RESOURCE EVALUATION

This sheet describes population changes, water use, and a regional water budget in the Salem River study area. The most recent census (1990) for the area and changes in population during 1930-90 are presented. Water-use data are compiled, and quantities of water withdrawn and consumed from the unconfined aquifers and from surface water in the study area are estimated. A water budget evaluates major gains and losses to and from the surface- and ground-water systems.

Population

The census data that are gathered at the beginning of each decade (decennial census) were used to describe population trends in the Salem River study area. The estimated total population of the study area at each decennial census beginning in 1930 is shown in figure 5-1. Population of the study area for each decennial census period was estimated by multiplying the reported population of each municipality by a percentage equal to the percentage of land of the municipality that is in the study area. The population was assumed to be evenly distributed throughout the municipality, which may underestimate the population in urban areas and overestimate the population in rural areas. Table 5-1 lists the 1990 population and land area of each municipality in the Salem River study area and the total estimated population of the study area. The estimated population of the study area in 1990, 69,033, accounts for less than 1 percent of the total population of New Jersey in 1990 (New Jersey Department of Labor, 1991b). In general the population of the Salem River study area has increased slowly (less than 10 percent over each 10-year period) since 1940. The one exception is 1950-60, when the population of the study area experienced its highest rate of growth, a 24-percent increase.

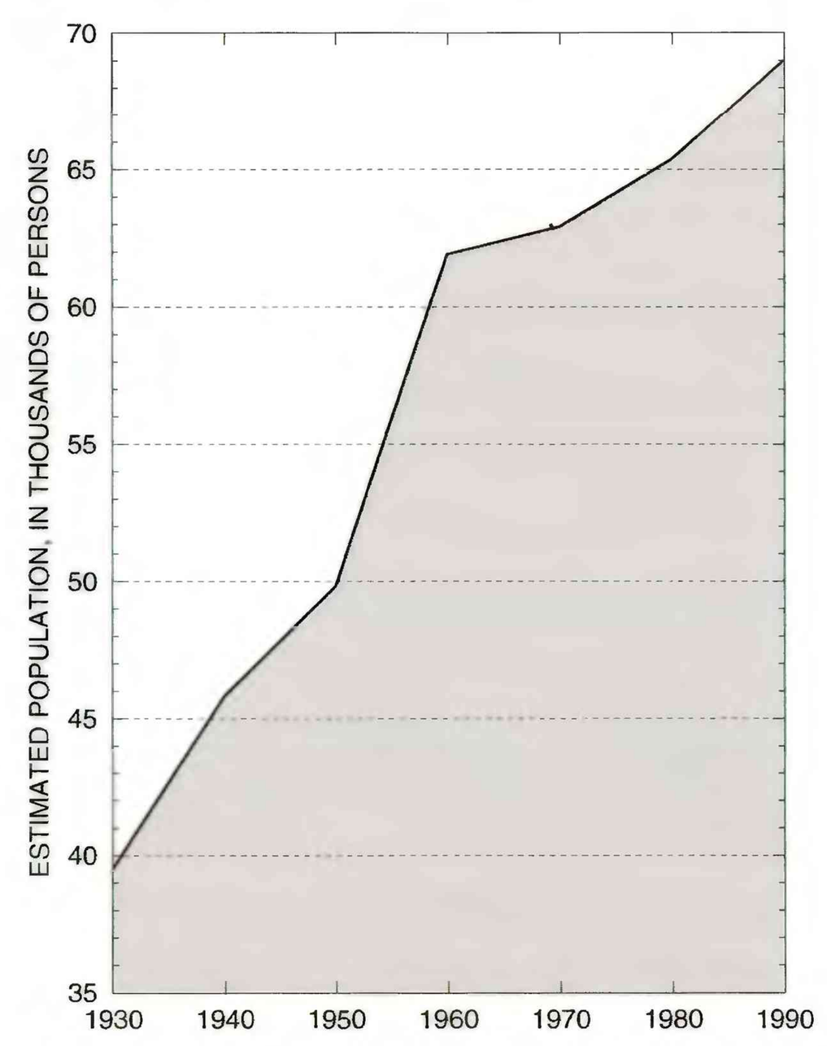


Figure 5-1. Estimated population in the Salem River study area, New Jersey, 1930-90. (Data from New Jersey Department of Labor, 1991a, 1991b.)

Table 5-1. Estimated population of the Salem River study area, New Jersey, based on percentage of land in the study area
[Population data from New Jersey Department of Labor, 1991b; <, less than]

County / Municipality	Total population, 1990	Land area within study area (percent)	Estimated population within study area, 1990
Cumberland County			
Greenwich Township	911	42	383
Hopewell Township	4,215	<1	8
Shiloh Borough	408	8	33
Stow Creek Township	1,437	89	1,279
Gloucester County			
Elk Township	3,806	35	1,332
Glassboro Borough	15,614	10	1,561
Harrison Township	4,715	82	3,866
Logan Township	5,147	45	2,316
South Harrison Township	1,919	100	1,919
Swedesboro Borough	2,024	100	2,024
Woolwich Township	1,459	85	1,240
Salem County			
Alloway Township	2,795	78	2,180
Carneys Point Township	8,443	100	8,443
Elsinboro Township	1,170	100	1,170
Lower Alloways Creek Township	1,858	100	1,858
Mannington Township	1,693	100	1,693
Oldmans Township	1,683	100	1,683
Penns Grove Borough	5,228	100	5,228
Pennsville Township	13,794	100	13,794
Pilesgrove Township	3,250	100	3,250
Quinton Township	2,511	100	2.511
Salem City	6,883	100	6,883
Upper Pittsgrove Township	3.140	39	1.225
Woodstown Boro	3,154	100	3,154
Total	97,257		69,033

Water Use

Estimates of water use in the Salem River study area are presented below. Reported values for 1990 were used to estimate annual withdrawals of water for public- and self-supplied domestic use, irrigation, industrial use, thermoelectric power, and commercial use. From these estimates, the consumptive use of water (that part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment (Solley and others, 1993, p. v)) in each category was calculated and totaled for use in a water budget for the study area. Only water withdrawn from the unconfined parts of aquifers and from surface water were considered in the water budget. However, water withdrawn from both the confined and unconfined parts of each aquifer are presented here to allow comparison between water use from those sources. Because available information was insufficient to determine whether wells screened in the Potomac-Raritan-Magothy aquifer system were in the confined part of the aquifer, those wells located downdip from the outcrop areas of the Potomac-Raritan-Magothy aquifers were considered to be confined, and those located in the outcrop areas were considered to be unconfined. In reality, these wells could be in unconfined or semiconfined parts of the aquifer, and a few actually may be in confined parts of the aquifer.

