ESTIMATED DEMAND FOR AGRICULTURAL WATER FOR IRRIGATION USE IN NEW JERSEY, 1990

By Elizabeth O. Titus, Rick M. Clawges, and Charles L. Qualls

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply inch-pound units	by	To obtain SI units
inch (in.)	25.4	millimeter (mm)
acre	0.4047	hectare
gallons per acre (gal/acre)	0.009353	cubic meter per hectare (m^3/ha)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
billion gallons (billion gal)	3,785,000	cubic meter (m^3)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
degree Fahrenheit (°F)	°C = 5/9(°F - 32)	degree Celsius (°C)

Multiply SI unit	by	To obtain inch-pound unit
millimeter (mm)	0.03937	inch (in.)
hectare (ha)	2.471	acre
cubic meter per hectare (m^3/ha)	106.9	gallons per acre (gal/acre)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
degree Celsius (°C)	°F = 9/5(°C) + 32	degree Fahrenheit (°F)

EXPLANATION OF UNITS OF MEASUREMENT

An inch-pound unit of measurement, Mgal/d (million gallons per day), is used in this report to express a quantity of water used or demanded. Whereas this unit of measurement is not complex, it is not easy to visualize how much water this represents in terms of everyday water use. The most common sources of water are streams and ground water[1] from wells. A stream that is one foot wide and one foot deep, where the water is flowing at a velocity of one foot per second, discharges at a rate of one cubic foot per second. There are 7.48 gallons in a cubic foot and 86,400 seconds in a day, so the flow of this stream is 646,000 gallons per day, or 0.646 Mgal/d.

Another unit of measurement used in this report is gal/acre (gallons per acre). Estimates are made of the deficit in the number of gallons of water that must be applied to each acre of irrigated cropland in order to satisfy the nutritive needs of the crops planted on this land. An acre is about 209 feet square and amounts to 43,560 square feet. An acre-ft (acre-foot) is the quantity of water that would cover one acre to a depth of one foot. One acre-foot of water is equivalent to 43,560 cubic feet, or about 326,000 gallons.

[1]In this report, underlined terms are defined in the Glossary.

ESTIMATED DEMAND FOR AGRICULTURAL WATER FOR IRRIGATION USE IN NEW JERSEY, 1990

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ABSTRACT

As part of an effort to determine if an adequate supply of agricultural water for irrigation use will be available to farmers in the future, the U.S. Geological Survey prepared preliminary estimates of demand for agricultural water for irrigation use in 1990 based on six possible scenarios of future conditions. These scenarios incorporate both normal and drought climatic conditions and three alternative estimates of the total acreage of farmland that may be irrigated in 1990.

Preliminary estimates of water demand based on water deficits were obtained by using methods for calculating climatic water budgets. These estimates ranged from 3.0 billion gallons per growing season (May through September), under normal climatic conditions and a 2-percent annual decline in irrigated acreage since 1984, to 28.9 billion gallons per growing season, under drought conditions and a 2-percent annual increase in irrigated acreage since 1984. Preliminary estimates of water demand made for the 1986 growing season reasonably approximate reported water use for that period.

INTRODUCTION

Irrigated crops are an important part of the revenue produced by agriculture in New Jersey. In 1987, the market value of agricultural products sold from farms with irrigated land was $301 million, more than 60 percent of the market value ($496 million) of agricultural products sold from all farms in the State (U.S. Bureau of the Census, 1989). The New Jersey Statewide Water Supply Plan (Havens and Emerson, Inc., 1980) does not include provisions that ensure that an adequate supply of <u>agricultural water</u> will be available to farmers in the future. The Plan dismisses the potentially increasing need for agricultural water, stating that farming activity is not considered a growth sector in New Jersey's economy, that its future water demand will not increase significantly in the future, and that implementation of a sophisticated water-forecasting model for agriculture is unwarranted. In addition, increasing numbers of <u>domestic</u>, <u>commercial</u>, and <u>industrial water users</u> are competing with farmers for water.

In order to provide information that would be useful to agencies and individuals responsible for allocation of water resources in the state, the U.S. Geological Survey, in cooperation with the New Jersey Department of Agriculture (NJDA), conducted a study to estimate the quantity of water that may be used by New Jersey farmers in the future. The New Jersey Department of Environmental Protection (NJDEP) faces the problem of allocating water among competing users. The NJDA is responsible for advising the NJDEP on future water needs of farmers. In order to develop both short- and long-term estimates of demand for agricultural water, the NJDA formed the Agricultural Water Advisory Committee in 1987. The Committee includes representatives of the NJDEP, the NJDA, Rutgers University, the U.S. Soil Conservation Service, and the U.S. Geological Survey.

In order to understand the demand for agricultural water in general, the specific user groups and their uses of water within the agricultural community of New Jersey must first be defined. Some types of agriculture, such as cranberry farming, plant and tree nurseries, and dairy and other livestock, use water throughout the year. Greenhouses and other container-grown nursery stock depend greatly on water; although they may use relatively small quantities of water, they require frequent (sometimes daily) irrigation year-round. The sale of nursery and greenhouse stock represents a major segment of the agricultural revenue produced in New Jersey. In 1986, for example, cash receipts in the nursery industry totaled $166 million, which was 29 percent of total revenue from agriculture for that year (New Jersey Agricultural Statistics Service, 1987, p. 80-81). Other crop types, such as vegetable and field crops (grains, hay, silage, soybeans, and potatoes), require irrigation only from April through October, and not all acreage devoted to these crop types is irrigated. In 1982, 3.23 percent of harvested acreage in field crops was irrigated, and 64.7 percent of harvested acreage in vegetables was irrigated (U.S. Bureau of the Census, 1985).

