Table 9.--*Measured and simulated water levels in observation wells and ponds in Plymouth-Carver aquifer, December 1984.*

Model			Well or pond (fig. 18)	Water level, in feet		
Row	Column	Layer		Measured	Simulated	Residual
8	78	1	PWW-501	5.88	0.97	4.91
19	40	1	PWW-502	81.63	81.86	- .23
19	48	1	PWW-261	74.05	70.30	3.75
20	44	1	PWW-503	77.41	76.09	1.32
22	77	1	PWW-313	38.59	39.25	- .66
23	67	1	PWW-241	67.73	64.29	3.44
23	77	1	PWW-285	36.60	41.49	-4.89
24	49	1	PWW-215	81.90	84.14	-2.24
24	52	1	PWW-516	77.03	81.38	-4.35
24	66	1	PWW-242	72.59	67.56	5.03
24	73	1	PWW-245	57.79	55.66	2.13
25	28	1	PWW-413	123.73	119.03	4.70
25	72	1	PWW-240	71.78	63.91	7.87
26	46	1	PWW-504	99.03	90.99	8.04
27	66	1	PWW-243	79.20	77.59	1.61
28	38	1	PWW-505	118.30	110.40	7.90
28	47	1	PWW-306	101.66	97.65	4.01
28	68	1	PWW-244	87.20	78.93	8.27
29	46	1	PWW-305	102.07	98.99	3.08
30	26	1	PWW-517	123.73	122.93	.80
30	52	1	PWW-506	98.88	97.77	1.11
30	66	1	PWW-379	82.05	85.35	-3.30
34	34	1	PWW-22	120.98	119.18	1.80
34	53	1	PWW-315	102.71	103.69	- .98
35	71	1	PWW-509	70.45	78.82	-8.37
36	24	1	CDW-119	114.70	115.84	-1.14
37	46	1	PWW-507	112.95	112.74	.21
38	78	1	PWW-414	64.07	68.56	-4.49
39	50	1	PWW-416	108.18	111.75	-3.57
40	82	1	PWW-518	52.39	56.53	-4.14
41	92	1	PWW-319	21.04	19.23	1.81
42	29	1	CDW-120	92.60	98.53	-5.93
42	92	1	PWW-418	22.16	22.54	- .38
44	31	1	CDW-121	103.23	102.31	.92
44	82	1	PWW-253	46.59	54.62	-8.03
46	61	1	PWW-510	98.53	99.92	-1.39
46	84	1	PWW-251	43.60	49.10	-5.50
47	56	1	PWW-511	101.01	104.38	-3.37
49	83	1	PWW-513	47.75	50.76	-3.01
51	40	1	BHW-126	99.95	87.98	11.97
51	50	1	CDW-99	98.92	103.27	4.35
51	59	1	PWW-415	91.34	96.06	-4.72
53	82	1	PWW-514	48.22	49.64	-1.42
53	84	1	PWW-520	47.02	46.88	.14
54	55	1	CDW-123	83.97	89.90	-5.93
54	56	1	PWW-521	89.77	88.64	1.13
56	52	1	CDW-125	79.66	89.74	-10.08
57	84	1	PWW-519	46.61	42.69	3.92
58	58	1	PWW-431	75.15	80.19	-5.04
59	63	1	PWW-512	69.78	69.07	.71

Table 9.--*Measured and simulated water levels in observation wells and ponds in Plymouth-Carver aquifer, December 1984*--Continued.