Public Supply

Although much of the Salem River study area is rural, at least some of the population in many of the municipalities depends on public-supply water. Less than half of this public-supply water comes from unconfined aquifers. Although public-supply systems commonly provide water for both domestic and industrial users, public-supply water in this report is considered to be only that water used for domestic purposes. In New Jersey, more than 75 percent of public-supply water is allotted for domestic supply (Carr and others, 1990, p. 371). Reported annual public-supply withdrawals from both confined and unconfined aquifers in the Salem River study area during 1975-90 are listed in table 5-2. Most withdrawals were from the Potomac-Raritan-Magothy aquifer system, but in past years withdrawals also were made from the Wenonah-Mount Laurel aquifer and the Kirkwood-Cohansey aquifer system. In 1990, 359 Mgal of water reportedly was withdrawn from the unconfined part of the Potomac-Raritan-Magothy aquifer system in the study area for public supply (U.S. Geological Survey Site-Specific Water Use Data System, unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.). No other reported public-supply withdrawals were made from unconfined aquifers in the study area in 1990.

Domestic wastewater from Logan Township, Carney's Point Township, and Penns Grove Borough (sheet 1, fig. 1-3, the municipalities that use unconfined public-supply water) is treated and released into the Delaware River outside the Salem River study area. It is assumed that all residents who use public-supply water also are served by public sewer systems, so consumptive use of this water is considered to be 100 percent. Therefore, consumptive use of ground-water withdrawals from the unconfined Potomac-Raritan-Magothy aquifer system in the study area for public-supply domestic purposes is about 359 Mgal, or about 0.058 inch over the study area, of water per year.

Domestic Self-Supply

Estimation of self-supplied domestic water use is difficult because withdrawals are not reported to any public agency. The amount of self-supplied domestic water withdrawn in the Salem River study area was approximated by estimating the percentage of the population in each municipality that is not served by public-water suppliers. This percentage was multiplied by a per capita domestic-water-use value of 75 gallons per day; the result was multiplied by the consumptive-use rate of 18 percent for domestic water used in New Jersey (Solley and others, 1993, p. 29). All residents who use self-supplied water for domestic purposes were assumed to treat their wastewater with on-site septic systems. Slightly more than half of the self-supplied water used for domestic purposes was assumed to come from unconfined aquifers as determined from information from the USGS GWSI data base. Total withdrawals from unconfined aquifers in the Salem River study area consumed for self-supplied domestic use are estimated to be about 78 Mgal, or about 0.012 inch over the study area, of water per year.

Irrigation

Almost half of the land in the Salem River study area is used for agriculture, and much of that land is irrigated. Agricultural irrigation withdrawals are regulated by the State under a special agricultural/horticultural certification program (J.P. Nawyn, U.S. Geological Survey, written commun., 1993). The withdrawals can be metered, but they rarely are; instead, agricultural withdrawals for irrigation typically are estimated on the basis of pump capacity and time of pumping. Most irrigation water in the Salem River study area is withdrawn from unconfined aquifers or from surface-water sources. In 1990, unconfined withdrawals accounted for 84 percent of total ground-water withdrawals for irrigation in the study area. Surface-water diversions were more than four times ground-water withdrawals. Table 5-3 lists reported withdrawals for irrigation in the study area during 1988-90. Long-term data on water use for irrigation were not available. Irrigation withdrawals were much higher in 1988 than in 1989 or 1990 because precipitation in 1988 was lower than average and therefore irrigation was higher than average. In 1990, 74 Mgal of unconfined ground water and 391 Mgal of surface water were withdrawn for irrigation (U.S. Geological Survey Site-Specific Water Use Data System, unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.) in the Salem River study area. About 90 percent of water used for irrigation in New Jersey is consumed (Solley and others, 1988). Thus, estimated water consumption for irrigation from unconfined aquifers is about 67 Mgal, or 0.011 inch over the study area, and from surface water is about 352 Mgal, or 0.057 inch over the study area, of water per year.

Table 5-2. Reported annual withdrawals for public supply from aquifers in the Salem River study area, New Jersey, 1975-90
[Withdrawal data from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.; all values in million gallons; all values rounded to the nearest million gallon; small differences in totals may be caused by independent rounding; MRPA, Potomac-Raritan-Magothy aquifer system; MLRW, Wenonah-Mount Laurel aquifer; CKKD, Kirkwood-Cohansey aquifer system; --, no reported withdrawals]

	Unconfined			Confined			Total				Percentage of total withdrawals from unconfined aquifers			
Year	MRPA[1]	CKKD	Total	MRPA	MLRW	Total	MRPA	MLRW	CKKD	Total	MRPA	CKKD	Total	Year
1975	340	--	340	876	--	876	1,216	--	--	1,216	28	--	28	1975
1976	326	--	326	935	--	935	1,261	--	--	1,261	26	--	26	1976
1977	354	--	354	926	5	931	1,281	5	--	1,285	28	--	28	1977
1978	297	--	297	1,013	--	1,013	1,310	--	--	1,310	23	--	23	1978
1979	353	--	353	1,028	--	1,028	1,382	--	--	1,382	26	--	26	1979
1980	313	--	313	985	--	985	1,298	--	--	1,298	24	--	24	1980
1981	426	--	426	1,026	--	1,026	1,452	--	--	1,452	29	--	29	1981
1982	439	--	439	1,020	12	1,032	1,459	12	--	1,471	30	--	30	1982
1983	430	--	430	1,112	--	1,112	1,542	--	--	1,542	28	--	28	1983
1984	475	9	483	1,017	--	1,017	1,491	--	9	1,500	32	100	32	1984
1985	423	10	433	917	--	917	1,341	--	10	1,350	32	100	32	1985
1986	458	--	458	884	--	884	1,342	--	--	1,342	34	--	34	1986
1987	444	--	444	1,051	--	1,051	1,495	--	--	1,495	30	--	30	1987
1988	445	--	445	1,030	--	1,030	1,475	--	--	1,475	30	--	30	1988
1989	418	--	418	735	--	735	1,153	--	--	1,153	36	--	36	1989
1990	359	--	359	887	--	887	1,247	--	--	1,247	29	--	29	1990

