 percent (1,430 Mgal/yr) of the water supplied to systems discharging to the county wastewater system was lost to consumptive uses. If infiltration and inflow were not considered, only 31 percent (983 Mgal/yr) of the available water was consumed. If 82 percent of the water used at the Dover power plant were subtracted from the 3,130 Mgal/yr supplied (because of the 82-percent consumptive-use rate), the 46-percent value (1,430 Mgal/yr) would decrease to 40 percent (1,128 Mgal/yr) and the 31- percent value would decrease to 24 percent (681 Mgal/yr), close to the national average of 21-percent consumptive use for public-supply systems (Solley and others, 1983, p.12). Determining consumptive use by water-use category in areas served by the county wastewater system was not possible because waste-water meters usually measure combined water from two or more use categories. This analysis does not account for irrigation applications of public-supplied water (domestic or commercial lawn watering). Excess water from lawn watering will recharge ground water, increase the calculated amount of return flow, and decrease the calculated amount of consumptive use.

Consumptive-use rates given in this report are basin-wide estimates. Nearly all public-supplied water is withdrawn from the deeper confined aquifers, but is eventually discharged to the surface-water system by way of the Kent County Wastewater System. The confined aquifers are not recharged by the return flows from the wastewater system, resulting in a consumptive use rate of 100 percent for withdrawals from the confined aquifers.

The largest amount of consumptive water use by self-supplied users is due to evapotranspiration from irrigation. Solley and others (1983) reported national averages for consumptive use in irrigation to be 55 percent of the total water withdrawn. Assuming that the nationwide average is representative locally, about 582 Mgal/yr is lost to consumptive use by irrigation.

Table 4 shows estimated consumptive water use for 1985 in the St. Jones River basin by water-use category, based primarily on national averages (Solley and others, 1983). Estimates of power generation consumptive use (table 4) differ from the national average of 2 percent because of local differences in cooling techniques.

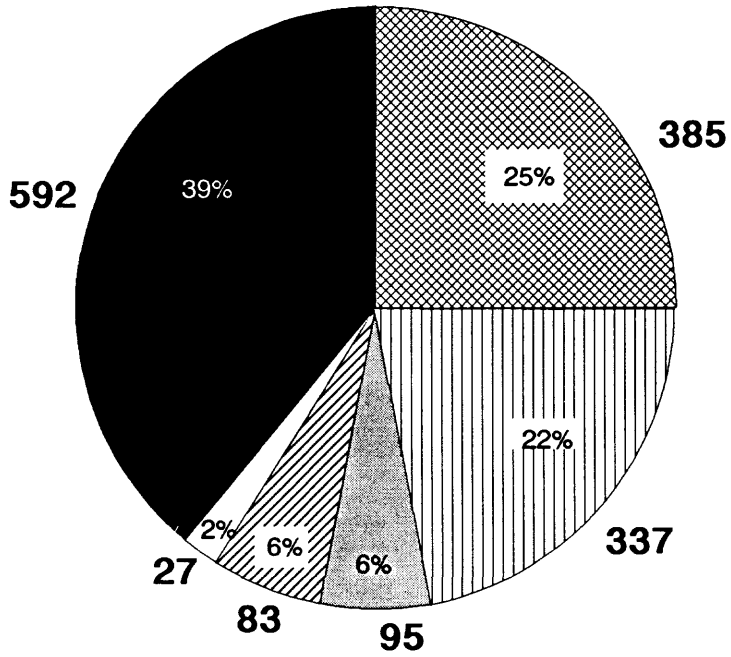
In 1985, total consumptive water use in the basin was 1,519 Mgal. Figure 10 shows that agriculture is the largest consumptive-use category in the basin, accounting for 39 percent (592 Mgal) of total consumptive use. Power generation and public supply (domestic and commercial) were the next largest, with 25 percent (385 Mgal) and 22 percent (337 Mgal) of total amount of water consumed, respectively. The remaining consumptive water use was by self-supplied commercial users including the Dover Air Force Base [6 percent (95 Mgal)], industrial [6 percent (83 Mgal)], and domestic self-supplied [2 percent (27 Mgal)].

Table 4.--Consumptive water use in the St. Jones River basin, Delaware, 1985

[*Mgal/yr, million gallons per year*]

Water-use category	*Amount used [Mgal/yr]*	*Percentage consumed (national averages)* [1]	*Consumptive use [Mgal/yr]*	*Percent of total consumptive use*
Public supply [2]	1,605	21	337	22
Industrial				6
Public-supplied	369	13	48	
Self-supplied	269	13	35	
Power generation				25
Public-supplied	389	[3] 82	319	
Self-supplied	80	[3] 82	66	
Domestic				2
Self-supplied	116	[4] 23	27	
Commercial				6
Self-supplied				
Dover Air Force Base	418	21	88	
Other	35	21	7	
Agricultural				39
Irrigation	1,058	55	582	
Nonirrigation	11	88	10	
Total	4,350		1,519	

[1] Solley and others, 1983.
[2] Domestic and commercial uses only.
[3] Based on estimated consumptive use in basin, not national average.
[4] Solley and others, 1988.