In addition, demand for agricultural water can be divided further into nonconsumptive water uses and consumptive water uses. Cranberry bogs are one example of nonconsumptive water use; the bogs are flooded in the fall for harvesting and in the winter for frost protection. Analysis of annual water-use data collected by the NJDEP for 1986 indicates that 53 percent (27.9 billion gal (billion gallons)) of agricultural water use (52.7 billion gal) was reported by cranberry farmers. Most of this reported water use was nonconsumptive.

Purpose and Scope

This report describes the results of an effort to estimate short-term consumptive demand for agricultural water for irrigation use in New Jersey in 1990. It presents rough estimates calculated from readily available physiographic and climatic data. Although preliminary estimates of consumptive demand for agricultural water for irrigation use by field-grown crops are given, no estimates are made for nonconsumptive water use by crops or greenhouse water use. Irrigated field-grown crops use most of the agricultural water during the summer, when water for all uses potentially is limited.

Approach

Preliminary estimates of demand for agricultural water for irrigation use were produced using methods developed by C. W. Thornthwaite (Mather, 1978) for calculating climatic water budgets. The consumptive water use by irrigated field-grown crops was estimated. Estimates were produced for six possible scenarios of future conditions. These scenarios include combinations of normal and drought climatic conditions and three alternative estimates of the total acreage of irrigated farmland in 1990. This approach produced a range of values and provided an indication of the degree of sensitivity of the estimates to changes in the parameters used to develop them.

METHODS

For the purposes of this report, demand for agricultural water is equal to the water deficit multiplied by the quantity of irrigated acreage for field-grown crops. No estimates are made for greenhouse demand for water or nonconsumptive water uses. Water demand is equated with the water deficit based on the assumption that farmers will irrigate at least enough to maintain soil moisture in the root zone of their crops. Water demand was estimated from the calculated water deficit and the estimated quantity of irrigated acreage in cropland.

Estimation of Water Deficit

The Thornthwaite method, as adapted by Mather (1978), was used to calculate the water deficit that exists for irrigated field-grown crops in New Jersey during the growing season (May through September). The Thornthwaite method provides estimates of the components of the climatic water budget for a region from climatological and physical data; the water deficit is one of the estimated components of the climatic water budget.

A simplified mathematical model of the Thornthwaite method for calculating the climatic water budget can be represented as follows:

Water surplus or deficit = [P - PE] - dST,

where P = precipitation,
PE = potential evapotranspiration, and
dST = change in soil-moisture storage, where a decrease in storage is expressed as a negative value.

Potential evapotranspiration and soil-moisture storage are computed using a number of parameters as input (see Appendix for example calculations).

The climatic water budget is a comparison of water supply (precipitation or P) with climatic demands for water (potential evapotranspiration or PE). Potential evapotranspiration is primarily a function of climatic conditions (energy from the sun) and is not a function of vegetation type or land-management practices. Actual evapotranspiration, or the actual loss of water from plant and soil surfaces, depends on such factors as soil type, land use, plant cover, and soil-moisture content but, in practice, is extremely difficult to measure. Thus potential evapotranspiration is used as a measure of climatic water demand in the computation of the climatic water budget (Mather, 1978, p. 2 and 8).

Where precipitation exceeds potential evapotranspiration, soil moisture increases, a water surplus can develop, the ground-water table may rise, and runoff from the area may increase. Where potential evapotranspiration is greater than precipitation, soil-moisture storage is depleted, the water table may fall, and there will be a deficit of water in the soil. By comparing precipitation with potential evapotranspiration for daily or monthly periods, quantitative values of the following variables are obtained: (1) The quantity of water stored in the soil; (2) any excess or water surplus where precipitation exceeds potential evapotranspiration; (3) the quantity of runoff, if the water surplus is sufficiently large to produce runoff; and (4) the quantity of water deficit in soil-moisture storage where potential evapotranspiration exceeds precipitation (Mather, 1978, p. 8).

Data requirements for the climatic water-budget calculation include total monthly precipitation and mean monthly temperature. These data were obtained from the National Oceanic and Atmospheric Administration (NOAA) for the weather station in Shiloh (fig. 1). Shiloh, in Cumberland County, was chosen because its physiography and climate are representative of southern New Jersey. In 1984, more than 90 percent of irrigated cropland in New Jersey was south of the Fall Line bordering the western edge of the New Jersey coastal plain.

Latitude and soil type also were needed as inputs in the computation of the climatic water budget (see Appendix for example calculations). The approximate latitude of Shiloh (39.5 °N) was used. The sandy-loam soil type with moisture retention of 5.91 in. (inches) was used as the soil type most representative of soils under irrigation in southern New Jersey (T. Drewes, U.S. Soil Conservation Service, oral commun., 1987).

In order to obtain a range in the preliminary estimate of demand for water, climatic water budgets were calculated for two climatological scenarios--normal and drought. A normal climate scenario is described using values of 30-year (1951-80) mean monthly precipitation and temperature (table 1). A drought climate scenario refers to a period of severely below-normal precipitation. In this report, the year 1965 was chosen to represent such a period (table 2). New Jersey experienced a prolonged drought from 1961 through 1966, and 1965 was the year with the least precipitation during this period (R. Harnack, Department of Meteorology and Physical Oceanography, Rutgers University, oral commun., 1987).