[1] Withdrawals listed under the unconfined part of the Potomac-Raritan-Magothy aquifer system are from wells located at or near the outcrop areas of the Upper and Middle Potomac-Raritan-Magothy aquifers. Available information is insufficient to determine exactly where these wells are screened. Water in most of these wells is likely to exist under unconfined or semiconfined conditions. However, a small percentage of the withdrawals in this category may be from wells screened in the confined part of the aquifers.

Industry

Table 5-4 shows annual use of self-supplied water in the Salem River study area reported by industries during 1975-90. Most of the self-supplied water used for industrial purposes is from surface water and from the unconfined part of the Potomac-Raritan-Magothy aquifer system in the western part of the study area. In 1990, 1,516 Mgal of unconfined ground water and 3,896 Mgal of surface water were withdrawn by industrial self-supplied water users (U.S. Geological Survey Site-Specific Water Use Data System, unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.). Because in this report public-supply water is considered to be used for domestic purposes only, self-supplied industrial water use is considered equal to total industrial water use. According to Solley and others (1993, p. 45), about 8 percent of the water withdrawn for industrial purposes is consumed. Therefore, in 1990 121 Mgal, or 0.019 inch over the study area, of unconfined ground water and 312 Mgal, or 0.050 inch over the study area, of surface water were consumed.

Thermoelectric Power

Withdrawals used for thermoelectric power include water used in the generation of electric power with fossil-fuel or nuclear energy (Solley and others, 1993, p. 50). Two power plants in the Salem River study area use water to generate electricity. One plant, in Pennsville Township, uses fossil fuel; the other, in Lower Alloways Creek Township, uses nuclear energy. Table 5-5 shows reported use of ground water for thermoelectric power during 1975-90. In 1990, 235 Mgal, or 0.037 inch over the study area, of unconfined ground water was used to generate electric power. Solley and others (1993, p. 53) estimate that water use for thermoelectric power is virtually nonconsumptive. However, because water at both plants is treated and released into the Delaware River, consumptive use of this water for the purposes of this report is considered to be 100 percent.

Commercial Use

Commercial water use includes water used and supplied by motels, hotels, restaurants, office buildings, and other commercial facilities (Solley and others, 1993, p. 30). A small amount of confined ground water was withdrawn from the Salem River study area for commercial use in 1990 (table 5-6). No withdrawals were made from unconfined aquifers or from surface water for commercial use.

Total Water Use

Water for domestic use (both public- and self-supplied), irrigation, industry, thermoelectric power, and commercial purposes accounts for all significant water use in the Salem River study area. Figure 5-2 summarizes the estimates of consumptive use of surface water and unconfined ground water in the study area for these water-use categories. Irrigation and industrial water use together account for more than half the total consumption of surface water and unconfined ground water in the study area, whereas domestic use accounts for less than one-third. Figure 5-3 summarizes the estimates of consumptive use of surface water and all confined and unconfined ground water combined in the Salem River study area for each water-use category. Domestic use (both public- and self-supplied) accounts for nearly half the total consumptive water use in the study area. Figure 5-4 summarizes the consumptive use of water from the unconfined sytem (the five unconfined aquifers and the surface-water sources) in the Salem River study area. More than 90 percent of the water consumed from the unconfined system is withdrawn either from surface-water sources or from the Potomac-Raritan-Magothy aquifer system.

Table 5-3. Reported annual withdrawals for use in irrigation from aquifers and surface water in the Salem River study area, New Jersey, 1988-90
[Withdrawal data from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.; all values in million gallons; all values rounded to the nearest million gallon; small differences in totals may be caused by independent rounding; MRPA, Potomac-Raritan-Magothy aquifer system; MLRW, Wenonah-Mount Laurel aquifer; CKKD, Kirkwood-Cohansey aquifer system; SW, surface water; GW, ground water; --, no reported withdrawals]

	Unconfined				Confined	Total						Percentage of total withdrawals from unconfined aquifers and surface water					
Year	MRPA[1]	MLRW	CKKD	Total	MRPA	MRPA	MLRW	CKKD	GW total	SW	GW and SW total	MRPA	MLRW	CKKD	GW total	GW and SW total	Year
1988	--	2	319	321	23	23	2	319	343	1,612	1,955	0	100	100	93	16	1988
1989	--	<1	15	16	9	9	<1	15	25	351	375	0	100	100	65	4	1989
1990	8	<1	66	74	14	22	<1	66	88	391	479	37	100	100	84	15	1990

[1] Withdrawals listed under the unconfined part of the Potomac-Raritan-Magothy aquifer system are from wells located at or near the outcrop areas of the Upper and Middle Potomac-Raritan-Magothy aquifers. Availiable information is insufficient to determine exactly where these wells are screened. Water in most of the wells is likely to exist under unconfined or semiconfined conditions. However, a small percentage of the withdrawals in this category may be from wells screened in the confined part of the aquifers.