Model			Well or pond (fig. 18)	Water level, in feet		
Row	Column	Layer		Measured	Simulated	Residual
61	87	1	PWW-368	28.98	30.64	-1.66
61	93	1	BHW-293	25.22	19.65	5.57
63	56	1	PWW-430	61.56	66.69	-5.13
64	37	1	CDW-122	76.10	80.67	-4.57
64	53	1	CDW-86	64.80	66.41	-1.61
65	36	1	CDW-201	78.14	76.65	1.49
65	57	1	PWW-236	55.71	60.72	-5.01
66	53	1	CDW-85	62.84	62.02	.82
66	55	1	PWW-369	56.02	56.13	- .11
66	61	1	PWW-238	55.51	54.20	1.31
66	64	1	WFW-296	45.48	45.55	- .07
68	57	1	PWW-237	51.09	52.64	-1.55
69	61	1	WFW-295	45.81	44.37	1.44
69	64	1	WFW-297	39.49	38.75	.74
70	57	1	WFW-245	46.21	44.75	1.46
70	79	1	WFW-211	16.49	18.25	-1.76
8	73	1	BARTLETT POND	6.53	3.13	3.40
16	78	1	FRESH POND	14.24	14.81	- .57
20	75	1	BEAVER POND	20.66	34.29	13.63
20	81	1	SHALLOW POND	31.19	23.79	7.40
21	33	1	LITTLE MUDDY POND	108.70	101.29	7.41
21	57	1	RUSSELL MILL POND	51.79	58.32	-6.53
21	74	1	ISLAND POND	42.28	40.03	2.25
24	43	1	BRIGGS RESERVOIR	87.41	90.35	-2.94
24	48	1	COOKS POND	87.08	86.24	.84
24	87	1	LILLY POND	11.09	11.33	- .24
28	41	1	MICAJAH POND	108.20	105.30	2.90
28	58	1	ISLAND POND	88.79	89.47	- .68
28	83	1	MOREY POND	48.74	41.67	7.07
30	93	1	BLACK POND	4.43	0	4.43
31	20	1	UNAMED POND WEST OF CEDAR SWAMP	122.44	120.25	2.19
33	59	1	CROOKED POND	95.78	98.32	-2.54
34	89	1	SAVERY POND	26.08	24.22	1.86
37	48	1	WIDGEON POND	108.17	111.79	-3.62
38	46	1	CURLEW POND	108.00	112.84	-4.84
39	47	1	ROCKY POND	107.52	112.43	-4.91
40	82	1	GRASSY POND, PWW-518	51.16	56.18	-5.02
41	58	1	COLLEGE POND	103.58	106.49	-2.91
42	88	1	HODGES POND	33.52	36.52	-3.00
48	26	1	VAUGHN POND	101.81	102.97	-1.16
49	83	1	LITTLE DUCK POND	47.07	50.76	-3.69
57	83	1	LITTLE ROCKY POND	46.87	43.38	3.49
59	67	1	UNAMED POND SOUTH-EAST OF CHARGE POND	57.07	60.25	-3.18
59	89	1	HORSE POND	40.64	30.93	9.71
64	50	1	GOLDEN FIELD POND	74.04	75.49	-1.45

Table 9.--*Measured and simulated water levels in observation wells and ponds in Plymouth-Carver aquifer, December 1984*--Continued.

Model			Well or pond (fig. 18)	Water level, in feet		
Row	Column	Layer		Measured	Simulated	Residual
64	90	1	GOAT PASTURE POND	20.76	16.78	3.98
65	36	1	BATES POND	79.08	78.54	.54
65	39	1	POND NEAR HUCKLEBERRY CORNER	72.91	74.48	-1.57
65	42	1	POND ON CRANE BROOK	67.63	68.65	-1.02
65	89	1	ELLIS POND	16.17	13.80	2.37
77	54	1	UNAMED POND AT INTERSECTION OF I-195 AND I-25	38.83	34.93	3.90

Absolute value of the mean of the water-level residuals, in feet 0.15

Mean of the absolute values of the water-level residuals, in feet 3.46

Standard deviation of the water-level residuals, in feet 4.42

Total number of observations = 101.

2.8 percent (3.46 ft/125 ft) of the total relief of the water table. A value less than about 5 percent is considered to indicate excellent overall agreement between measured and simulated water levels, and a value less than about 10 percent is considered acceptable. The overall agreement for this calibrated model is considered excellent.

Comparison of stream base-flow to simulated ground-water discharge measured in July 1986 is shown in table 10. A measure of the match between measured and simulated discharge to streams can be obtained by comparing the ratio of the residual to the total ground-water discharge measured in the modeled area. Total stream discharge from the modeled area on July 21-22, 1986, was about 139 ft^3/s (table 10). The mean of the absolute value of the discharge residuals for the calibrated model is about 1.6 percent (2.2 $ft^3/s \div 139$ ft^3/s) of the total stream discharge. A value less than about 5 percent is considered to indicate excellent overall agreement between measured and simulated discharges, and a value less than about 10 percent is considered acceptable. The value of 1.6 percent indicates that the overall match between measured and simulated discharge is excellent.