Monthly values of the parameters used to calculate the Thornthwaite climatic water-budget estimates for the normal and drought scenarios are given in tables 3 and 4, respectively. Water deficits for each month, in inches, appear in the rows labeled "D." Water deficits in inches and gallons per acre are given in tables 5 and 6. Water deficits are present from June through September for normal (1951-80) climatic conditions and from May through October for drought (1965) climatic conditions. Although Thornthwaite calculations yielded a water deficit for October for the drought (1965) scenario, demand for water was not calculated because the estimate is much smaller than that for other months.

Mather (1978, p. 167-193) contains tables from which values of potential evapotranspiration (PE) and changes in soil-moisture storage (dST) may be derived. Data in these tables were used to calculate estimates of water demand for New Jersey. The appendix to this report explains the computations necessary to develop a monthly climatic water budget.

Estimation of Irrigated Acreage

Three scenarios of acreage under irrigation in 1990 were considered: (1) no change in acreage from 1984 through 1990, (2) a 2-percent annual increase in acreage from 1984 through 1990, and (3) a 2-percent annual

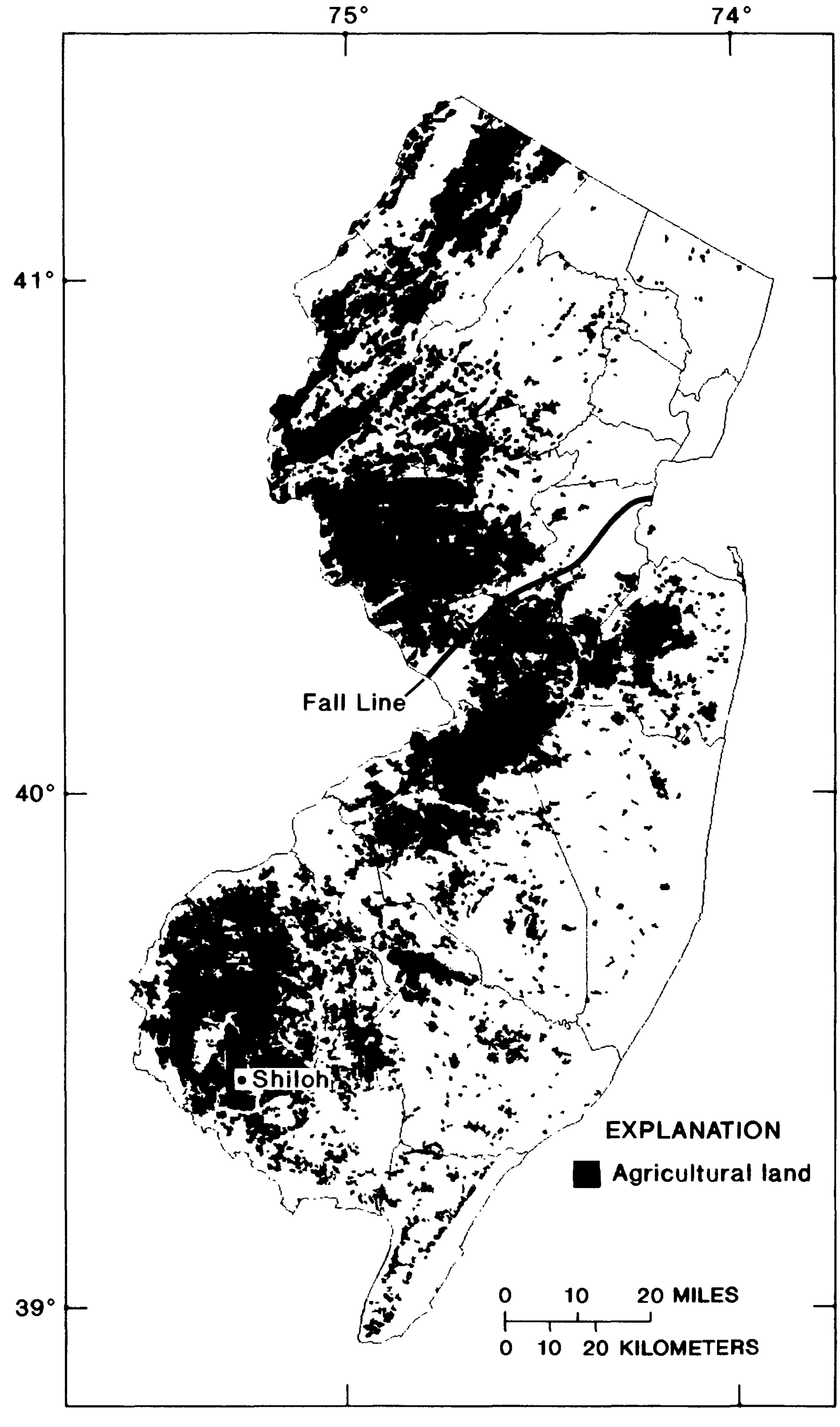

Figure 1.--Agricultural land in New Jersey, 1974.