Table 5-4. Reported annual withdrawals for use in industry from aquifers and surface water in the Salem River study area, New Jersey, 1975-90
[Withdrawal data from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.; all values in million gallons; all values rounded to the nearest million gallon; small differences in totals may be caused by independent rounding; MRPA, Potomac-Raritan-Magothy aquifer system; MLRW, Wenonah-Mount Laurel aquifer; SW, surface water; GW, ground water; --, no reported withdrawals]

	Unconfined	Confined			Total					Percentage of total withdrawals from unconfined aquifers and surface water			
Year	MRPA[1]	MRPA	MLRW	Total	MRPA	MLRW	GW total	SW	GW and SW total	MRPA	GW total	GW and SW total	Year
1975	1,732	679	21	699	2,411	21	2,432	--	2,432	72	71	71	1975
1976	2,367	678	21	699	3,045	21	3,066	--	3,066	78	77	77	1976
1977	2,132	704	21	724	2,836	21	2,857	--	2,857	75	75	75	1977
1978	1,461	692	21	712	2,153	21	2,174	--	2,174	68	67	67	1978
1979	1,097	232	66	297	1,328	66	1,394	--	1,394	83	79	79	1979
1980	1,421	96	27	123	1,517	27	1,543	--	1,543	94	92	92	1980
1981	1,374	62	27	89	1,436	27	1,463	--	1,463	96	94	94	1981
1982	1,398	58	27	85	1,457	27	1,483	3,894	5,378	96	94	26	1982
1983	1,405	59	--	59	1,464	--	1,464	3,207	4,671	96	96	30	1983
1984	1,445	13	--	13	1,458	--	1,458	--	1,458	99	99	99	1984
1985	1,429	15	--	15	1,444	--	1,444	--	1,444	99	99	99	1985
1986	1,549	14	--	14	1,563	--	1,563	3,438	5,001	99	99	31	1986
1987	1,275	32	--	32	1,307	--	1,307	3,955	5,261	98	98	24	1987
1988	1,387	18	--	18	1,405	--	1,405	3,807	5,211	99	99	27	1988
1989	1,932	13	--	13	1,946	--	1,946	3,268	5,214	99	99	37	1989
1990	1,516	29	--	29	1,545	--	1,545	3,896	5,441	98	98	28	1990

[1] Withdrawals listed under the unconfined part of the Potomac-Raritan-Magothy aquifer system are from wells located at or near the outcrop areas of the Upper and Middle Potomac-Raritan-Magothy aquifers. Available information is insufficient to determine exactly where these wells are screened. Water in most of the wells is likely to exist under unconfined or semiconfined conditions. However, a small percentage of the withdrawals in this category may be from wells screened in the confined part of the aquifers.

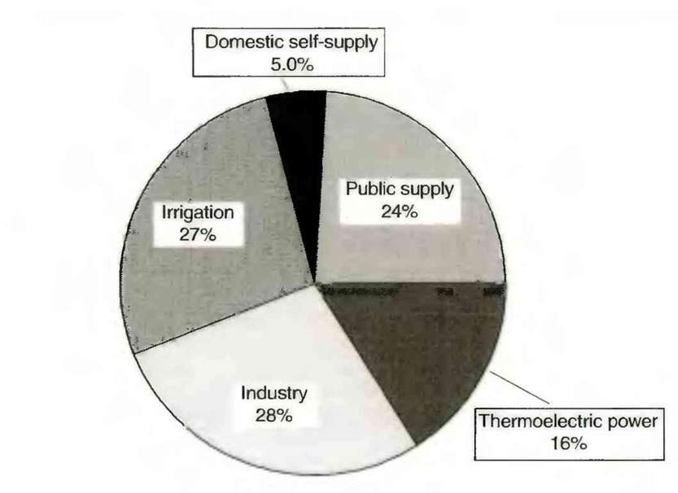
Table 5-5. Reported annual withdrawals for thermoelectric power from aquifers in the Salem River study area, New Jersey, 1975-90
[Withdrawal data from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.; all values in million gallons; all values rounded to the nearest million gallon; small differences in totals may be caused by independent rounding; MRPA, Potomac-Raritan-Magothy aquifer system; MLRW, Wenonah-Mount Laurel aquifer; CKKD, Kirkwood-Cohansey aquifer system; --, no reported withdrawals]

	Unconfined			Confined			Total				Percentage of total withdrawals from unconfined aquifers			
Year	MRPA[1]	CKKD	Total	MRPA	MLRW	Total	MRPA	MLRW	CKKD	Total	MRPA	CKKD	Total	Year
1975	300	--	300	--	95	95	300	95	--	395	100	--	76	1975
1976	300	--	300	--	85	85	300	85	--	385	100	--	78	1976
1977	300	--	300	--	245	245	300	245	--	545	100	--	55	1977
1978	300	--	300	--	449	449	300	449	--	749	100	--	40	1978
1979	300	--	300	--	380	380	300	380	--	680	100	--	44	1979
1980	302	--	302	223	120	343	525	120	--	645	58	--	47	1980
1981	323	--	323	223	120	343	546	120	--	666	59	--	48	1981
1982	216	--	216	120	65	185	336	65	--	401	64	--	54	1982
1983	265	--	265	77	135	212	342	135	--	477	77	--	56	1983
1984	306	--	306	331	105	436	637	105	--	742	48	--	41	1984
1985	364	80	444	318	69	387	682	69	80	831	53	100	53	1985
1986	352	85	437	196	58	254	548	58	85	691	64	100	63	1986
1987	345	71	416	190	24	214	535	24	71	630	64	100	66	1987
1988	243	16	259	161	23	184	404	23	16	443	60	100	58	1988
1989	214	52	266	164	24	188	378	24	52	454	57	100	59	1989
1990	226	9	235	144	8	152	370	8	9	387	61	100	61	1990

[1] Withdrawals listed under the unconfined part of the Potomac-Raritan-Magothy aquifer system are from wells located at or near the outcrop areas of the Upper and Middle Potomac-Raritan-Magothy aquifers. Availiable information is insufficient to determine exactly where these wells are screened. Water in most of the wells is likely to exist under unconfined or semiconfined conditions. However, a small percentage of the withdrawals in this category may be from wells screened in the confined part of the aquifers.