The steady-state ground-water budget (table 11) indicates that, under long-term average conditions, ground water flows into and out of the modeled area at a rate of 331 ft^3/s. About 95 percent of the inflow is recharge from precipitation. About 51 percent of the outflow is discharge to streams and ponds; 44 percent is discharge to the ocean and to constant-head boundaries in the modeled areas of the Taunton River and Jones River basins, 3.3 percent is public-supply and industrial pumping, and 1.7 percent is loss from cranberry-bog operations.

Transient Model Calibration and Validation

Transient calibration of the ground-water-flow model was achieved by matching measured to simulated water-level changes in observation well PWW-22 during the drought from 1964-66 (fig. 11). Validation that the model correctly simulates aquifer response was achieved by comparing measured and simulated water-level changes from April 1984 through October 1985. No data were available regarding the regional effects of large-scale pumping for transient calibration or valification. Individual wells were pumped from 1980 through 1985 at rates small enough that, in general, drawdown only exceeded 10 ft in the immediate vicinity of the wells.

Table 10.--*Measured and simulated ground-water discharge to streams in the Plymouth-Carver aquifer, July 21-22, 1986*

[---, no data available; ft^3, cubic foot per second]

Stream-measurement site (plate 1)	Date of measurement (month-day-year)	Discharge[1] (ft3/s)		
		Measured	Simulated	Residual
Town Brook at Plymouth upstream of site 2 (01105874)	07-21-86	14.6	---	---
	07-22-86	15.3	9.0	6.3
Eel River near Plymouth upstream of site 4 (01105876)	07-21-86	23.2	22.7	.5
Eel River at Sandwich Road near Plymouth upstream of site 4a	07-22-86	14.9	13.4	1.5
Eel River tributary near Plymouth upstream of site 4b	07-22-86	7.87	3.4	4.47
Beaver Brook at White Horse Beach upstream of site 5 (01105878)	07-21-86	12.7	---	---
	07-22-86	11.8	14.7	[1]-2.9
Indian Brook at Manomet Beach upstream of site 6	07-21-86	1.18	[1]-.72	1.9
Herring River between outlet from Great Herring Pond and Cape Cod Canal between site 8a and 8	07-21-86	[1]-.93	[1]-.91	[1]-.02
Red Brook near Buzzards Bay upstream of site 13	07-21-86	6.13	5.9	.23
Agawam River at East Wareham upstream of site 16	07-21-86	33.5	30.7	2.8
Wankinco River at East Wareham upstream of site 21	07-21-86	18.6	18.7	[1]-.1
Weweantic River at South Wareham upstream of site 22	07-21-86	81.2	---	---
	07-22-86	11.9	---	---
	(Average)	46.5	51.0	[1]-4.5
Agawan River between site 16 and the confluence of the Agawam and Wankinco Rivers	07-21-86	2.1	5.4	[1]-3.3
Agawam River just upstream of the confluence with Wankinco River, Wareham	07-21-86	35.6	36.1	[1]-.5
Absolute value of the mean of the water-level residuals, in ft				0.5
Mean of the absolute values of the water-level residuals, in ft				2.2
Standard deviation of the water-level residuals, in ft				3.0

[1]Negative discharge means that water moves from the stream into the underlying aquifer.

Table 11.--*Simulated steady-state ground-water budget of the Plymouth-Carver aquifer*

[ft^3/s, cubic foot per second]

Inflow	Rate (ft^3/s)	Outflow	Rate (ft^3/s)
Effective recharge[1]	315.6	Ground-water discharge to the ocean and to constant-head boundaries on west and northwest edge of modeled area	145
Leakage from streams and ponds into the aquifer	7.7	Ground-water discharge to streams	169.1
Flow into the aquifer from constant-head boundaries	7.7	Pumpage	11.2
		Loss from cranberry bogs	5.8
Total inflow	331.0	Total outflow	331.1

[1] Effective recharge = Precipitation - Evapotranspiration.