Table 1.--Mean monthly precipitation and temperature for normal climatic conditions, National Oceanic and Atmospheric Administration weather station at Shiloh

[Data from R. Harnack, Department of Meteorology and Physical Oceanography, Rutgers University, written commun., 1987; data for normal climatic conditions based on 30-year (1951-80) mean monthly precipitation and temperature values; data may not add to totals because of independent rounding]

Month	Mean precipitation		Mean temperature	
	Inches	Milli-meters	Degrees Fahrenheit	Degrees Celsius
January	3.08	78.2	32.6	0.33
February	2.64	67.1	34.3	1.28
March	3.47	88.1	42.5	5.83
April	3.11	79.0	52.8	11.6
May	3.23	82.0	62.4	16.9
June	3.48	88.4	70.9	21.6
July	4.23	107	75.7	24.3
August	4.21	107	74.5	23.6
September	3.41	86.6	68.3	20.2
October	3.28	83.3	57.3	14.1
November	3.51	89.2	46.8	8.22
December	3.36	85.3	36.8	2.67
Total:	41.0	1,040		

Table 2.--Total monthly precipitation and temperature for drought climatic conditions, 1965, National Oceanic and Atmospheric Administration weather station at Shiloh

[Data are for 1965, a representative severe drought year; data from R. Harnack, Department of Meteorology and Physical Oceanography, Rutgers University, written commun., 1987; data may not add to totals because of independent rounding]

Month	Total precipitation		Mean temperature	
	Inches	Millimeters	Degrees Fahrenheit	Degrees Celsius
January	2.51	63.8	30.3	-0.94
February	1.98	50.3	34.4	1.33
March	3.23	82.0	38.6	3.67
April	2.29	58.2	48.7	9.28
May	2.51	63.8	65.9	18.8
June	1.10	27.9	70.6	21.4
July	1.60	40.6	75.1	23.9
August	1.67	42.4	74.3	23.5
September	1.46	37.1	70.1	21.2
October	1.65	41.9	53.3	11.8
November	0.99	25.1	45.1	7.28
December	1.49	37.8	37.4	3.00
Total:	22.5	571		

Table 3.--Worksheet for calculation of water-budget estimates for normal (1951-80) climatic conditions

[Parameters: T, temperature; i, monthly heat index; I, annual heat index, the sum of 12 monthly heat indices; UnPE, unadjusted daily potential evapotranspiration; PE, monthly potential evapotranspiration; P, precipitation; ST, soil-moisture storage in the root zone; dST, change in ST from previous to current month; AE, actual evapotranspiration; D, water deficit; S, water surplus. All values except T (in degrees Celsius) and I (dimensionless) are in inches. Worksheet modified from Mather, 1978, p. 168. Data may not add to totals because of independent rounding]

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
T	0.333	1.28	5.83	11.5	16.9	21.6	24.3	23.6	20.2	14.1	8.22	2.67	
i	.0100	.130	1.26	3.55	6.32	9.17	10.9	10.5	8.25	4.78	2.12	.38	I = 57.4
UnPE	0	.00394	.0197	.0551	.0945	.134	.157	.150	.122	.0709	.0354	.00787	
PE	0	.0992	.606	1.83	3.49	4.96	5.94	5.31	3.81	2.04	.894	.194	
P	3.08	2.64	3.47	3.11	3.23	3.48	4.23	4.21	3.41	3.28	3.51	3.36	41.0
P-PE	3.08	2.55	2.86	1.28	-.257	-1.50	-1.71	-1.09	-.398	1.24	2.62	3.17	
ST	5.91	5.91	5.91	5.91	5.63	4.37	3.23	2.68	2.52	3.76	5.91	5.91	
dST	0	0	0	0	-.276	-1.26	-1.14	-.551	-.157	3.76	2.15	0	
AE	0	.0992	.606	1.83	3.50	4.72	5.37	4.76	3.57	2.04	.894	.194	
D	0	0	0	0	0	.240	.570	.535	.241	0	0	0	
S	3.08	2.55	2.86	1.28	0	0	0	0	0	0	0	3.17	

Table 4.--Worksheet for calculation of water-budget estimates for drought (1965) climatic conditions

[Parameters: T, temperature; i, monthly heat index; I, annual heat index, the sum of 12 monthly heat indices; UnPE, unadjusted daily potential evapotranspiration; PE, monthly potential evapotranspiration; P, precipitation; ST, soil-moisture storage in the root zone; dST, change in ST from previous to current month; AE, actual evapotranspiration; D, water deficit; S, water surplus. All values except T (in degrees Celsius) and I (dimensionless) are in inches. Worksheet modified from Mather, 1978, p. 168. Data may not add to totals because of independent rounding]

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
T	-0.944	1.32	3.67	9.28	18.8	21.4	23.9	23.5	21.2	11.8	7.28	3.00	
i	0	.130	.630	2.56	7.43	9.04	10.7	10.4	8.85	3.67	1.96	.480	I = 55.8
UnPE	0	.00394	.0118	.0433	.110	.134	.154	.150	.130	.0591	.0354	.0118	
PE	0	.0992	.365	1.44	4.06	4.96	5.79	5.31	4.06	1.70	.894	.291	
P	2.51	1.98	3.23	2.29	2.51	1.10	1.60	1.67	1.46	1.65	.988	1.49	22.5
P-PE	2.51	1.88	2.87	.846	-1.56	-3.88	-4.17	-3.63	-2.59	-.0508	.0972	1.20	
ST	5.91	5.91	5.91	5.91	4.49	2.32	1.14	.591	.394	.394	.492	1.69	
dST	0	0	0	0	-1.42	-2.17	-1.18	-.551	-.197	0	.0972	1.20	
AE	0	.0992	.365	1.44	3.93	3.26	2.78	2.22	1.66	1.65	.894	.291	
D	0	0	0	0	1.79	1.71	3.02	3.07	2.40	.0512	0	0	
S	2.51	1.88	2.87	.846	0	0	0	0	0	0	0	0	