Table 5-6. Reported annual withdrawals for commercial use from aquifers in the Salem River study area, New Jersey, 1975-90
[Withdrawal data from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.; all values in million gallons; all values rounded to the nearest million gallon; small differences in totals may be caused by independent rounding; MRPA, Potomac-Raritan-Magothy aquifer system; EGLS, Englishtown aquifer system; MLRW, Wenonah-Mount Laurel aquifer; --, no reported withdrawals; <, less than]

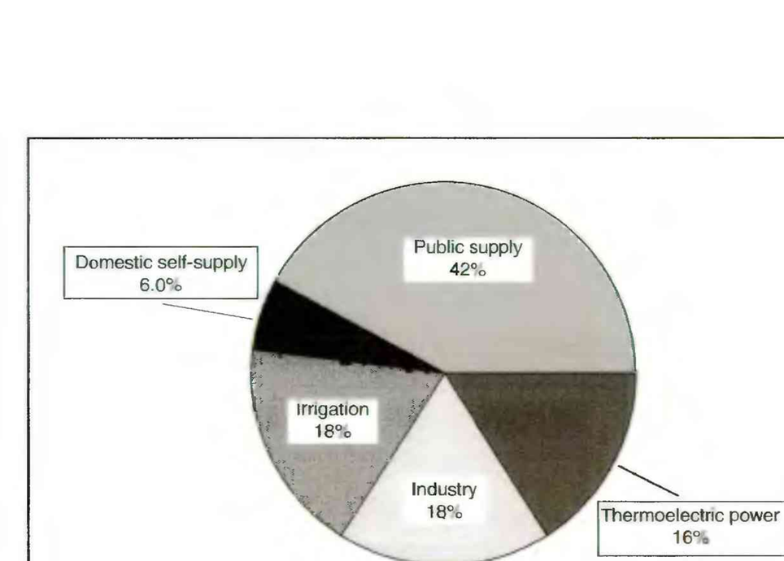
	Confined			
Year	MRPA	EGLS	MLRW	Total
1975	38	--	9	47
1976	40	--	9	49
1977	42	--	9	52
1978	40	--	9	49
1979	58	--	--	58
1980	47	--	--	47
1981	36	<1	--	36
1982	29	<1	--	29
1983	28	<1	--	28
1984	41	--	--	41
1985	43	--	--	43
1986	20	--	--	20
1987	20	--	--	20
1988	22	--	--	22
1989	21	--	--	21
1990	19	--	--	19



Water-use category	Unconfined ground water: Million gallons	Unconfined ground water: Inches over the study area	Surface water: Million gallons	Surface water: Inches over the study area	Unconfined ground water and surface water: Million gallons	Unconfined ground water and surface water: Inches over the study area
Public supply[1]	359	0.058	0	0	359	0.058
Domestic self-supply	78	.012	0	0	78	.012
Irrigation[1]	67	.011	352	.057	418	.067
Industry[1]	121	.019	312	.050	433	.070
Thermoelectric power[1]	235	.037	0	0	235	.037
Total consumptive use[2]	860	.137	664	.107	1,524	.244

[1]Water-use data for public supply, irrigation, industry, and thermoelectric power are from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.
[2]Small differences in totals may be caused by independent rounding.

Figure 5-2. Consumptive use of ground water from unconfined aquifers and of surface water in the Salem River study area, New Jersey, by water-use category.

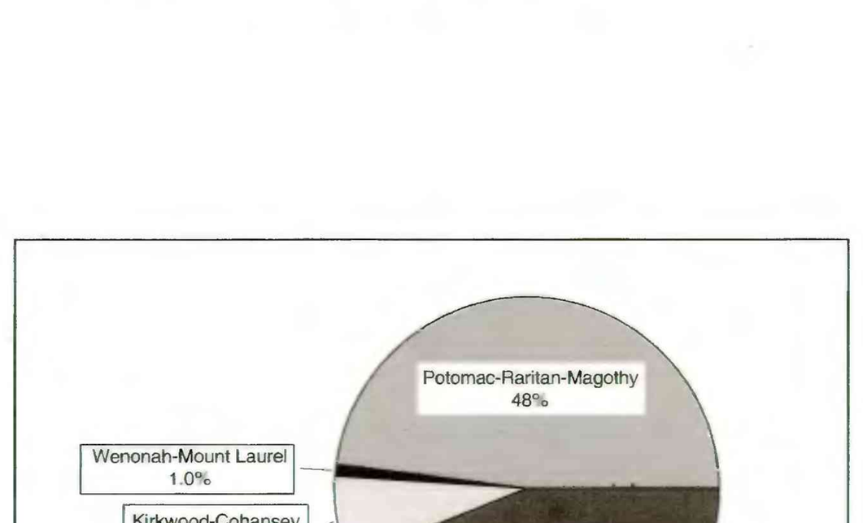


Note: Water use for commercial purposes comprises less than 1 percent of the total consumptive use of water in the Salem River study area.

Water-use category	Unconfined and confined ground water, and surface water: Million gallons	Unconfined and confined ground water, and surface water: Inches over the study area
Public supply[1]	1,028	0.165
Domestic self-supply	153	.025
Irrigation[1]	431	.069
Industry[1]	435	.070
Thermoelectric Power[1]	387	.062
Commercial[1]	.764	.00012
Total consumptive use[2]	2,434	.391

[1]Water-use data for public supply, irrigation, industry, thermoelectric power, and commercial use are from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.
[2]Small differences in totals may be caused by independent rounding.

Figure 5-3. Consumptive use of ground water from unconfined and confined aquifers and of surface water in the Salem River study area, New Jersey, by water-use category.



Note: Water use from the Englishtown aquifer system and the Vincentown aquifer combined comprises less than 1 percent of the total consumptive use of water in the Salem River study area.

Source of water	Unconfined ground water[1]: Million gallons	Unconfined ground water[1]: Inches over the study area
Potomac-Raritan-Magothy aquifer system	733	0.118
Englishtown aquifer system	.609	.00010
Wenonah-Mount Laurel aquifer	15	.002
Vincentown aquifer	2	.00038
Kirkwood-Cohansey aquifer system	108	.017
Surface water	664	.107
Total consumptive use[2]	1,524	.244

[1]Water-use data for public supply, irrigation, industry, thermoelectric power, and commercial use are from U.S. Geological Survey Site-Specific Water Use Data System--unpublished data on file at the U.S. Geological Survey office in West Trenton, N.J.
[2]Small differences in totals may be caused by independent rounding.

Figure 5-4. Consumptive use of ground water from unconfined aquifers and of surface water in the Salem River study area, New Jersey, by source of water.