Determination of Specific Yield

Estimates of storage coefficient and specific yield of the Plymouth-Carver aquifer were needed for transient calibration of the model. The value for the storage coefficient was assigned on the basis of model results for another aquifer in Massachusetts (de Lima and Olimpio, 1989). As discussed previously, values of specific yield calculated from aquifer tests ranged from 0.02 to 0.35. From within this range of values, a single value for the specific yield was assigned in the model on the basis of hydrograph analysis, as explained later in this section.

Sensitivity testing of a model of a small aquifer near Woburn, Mass., about 50 miles north of the study area, resulted in virtually no difference in the response of the aquifer to pumping for storage coefficients ranging from 10^{-2} to 10^{-4} (de Lima, U.S. Geological Survey, oral commun., 1988). Consequently, a value of $5x10^{-3}$ was chosen for the storage coefficient for model layers 2, 3, and 4 for simulation of those layers under fully saturated conditions.

The specific yield of the aquifer was estimated from measured water-level altitudes in observation well PWW-22 (fig. 19) and the average annual rate of recharge (27 in.) used for the calibrated steady-state model. The hydrograph of observation well PWW-22 shows that, except for a short period in early 1965, water levels declined continuously from 1964 through 1966. During the 8 months from May through December 1964, the water level in PWW-22 declined about 4.2 ft. This 8-month decline extrapolates to an annual decline of about 6.3 ft (76 in.). Specific yield can be calculated by dividing the average annual recharge to the aquifer (27 in/yr from the calibrated steady-state model) by the total water-level decline during a year of no recharge. Therefore, the calculated specific yield of the Plymouth-Carver aquifer near observation well PWW-22 is 0.35. Additional calculations of aquifer specific yield near well PWW-22 were made using hydrograph recessions measured during two other periods of no recharge--from June through November 1983, and from June through December 1984 (fig. 20). During the 6 months from June through November 1983, the water level in well PWW-22 declined 4.5 ft. This 6-month decline, extrapolated for an additional 6 months of decline would result in an annual decline of about 9.0 ft or 108 in. Therefore, the specific yield of the aquifer near observation well PWW-22 was calculated as 0.25. During the 7 months from June through December 1984, the water level in PWW-22 declined 4.6 ft. This 7-month decline, extrapolated for an additional 5 months of decline would result in an annual decline of about 7.9 ft or 94.8 in. Therefore, the specific yield of the aquifer near observation well PWW-22 was calculated as 0.28. Results of these calculations of specific yield of the Plymouth-Carver aquifer near observation well PWW-22 are summarized in table 12.

The average of the three specific-yield values for sediments near well PWW-22 is 0.29. The method of calculating the specific yield assumes that no recharge occurred during the periods of hydrograph recession. Probably some recharge did occur during each of the