Table 5.--Estimate of water deficit under normal climatic conditions

[Data based on 30-year (1951-80) mean monthly precipitation and temperature values; data may not add to totals because of independent rounding]

Month	Deficit (gallons per acre)	Deficit (inches)
June	6,520	0.240
July	15,500	.570
August	14,500	.535
September	6,550	.241
Total:	43,100	1.59

Table 6.--Estimate of water deficit under drought climatic conditions

[Data are for 1965, a representative severe drought year; data may not add to totals because of independent rounding]

Month	Deficit (gallons per acre)	Deficit (inches)
May	48,600	1.79
June	46,400	1.71
July	82,000	3.02
August	83,400	3.07
September	65,200	2.40
Total:	326,000	12.0

decrease in acreage from 1984 through 1990. A 2-percent annual change in irrigated acreage was considered reasonable because the U.S. Census of Agriculture reported a 10-percent increase in irrigated land in New Jersey between 1982 and 1987 (U.S. Bureau of the Census, 1989, p. 1).

Projections of irrigated acreage in 1990 were calculated based on data from the 1984 Farmland Assessment Survey (J. Gibson, New Jersey Agricultural Statistics Service, written commun., 1987). Actual irrigated acreage in 1984 (scenario 1) and projected irrigated acreage in 1990 for scenarios 2 and 3 are listed by county in table 7.

Estimation of Demand for Agricultural Water for Irrigation Use

The combination of the two water-deficit scenarios and the three irrigated-acreage scenarios resulted in six scenarios of demand for agricultural water for irrigation use in 1990. Estimates of water deficit, in inches, were multiplied by estimates of irrigated acreage, yielding estimates of demand for water for irrigation use.

ESTIMATED DEMAND FOR AGRICULTURAL WATER FOR IRRIGATION USE

Table 8 shows monthly demand for water during the growing season under both normal and drought climatic conditions for the three scenarios of irrigated acreage. Estimates of daily demand for water were computed by dividing the demand for water for each month by the number of days in that month. Estimates of daily demand for water during the growing season are indicated in table 9. The average seasonal daily demand for water was calculated by dividing the total seasonal demand for water by 153, the number of days in the growing season (May through September). Estimates of average seasonal daily demand for water range from 19.6 to 189 Mgal/d. Estimates of total seasonal demand for water range from 3.0 billion gal to 28.9 billion gal per growing season (table 10).

Estimates of total water demand under the six climate-and-acreage scenarios are presented by county in table 11. These estimates were made by disaggregating the State water-demand estimate by county using 1984 proportions of irrigated farmland. These proportions were calculated by dividing the number of irrigated acres in each county by the total number of irrigated acres in the State. Proportions were assumed to be constant through time. Estimates by county are useful because the NJDEP allocates agricultural water in the State at the county level. In addition, estimates by county may be compared easily with water-use data, which also are compiled by county.

Comparison of Estimated Demand with Reported Use

The Thornthwaite method produces reasonable estimates of seasonal water demand when compared with reported water use for irrigated field-grown crops in New Jersey. Data in table 12 indicate total agricultural water use reported by the farm community in 1986. Cranberry water use for that year was subtracted from the total, yielding water-use values for field-grown crops and greenhouse plants. Greenhouse water use could not be separated from non-cranberry water use. Reported non-cranberry water use from November through February was extremely small. This water generally is used

Table 7.--Actual irrigated acreage for 1984 (no growth) and projected irrigated acreage for 1990 by county assuming a 2-percent increase per year and a 2-percent decrease per year

[1984 irrigated-acreage data from J. Gibson, New Jersey Agricultural Statistics Service, New Jersey Department of Agriculture, written commun., 1987; data may not add to totals because of independent rounding]

County	Actual irrigated acreage 1984 (no growth)	Projected irrigated acreage, 1990	
		2-percent increase per year	2-percent decrease per year
Atlantic	9,640	10,900	8,540
Bergen	253	285	224
Burlington	9,170	10,300	8,120
Camden	2,110	2,380	1,870
Cape May	1,240	1,400	1,100
Cumberland	13,800	15,500	12,200
Essex	9	10	8
Gloucester	13,300	15,000	11,800
Hudson	0	0	0
Hunterdon	353	398	313
Mercer	2,930	3,300	2,600
Middlesex	4,420	4,980	3,920
Monmouth	6,170	6,950	5,470
Morris	520	586	461
Ocean	886	998	785
Passaic	52	59	46
Salem	12,100	13,600	10,700
Somerset	492	554	436
Sussex	514	579	455
Union	34	38	30
Warren	835	940	740
Total:	78,800	88,800	69,800

Table 8.--Projected monthly demand for agricultural water for irrigation use, 1990, under normal and drought climatic conditions

[Data in million gallons; data may not add to totals because of independent rounding]

Month	Change in irrigated acreage		
	No growth	+2 percent per year	-2 percent per year
	NORMAL CLIMATIC CONDITIONS		
June	514	579	455
July	1,220	1,370	1,080
August	1,140	1,290	1,010
September	516	581	457
Total:	3,390	3,820	3,000
	DROUGHT CLIMATIC CONDITIONS		
May	3,830	4,320	3,390
June	3,660	4,120	3,240
July	6,460	7,280	5,720
August	6,570	7,400	5,820
September	5,140	5,790	4,550
Total:	25,700	28,900	22,700

Table 9.--Projected daily demand for agricultural water for irrigation use, 1990, under normal and drought climatic conditions

[Data in million gallons per day]