Water Budget

The hydrologic cycle of the Salem River study area is dynamic. For purposes of discussion, the hydrologic cycle can be conceptualized as a water budget in which inflows are balanced by equivalent outflows. The following budget analysis accounts for all water-system gains and losses in the study area. The water budget can be evaluated by using two internal budgets and their corresponding balance equations: one that describes gains and losses to and from the land surface, and another that describes gains and losses to and from the saturated, unconfined ground-water system. Many of the variables in the two internal budgets are difficult to estimate. One variable that cannot be measured or estimated without other hydrologic data, recharge to the aquifer, was determined separately in both equations, and the two values were compared. The values of precipitation, base flow, direct runoff, evapotranspiration, and withdrawals by pumping were discussed in previous sections.

In order to calculate the amount of water moving through the study area, a budget volume must be defined. A budget volume is the "package" of geologic material into and out of which the movement of water is calculated. For the purposes of this analysis, the budget volume is defined by the extent of the unconfined aquifers and the shallow part of the confining units in the study area (sheet 1, table 1-1). It is assumed that neither surface- nor ground-water flow is gained or lost across the side boundaries of the study area. Figures 5-5 and 5-6 are generalized hydrogeologic sections through the study area that illustrate the budget volume and generalized flow patterns within it. Figure 5-5 shows generalized flow in the unconfined aquifer in the southwest-northeast direction; figure 5-6 shows generalized flow from unconfined to confined aquifers in the northwest-southeast direction. Water is introduced to the land surface through precipitation and artificial recharge from water that was pumped from confined aquifers, used, treated, and released into the surface-water system. Water is lost from the land surface through evapotranspiration, direct runoff, water use from surface-water bodies, and natural recharge to the ground-water system. These terms represent the components of the land-surface equation. Water is introduced to the ground-water system through natural recharge (which was lost by the land surface) and artificial recharge from septic systems that treat domestic wastewater that was pumped initially from confined aquifers. Water is lost from the ground-water system through base flow, water use from the unconfined aquifer, leakage to confined aquifers, and flow from the unconfined part of each aquifer to the confined part of each aquifer. These terms represent the components of the ground-water-system equation.

The equation used to calculate the water budget for the land surface is

$$P + R_{as} = Q_{dr} + ET + W_s + R_n ,$$

and the equation for the ground-water system is

$$R_n + R_{ag} = Q_b + L + W_g .$$

The variables in the water budget are

- P = precipitation,
- Q_{dr} = direct runoff,
- ET = evapotranspiration,
- R_n = natural recharge to the aquifer,
- Q_b = base flow,
- L = leakage and flow to confined aquifers,
- W_s = consumptive water use from surface-water withdrawals,
- W_g = consumptive water use from unconfined-ground-water withdrawals,
- R_{as} = artificial recharge to the surface-water system, and
- R_{ag} = artificial recharge to the ground-water system.

The precipitation value (P) used in the water budget is consistent with reported values for the Coastal Plain of New Jersey. The precipitation data were obtained from the records for the Woodstown weather station. Values of precipitation were averaged over the last 10 years of record at the station, 1983-92. This average value, 45.4 inches, was used in the water-budget equation.

The discharge values (Q_{dr} and Q_b) used in the water-budget analysis were based on measurements at the Raccoon Creek near Swedesboro, N.J. (01477120), continuous-record streamflow-gaging station, and predicted discharges at nine low-flow partial-record stations (01413050, 01413060, 01477128, 01477510, 01482520, 01482530, 01482900, 01482950, and 01483010; see sheet 3). Discharge values were selected according to two criteria: the discharge could not have been measured at a station that is near known regulated impoundments, and, for gaged drainage areas, only the discharge measurements from the station located farthest downstream were used to avoid counting the same streamflow more than once in a drainage area. Discharge at Raccoon Creek near Swedesboro, N.J. (01477120), was averaged over the last 10 years of record available (1983-92). Discharge at each station was separated into base-flow and direct-runoff components and was totaled over the combined drainage areas of the 10 streamflow stations. This combined area amounts to only about 30 percent of the Salem River study area because of the discharge-measurement criteria and the fact that the streams typically are gaged above the limit of tidal influence. The tidal influence in the study area commonly extends from one-half to two-thirds of the way across the study area from the Delaware River and Delaware Bay. The values of the discharge components used in the water budget analysis, 13 inches for base flow (Q_b) and 6.3 inches for direct runoff (Q_{dr}), are based on discharge values from about 30 percent of the study area.

Evapotranspiration can be calculated by using any of several methods. For this study, potential evapotranspiration was calculated by using the Thornthwaite method (Thornthwaite and Mather, 1957). This method takes into account the latitude of and mean monthly temperature at the site, but does not consider precipitation, soil moisture, or vegetative cover. Several problems arise with the use of this method. First, evidence indicates that differences in soil and plant types can cause variations in evapotranspiration, even under conditions of adequate soil moisture (Warren and others, 1968, p. C24). Second, the Thornthwaite method is used to estimate a potential rate rather than an actual rate. Potential evapotranspiration is the amount of moisture that would transpire and evaporate if there was at no time a deficiency of water. The rate of potential evapotranspiration does not account for dry periods when little moisture is available for transpiration or evaporation; therefore, it is generally much higher than the actual evapotranspiration rate. Potential evapotranspiration in the Salem River study area was estimated to be 29.72 inches per year (see sheet 3). Alternatively, evapotranspiration can be calculated by examining the precipitation-runoff relation. This method takes into account the geology and topography of the area and requires a long period of record to make adjustments for changes in storage in the soil. Reported evapotranspiration rates in and near the Salem River study area calculated by Hardt and Hilton (1969, p. 54), Vowinkel and Foster (1981, p. 18), and Parker and others (1964, p. 111) with this method range from 18.5 to 27.5 inches per year.

To estimate actual evapotranspiration in the Salem River study area, monthly potential evapotranspiration rates were compared with monthly precipitation rates at the Woodstown weather station. For those months during which the precipitation rate was greater than the potential-evapotranspiration rate, the potential-evapotranspiration rate was used as the actual rate. For those months during which the precipitation rate was less than the potential-evapotranspiration rate, the monthly precipitation rate was used as the actual rate of evapotranspiration. These monthly "actual" evapotranspiration rates were totaled for the year and used in the water-budget analysis of the Salem River study area. The actual evapotranspiration (ET) is estimated to be 26 inches per year.