TOTAL = 1,519

EXPLANATION

CATEGORY OF CONSUMPTIVE WATER USE

- Agricultural
- Power generation
- Public supply (domestic and commercial only)
- Commercial (self-supplied)
- Industrial (public and self-supplied)
- Domestic (self-supplied)

592 Quantity of water used in million gallons per year

39% Percentage of total use

Figure 10.-- Consumptive water use in the St. Jones River basin, Kent County, Delaware, 1985.

SUMMARY

The Delaware Department of Natural Resources and Environmental Control presently requires water-use reports from users or suppliers of more than 50,000 gal/d. The St. Jones River basin was selected as a representative area for conducting a detailed water-use study because all types of water use that are practiced throughout Delaware are represented in this area. The results of this study will help water managers improve estimates of nonreported water use in similar areas throughout the State. Water-use data were collected in the 86-mi^2 St. Jones River basin during 1983-86.

In 1985, the population in the St. Jones River basin was about 47,900. Average population density was 560 persons per square mile. The city of Dover, Dover Air Force Base, and the towns of Camden, Wyoming, and Magnolia are the largest public-water suppliers in the basin.

A centralized system conveys wastewater from sewered areas of the basin to the Kent County Wastewater Treatment Plant near Frederica, Del. About 2,147 Mgal of wastewater leaves the St. Jones basin annually to the county treatment plant, and eventually discharges to the Murderkill River.

The city of Dover supplied 1,890 Mgal (5.2 Mgal/d) of water to all users in 1985. Thirty-three percent of the total amount of water was for domestic use, 32 percent for commercial and institutional use, 22 percent for industrial use, and 13 percent for thermoelectric power generation. In Dover, domestic water use in 1985 averaged 63 gal/d per capita.

The Dover Air Force Base used 418 Mgal (1.14 Mgal/d) of water in 1985. Off-base housing used an additional 51.3 Mgal/yr. The towns of Camden and Wyoming combined to use an average of 97.6 Mgal/yr from 1983 through 1985, serving about 3,600 residents. The town of Magnolia used 19.4 Mgal/yr in 1985, serving about 1,000 people.

Total public-supplied commercial water use in the basin was about 629 Mgal/yr in 1985. The 1,013 accounts used an average of 0.62 Mgal/yr per account. Public-supplied institutional users are included in commercial use because records are not kept separately by the water departments. Total public-supplied water use for schools in the basin was about 40 Mgal/yr.

About 90 percent of all residents (42,400) in the basin were served by public water-supply systems. Since the average domestic water use in Dover was about 63 gal/d per capita, the average daily domestic public-supplied water use in the basin was about 976 Mgal/yr (2.67 Mgal/d).

Thermoelectric power generation in the basin is supplied by the city of Dover power plant. Water is supplied by Dover's water department. Water use at the power plant averaged 389 Mgal/yr (1.07 Mgal/d) during 1983-86. The only self-supplied power generation is a food-processing company in Dover. Since 1985, the food-processing company has used approximately 80.3 Mgal/yr (0.22 Mgal/d) for cooling purposes.

Self-supplied industrial users in the basin withdrew 269 Mgal of ground water in 1985 (excluding self-supplied power-generation water use). Self-supplied commercial users accounted for about 33 Mgal/yr, and water use at the Dover Air Force Base averaged 470.7 Mgal/yr from 1983 through 1986. Total self-supplied institutional use was approximately 2 Mgal/yr during the course of the study. Self-supplied domestic use in the basin was approximately 116 Mgal/yr from 1983 through 1986.

Agricultural water use includes irrigation and livestock watering. Agricultural irrigation water use in the basin was about 1,050 Mgal/yr from 1983 through 1985. Nonagricultural irrigation (golf courses) used an additional 8 Mgal/yr. Nonirrigation agricultural uses were about 11 Mgal/yr during the same period, making irrigation accountable for 99 percent of all agricultural water use.

Approximately 4,350 Mgal of water was used in the St. Jones River basin in 1985. Ninety-three percent (4,045 Mgal) of the water used was ground water and the remaining 7 percent (305 Mgal) was surface water, which was used for irrigation. Fifty-four percent (2,363 Mgal) of all water used was public-supplied, and the remaining 46 percent (1,987 Mgal) was self-supplied.

Annual return flows to the Kent County wastewater system from pumping stations in the St. Jones River basin averaged 2,147 Mgal/yr from 1983 through 1986. Subtracting 21 percent for infiltration and inflow gives a net return flow of about 1,700 Mgal/yr. Total water available for eventual discharge to the wastewater system was about 3,130 Mgal/yr; therefore, about 46 percent of the supplied water was lost to consumptive uses.

Irrigation is the largest consumptive-use category in the basin. Thirty-nine percent (592 Mgal) of consumptive use in the basin is from agriculture. Power generation and public supply (both domestic and commercial) are the next two largest, with 25 percent (358 Mgal) and 22 percent (337 Mgal) of the total amount of water consumed, respectively. The remaining consumptive water use is by self-supplied commercial users [6 percent (95 Mgal)], industrial [6 percent (83 Mgal)], and domestic self-supplied [2 percent (27 Mgal)].

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