Month	Change in irrigated acreage		
	No growth	+2 percent per year	-2 percent per year
	NORMAL CLIMATIC CONDITIONS		
June	17.1	19.3	15.2
July	39.4	44.2	34.8
August	36.8	41.6	32.6
September	17.2	19.4	15.2
	DROUGHT CLIMATIC CONDITIONS		
May	124	139	109
June	122	137	108
July	208	235	185
August	212	239	188
September	171	193	152

Table 10.--Projected average seasonal daily demand for water and total seasonal demand for water, 1990, under normal and drought climatic conditions

[Growing season is May through September, or 153 days]

Average seasonal daily demand (million gallons per day)			Total seasonal demand (million gallons)		
Change in irrigated acreage			Change in irrigated acreage		
No growth	+2 percent per year	-2 percent per year	No growth	+2 percent per year	-2 percent per year
NORMAL CLIMATIC CONDITIONS					
22.2	25.0	19.6	3,390	3,820	3,000
DROUGHT CLIMATIC CONDITIONS					
168	189	148	25,700	28,900	22,700

Table 11.--Projected total seasonal demand for water for the six scenarios of climate and irrigated acreage, by county

[Data may not add to totals because of independent rounding]

County	Water demand under normal climatic conditions (million gallons)			Water demand under drought climatic conditions (million gallons)		
	Change in irrigated acreage			Change in irrigated acreage		
	No growth	+2 percent per year	-2 percent per year	No growth	+2 percent per year	-2 percent per year
Atlantic	414	467	367	3,140	3,530	2,770
Bergen	10.9	12.2	9.62	82.4	92.7	72.8
Burlington	394	444	349	2,990	3,360	2,640
Camden	90.7	102	80.3	688	773	607
Cape May	53.4	60.2	47.3	405	456	358
Cumberland	594	670	526	4,510	5,070	3,980
Essex	.40	.45	.36	3.05	3.43	2.69
Gloucester	573	646	508	4,350	4,890	3,840
Hudson	0	0	0	0	0	0
Hunterdon	15.2	17.1	13.4	115	129	102
Mercer	126	142	111	954	1,070	843
Middlesex	190	214	168	1,440	1,620	1,270
Monmouth	265	299	235	2,010	2,260	1,780
Morris	22.4	25.2	19.8	169	191	150
Ocean	38.1	42.9	33.7	289	325	255
Passaic	2.24	2.52	1.98	17.0	19.1	15.0
Salem	519	585	460	3,940	4,430	3,480
Somerset	21.1	23.8	18.7	160	180	141
Sussex	22.1	24.9	19.6	167	188	148
Union	1.44	1.63	1.28	10.9	12.3	9.67
Warren	35.9	40.5	31.8	272	306	240
Total:	3,390	3,820	3,000	25,700	28,900	22,700

for greenhouse plants, because irrigated field-grown crops use water only during the warm months of the growing season. If greenhouse plants use similar quantities of water in summer as in winter because they are grown in a controlled climatic environment, the non-cranberry water use reported from May through September is primarily for irrigated field-grown crops, the water use of interest in this report.

Data in table 12 also include estimates of demand for agricultural water for irrigation use in 1986. These estimates were computed using actual climatic data for 1986 from the weather station in Shiloh. The combined Thornthwaite estimate for the growing season months of May, June, July, August, and September is 11,500 Mgal. Total reported non-cranberry water use for May through September 1986 was 17,600 Mgal.

There is the probability that reported agricultural water use in New Jersey exceeds the actual water deficit for field-grown crops. Agricultural water usage is unmetered in New Jersey and thus the accuracy of reported values is undetermined. The Thornthwaite estimates are made for the water deficit for field-grown crops. The reported agricultural water use totals include uses in addition to irrigation of field-grown crops, such as livestock and greenhouse water use. Additionally, the Thornthwaite estimates do not take into account water losses from leaky pipes, irrigation system inefficiency, and surface runoff.

Given the above factors, it is likely that the estimated demand for agricultural water for irrigation use in 1986 is closer to actual demand than reported values would indicate. Thus, the Thornthwaite estimates reasonably approximate the demand for field-grown crops in New Jersey.

Limitations of the Thornthwaite Method

The Thornthwaite method produces only rough, preliminary estimates of demand for water for several reasons. The estimates produced are based on average conditions of climate and soil type. Soil types vary widely throughout New Jersey, and different types of soil have different water-holding capacities. Precipitation and temperature vary from day to day. The Thornthwaite method does not allow for consideration of long periods with no precipitation and high temperatures. During such periods farmers may increase the frequency of irrigation, thus possibly applying more water to maintain saturation of the soil-moisture zone than would be predicted by the Thornthwaite estimates.

Also, for this application, data from one weather station were used to produce estimates for the entire State for normal and drought climatic conditions. Spatial disaggregation of the agricultural regions of New Jersey and use of data from local weather stations as input in the Thornthwaite method probably would improve the accuracy of estimates of demand for water.