The rate of leakage and flow to confined aquifers (L) in the water budget is the vertical flow through confining units to the confined aquifers below plus horizontal flow in the downdip direction from the unconfined part of an aquifer to the confined part of the same aquifer, as shown in figure 5-6. These two types of flow are totaled for each aquifer that crops out in the Salem River study area. The flow rates were derived by using an updated version of the New Jersey Regional Aquifer System Analysis ground-water-flow model (Martin, 1990). This model includes pumpage information through 1988 to improve the accuracy of estimates of leakage and flow between aquifers in the Salem River study area. The total rate of leakage and flow to confined aquifers in the study area is 0.007 inch per year (D.A. Pope, U.S. Geological Survey, written commun., 1991).

The values for consumptive water use (W_s, W_g) in the Salem River study area are discussed in the section on water use. These values are 0.107 inch for consumptive water use from surface-water withdrawals (W_s) and 0.136 inch for consumptive water use from unconfined-ground-water withdrawals (W_g).

The values for artificial recharge (R_{as} and R_{ag}) were estimated from available water-use data. Artificial recharge to the surface-water system (R_{as}) was estimated from information on withdrawals from confined aquifers, on consumptive water-use rates, and on whether discharge points for wastewater-treatment plants were located inside or outside the study area. Artificial recharge to the unconfined ground-water system (R_{ag}) was estimated from approximations of self-supplied domestic withdrawals from confined aquifers (see section on water use) and from information on consumptive water-use rates.

Before all of the above variables are inserted into the water-budget equations, they must be examined to ensure that none of them has been accounted for more than once. Because the discharge measured at a gaging station may consistently be augmented by discharges from wastewater-treatment plants and depleted by surface-water withdrawals that occur at a relatively constant rate in the study area, these inflows and outflows are computed as part of base flow during hydrograph separation. Therefore, the value for base flow (Q_b) in this study already reflects artificial recharge to the surface-water system (R_{as}) and surface-water withdrawals (W_s). Because the recharge (R_{as}) and withdrawal (W_s) values are already included in the land-surface equation, they are not included in the value for base flow in the ground-water equation. In the Salem River study area, the values of R_{as} and W_s are insignificant compared to the value for base flow. Thus, the value used for base flow in the water-budget equation remains 13 inches.

The values discussed above and previously in the text can be used to determine a water budget for the study area. These values are as follows (in inches):

- P = 45.4 ,
- R_{as} = 0.035 ,
- Q_{dr} = 6.3 ,
- ET = 26 ,
- W_s = 0.107 ,
- R_{ag} = 0.112 ,
- Q_b = 13 ,
- L = 0.007 , and
- W_g = 0.136 .

By inserting these values into the land-surface and ground-water-system budget equations:

$$P + R_{as} = Q_{dr} + ET + W_s + R_n$$
$$45.4 + 0.035 = 6.3 + 26 + 0.107 + R_n$$
$$R_n = 13.03 \text{ inches}$$

and

$$R_n + R_{ag} = Q_b + L + W_g$$
$$R_n + 0.112 = 13 + 0.007 + 0.136$$
$$R_n = 13.03 \text{ inches} .$$

In this water budget, recharge from the land surface to the unconfined aquifers in the Salem River study area is about 13 inches per year, which is 29 percent of annual precipitation. Base flow is the primary means by which available recharge is removed from the ground-water system. Virtually all recharge is discharged as base flow. As a result, any increase in leakage and flow to confined aquifers or in ground-water withdrawals would reduce the amount of ground water available for base flow, thereby increasing the risk that streamflow would be reduced.

The primary and ultimate source of water in the hydrologic cycle is precipitation, and the two major discharge components of the hydrologic cycle are evapotranspiration and discharge. Evapotranspiration in this budget is 57 percent of the sum of precipitation and artificial recharge; discharge, composed of base flow and direct runoff, is 42 percent of the sum of precipitation and artificial recharge. Consumptive water use from unconfined aquifers in the Salem River study area is a very small percentage of the total, less than 1 percent. This hydrologic analysis estimates the flow of water into and out of the unconfined-ground-water and surface-water systems in the Salem River study area and indicates the extent of consumptive use of this water under current (1994) conditions. This analysis can be updated periodically to assess changes in the hydrologic system in the study area.