The accuracy of the estimates also might be improved if the method were applied to daily climatic data rather than to monthly climatic data, and if demand for water were calculated day to day. Mather (1978, p. 19) suggests that increased accuracy in the calculation of daily or weekly water budgets

Table 12.--Comparison of reported withdrawals of water for agriculture with estimates of demand for water made using 1986 climatic data

[Withdrawal data from J. Locke, New Jersey Department of Environmental Protection, Bureau of Water Allocation, oral commun., 1989; all data are in million gallons; data may not add to totals because of independent rounding]

Month	1986 reported withdrawals for total agriculture	1986 reported withdrawals for non-cranberry agriculture	1986 withdrawals estimated using actual climatic data
January	2,750	22.1	0
February	2,670	20.6	0
March	2,740	100	0
April	2,790	555	0
May	3,870	1,990	1,027
June	6,650	4,680	3,253
July	6,670	5,140	2,953
August	5,310	3,800	2,568
September	4,420	1,940	1,691
October	3,400	755	0
November	2,160	91.1	0
December	3,570	16.2	0
Total:	47,000	19,100	11,500

could be obtained by using an evapotranspiration expression other than Thornthwaite that takes into account daily variations in wind and humidity of the air and their effect on the daily rate of water loss.

A limitation of the Thornthwaite method, regardless of how it is applied, is that it is based on purely physical environmental conditions affecting crops grown in open fields. Irrigation has several other components in addition to physical conditions. One component is biology. Different crops have different water requirements, root depths, and transpiration rates; the influence of specific crops on soil-water retention has not been considered in this application. Another component of irrigation that was not estimated in this report is water loss. Irrigation water is lost through leaky pipes and surface runoff. In this way, the amount of water that is pumped exceeds that needed by the crop. An additional component is human practice. The decisions involved in irrigation--when and how much--are not likely to match the soil requirements exactly. Farmers often decide to irrigate based on factors other than immediate soil conditions, such as predicted weather, pumping costs, and convenience.

Finally, as noted previously, the Thornthwaite method as applied in this report calculates consumptive demand for water for irrigated field-grown crops during the growing season. No estimates are made for the consumptive demand for water for greenhouse crops or the nonconsumptive water use of cranberries and other crops requiring frost protection. Consideration of the special water needs of these crops will improve future estimates of demand for agricultural water.

SUMMARY AND CONCLUSIONS

The Thornthwaite method for calculating a water budget can be used to estimate demand for water where the demand is assumed to be equivalent to the water deficit. Estimates of demand for water for irrigated field-grown crops during the annual growing season, produced by applying this method to six scenarios of climate and land use in New Jersey, range from 3.0 to 28.9 billion gallons. Although the estimates produced using the Thornthwaite or other methods are not exact, the Thornthwaite method seems to generate realistic estimates of demand for agricultural water for irrigation use. Consideration of other factors such as water losses from leaky pipes and high-pressure spray irrigation equipment, which are not easily quantified, will improve estimates of water use.

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GLOSSARY

Water-use (demand for water) terms defined here are underscored where first used in this report.

acre-foot--the quantity of water (43,560 cubic feet) that would cover one acre to a depth of one foot.

agricultural water use--water used in all farming operations. Includes water used for irrigation, livestock, frost protection, harvesting of cranberries, and other miscellaneous farming operations.

climatic water budget--daily, monthly, or annual accounting of the total moisture gains and losses at a given place over a given area.

commercial water use--water used by hotels, motels, office buildings, restaurants, other commercial facilities, and civilian and military institutions.

consumptive water use--water that is no longer available because it has been evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the water environment.

cranberry water use--water used for consumptive and nonconsumptive needs of cranberry plants. Consumptive use by cranberry plants is for nutritive needs. Nonconsumptive water use by cranberry plants is for harvesting in fall and frost protection in winter and accounts for most cranberry water use.

domestic water use--water used for inside household purposes, such as bathing, drinking, flushing toilets, food preparation, washing clothes and dishes, and for outside household purposes, such as washing cars and watering lawns and gardens. It is also called residential water use.

drought climatic scenario--a hypothetical climatic condition characterized by severely below-normal precipitation.

field-grown crops--crops grown in open fields, including vegetables, field crops, nursery stock and sod, fruit trees, berries, and vineyards; does not include crops grown in greenhouses.

greenhouse water use--water used by containerized vegetables, berries, and nursery stock in greenhouses under permanent cover.

ground water--generally, all subsurface water, as distinct from surface water; specifically, that part of the subsurface water in the saturated zone.

industrial water use--water used by manufacturing facilities, including facilities that produce food and similar products, steel, chemical and allied products, and machinery; also includes printing and publishing facilities and petroleum refining. This category does not include power generation, the mining of minerals, or the extraction of crude petroleum and gases, which are separate water-use categories.

irrigation water use--water supplied to lands to assist in the growing of edible crops, nursery stock, and sod.

livestock water use--water used in the commercial raising of animals.

nonconsumptive water use--water that is used in some process but that is not evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the water environment. Examples of nonconsumptive water uses include washing of fruits and vegetables and the harvesting of cranberries. Nonconsumptive water is returned to the environment.

normal climatic scenario--a hypothetical climatic condition characterized by mean values of precipitation and temperature through some specified period of time.

nursery stock--plants grown primarily as ornamentals for residences and office buildings; includes evergreens, deciduous shade trees, shrubs, bedding plants, and cut flowers.

potential evapotranspiration--water loss from a large, homogeneous, vegetation-covered area that never experiences a lack of water.

reported water use--water use reported each year by certified irrigators to the New Jersey Department of Environmental Protection, Bureau of Water Allocation. Certified irrigators are those farmers who are registered with the New Jersey Department of Environmental Protection to use water and who own equipment capable of pumping 100,000 gallons or more each day from surface-water and (or) ground-water sources.

soil-moisture storage--moisture (usually expressed as a depth) stored in the capillaries of the root zone of a soil against the pull of gravity.

surface water--an open body of water such as a stream, lake, or pond.

water deficit--the amount by which available moisture (either from precipitation or stored soil moisture) fails to satisfy the climatic demands for water.

water surplus--soil moisture over and above that needed for evapotranspiration, or soil-moisture recharge which is lost from the soil by subsurface flow; gravitational water that moves out of the root zone of the soil.

withdrawals--water that is removed from the ground or diverted from a surface-water source for use.

APPENDIX--EXAMPLE CALCULATION OF MONTHLY WATER BUDGET

This appendix explains the computations necessary to determine a monthly water budget. The month of July for the normal-climatic-condition scenario (table 3) is used in the example calculations. The tables used to derive some of the values listed below are found in Mather (1978).

(1) The mean of 30-year (1951-80) temperature data for July at Shiloh was calculated, yielding 24.3 °C, the value of T.

(2) Data in Mather (1978, table A-2) provide values of the monthly heat index, i, for different monthly temperatures. The i value corresponding to 24.3 °C is 10.9. The sum of the twelve i values is 57.4, or I.

(3) Unadjusted 30-day potential evapotranspiration has been related to air temperature by Thornthwaite through the expression UnPE = $1.6(10t/I)^a$, where UnPE the unadjusted potential evapotranpiration in centimeters; t is mean monthly temperature in degrees Celsius; I is the annual heat index, the sum of twelve monthly heat indices, i; and a is an expression that varies with I. In this example, a is equal to -.962. For temperatures between 0 and 26.5 °C, data in Mather (1978, table A-3) provide values of unadjusted daily potential evapotranspiration (UnPE), in mm (millimeters), for different mean temperature and I values. The UnPE value corresponding to the July values for T and I is 4.00 mm, or 0.157 in.

(4) Data in Mather (1978, table A-4) provide latitudinal values of the product of the number of days in the month times the mean daily duration of sunlight expressed in units of 12 hours. These values are the correction factors by which the unadjusted daily potential evapotranspiration (UnPE) is multiplied to produce the adjusted monthly potential evapotranspiration (PE), or climatic demand for water. The correction factor for the month of July for the approximate latitude of Shiloh (39.5 °N) is 37.8. Multiplying this number by 0.157 in., the value of UnPE, yields 5.94 in., the PE value for July.

(5) The mean of 30-year (1951-80) precipitation data for July at Shiloh was calculated, yielding 4.23 in., the value of P.

(6) The adjusted monthly potential evapotranspiration (PE) for July, 5.94 in., was then subtracted from the 30-year mean monthly precipitation (P) for July, 4.23 in., yielding -1.71 in., the value of P-PE.

(7) Next, the value of soil-moisture storage in the root zone (ST) was determined. To obtain ST, the soil-moisture storage is assumed to be at maximum (5.91 in. for the sandy-loam-type soil at Shiloh) for all months beginning in January, until the first negative value of P-PE is met--in this instance, -0.257 in. for the month of May. The value of P-PE for each month with a negative value is added to the accumulated value for previous months with negative values of P-PE, and the value of ST is then determined. Data in Mather (1978, table A-7) provide values of the soil moisture stored in the root zone (ST) for different values of accumulated P-PE. In this example, the accumulated P-PE for July is -3.47 in. (-0.257 in. in May plus -1.50 in. in June plus -1.71 in. in July), and the quantity of water

retained in the soil (ST) is determined to be 3.23 in. When P-PE becomes positive (in October at Shiloh), these values are added directly to the storage value of the previous month until the total storage again reaches the water-holding capacity of the soil (5.91 in. for Shiloh).

(8) The change in soil-moisture storage (dST) is simply the change in soil moisture stored in the root zone (ST) from one month to the next. In equation form:

$$dST_m = ST_m - ST_{m-1},$$

where dST = the change in soil-moisture storage,
ST = the soil moisture stored in the root zone, and
m = the month of calculation.

In this example, July is the month of calculation. Thus, dST equals 3.23 in. minus 4.37 in., or -1.14 in.

(9) Actual evapotranspiration (AE) is equal to potential evapotranspiration (PE) when precipitation (P) is greater than or equal to PE. When P-PE is negative, actual evapotranspiration equals precipitation for the month plus the change in storage (disregarding the minus sign for storage change). The actual water used by the soil and plant cover equals all of the precipitation plus the quantity of additional water that plant roots can remove from the soil root zone (storage change). Actual evapotranspiration in July at Shiloh is 5.37 in., a total resulting from 4.23 in. of precipitation plus 1.14 in. of water removed from storage in the soil.

(10) The water deficit (D), as defined in this report, can be calculated as the difference between potential and actual evapotranspiration. In this instance, D is equal to 0.570 in. (5.94 in. minus 5.37 in.). A water surplus (S) is the excess water available to percolate through the soil as recharge to the ground-water table or as throughflow. Where storage reaches its capacity, surplus is equal to the amount that P exceeds PE (P-PE). When the soil storage is not at capacity, no surplus can exist. In that month in which the soil-moisture storage capacity is just satisfied, surplus equals the difference between P-PE and dST, because the quantity of water needed to bring the soil storage to its capacity (dST) must first be removed from the available excess water (P-PE) before a surplus can exist.

In the calculation of water surplus, the Thornthwaite method does not consider the possibility of long periods of no precipitation. During these periods, the topsoil becomes dry. In the event that large amounts of precipitation fall in a short time, as during a summer storm, the dry topsoil will not absorb the initial rainfall immediately, resulting in surface runoff or a water surplus. Thus in reality a water surplus can exist when soil-moisture storage is less than capacity.