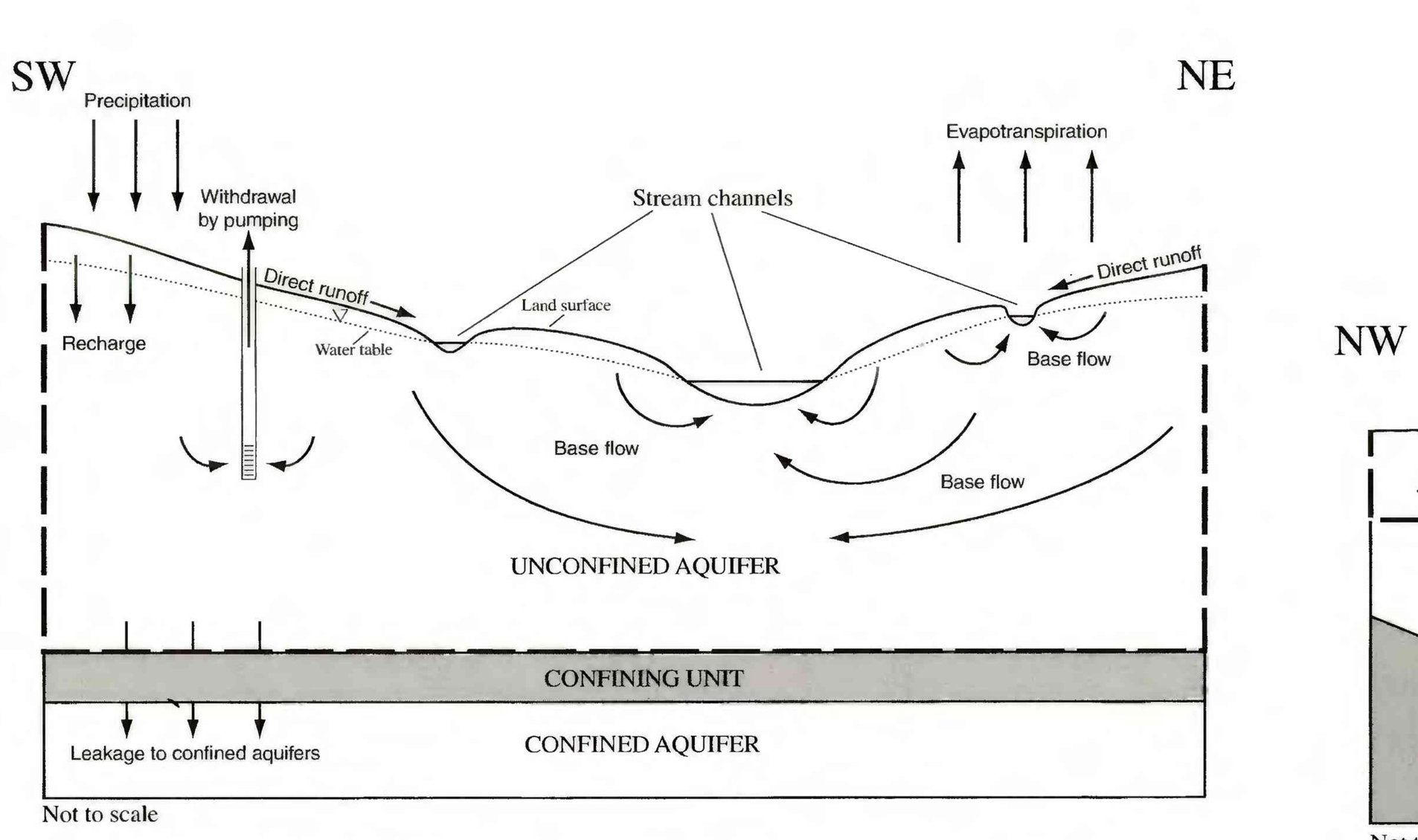


Figure 5-5. Generalized southwest-northeast hydrogeologic section through the Salem River study area, New Jersey, showing a schematic diagram of the hydrologic cycle. (Dashed line is budget-volume boundary.)

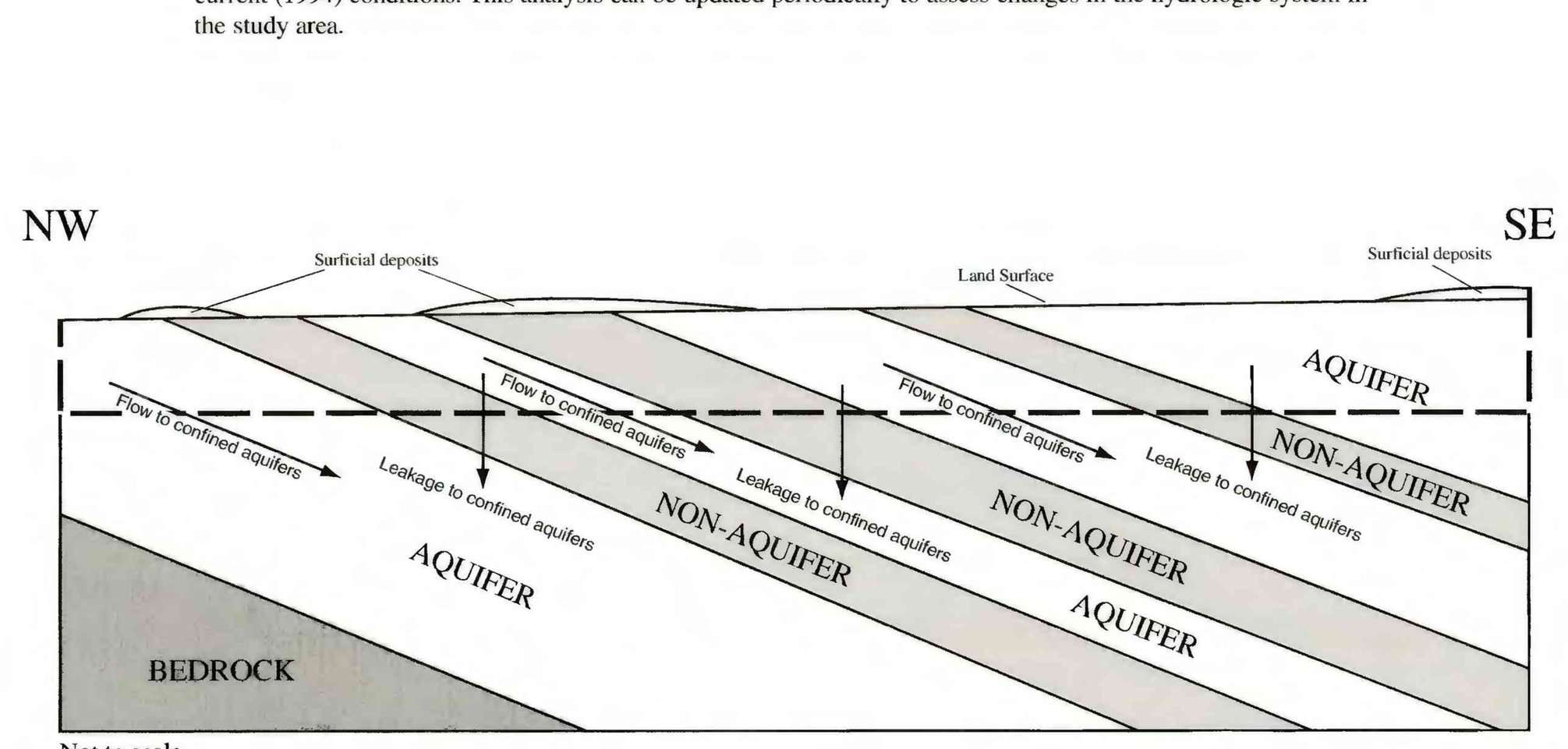


Figure 5-6. Generalized northwest-southeast hydrogeologic section through the Salem River study area, New Jersey, showing a schematic diagram of leakage and flow to confined aquifers. (Dashed line is budget-volume boundary.)

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