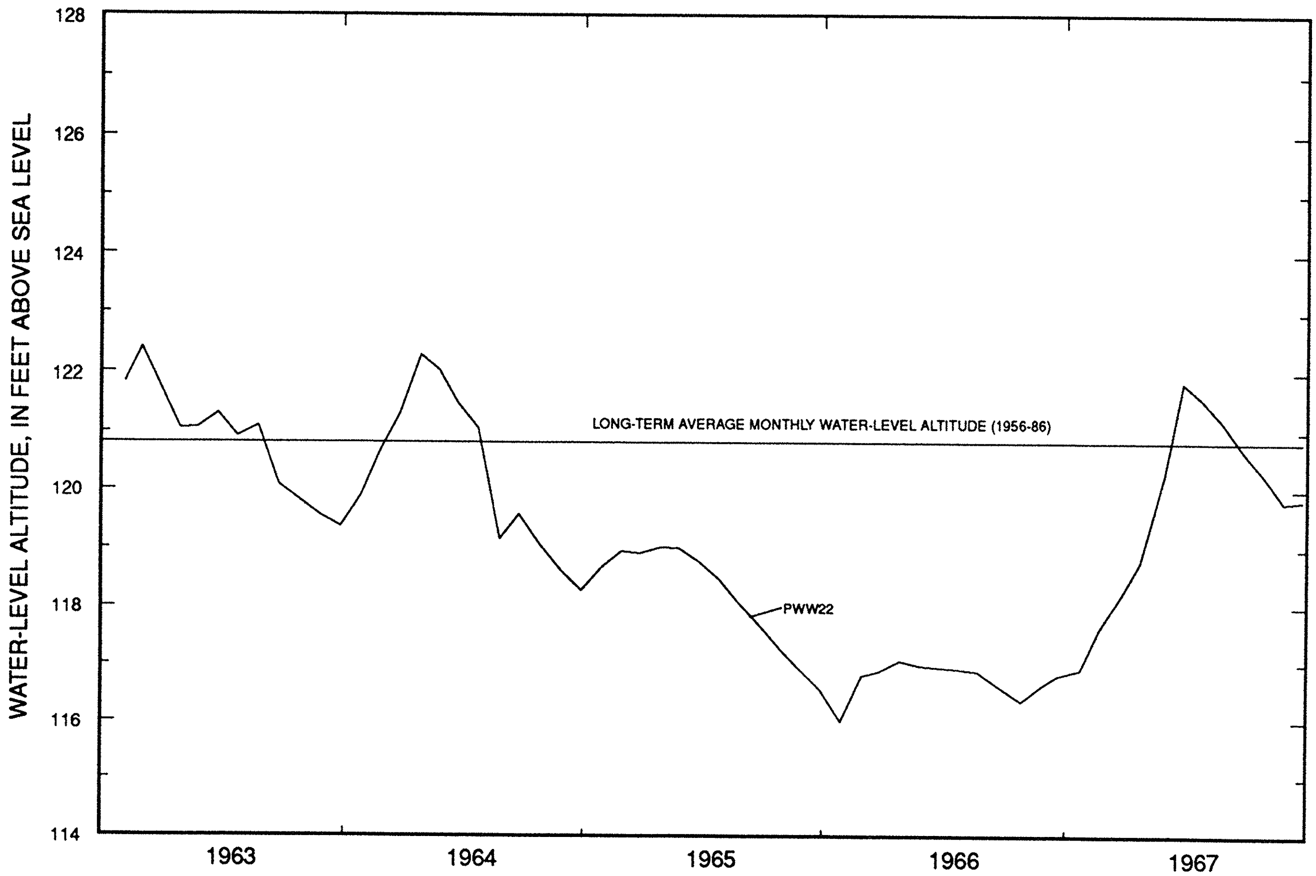

Figure 19.--Water-level altitude in observation well PWW-22, 1963-67.

three periods shown. Therefore, the actual value of specific yield of the aquifer near well PWW-22 probably is slightly less than 0.29; a value of 0.28 was chosen for specific yield of the aquifer for transient calibration of the model.

Calibration and Validation

The model was first calibrated to transient conditions on the basis of the water-level decline measured in one well during 1964-66. After the model was calibrated to transient conditions, the model's ability to simulate transient conditions was further tested by simulating hydrologic conditions that occurred during the early 1980s by comparing simulated declines to measured declines in water levels in 11 observation wells distributed throughout the modeled area.

The model was calibrated for transient conditions by testing how accurately it predicted water-level declines at well PWW-22 during the 1964-66 drought (fig. 21). The "assumed hydrograph recession" in figure 21 shows the expected water-level decline if recharge during January 1965 had not occurred. The water-level decline in well PWW-22 from August 1964, when water levels were at their average steady-state level, through the 2-year no-recharge period was simulated in the model. Though the simulated water levels are several feet lower than the measured water levels, the simulated recession closely parallels both the measured decline from August 1964 to January 1965, and the assumed recession that would have occurred after January 1965. The match between measured and simulated water-level declines in well PWW-22 indicates that, at least in the vicinity of observation well PWW-22, the calibrated model closely simulates transient water-level response in the aquifer.

The model's ability to simulate transient conditions was further tested after transient calibration by comparing measured and simulated water levels in 11 observation wells located throughout the basin from December 1983 to January 1985. As indicated on the hydrograph of well PWW-22 (fig. 20), recharge caused

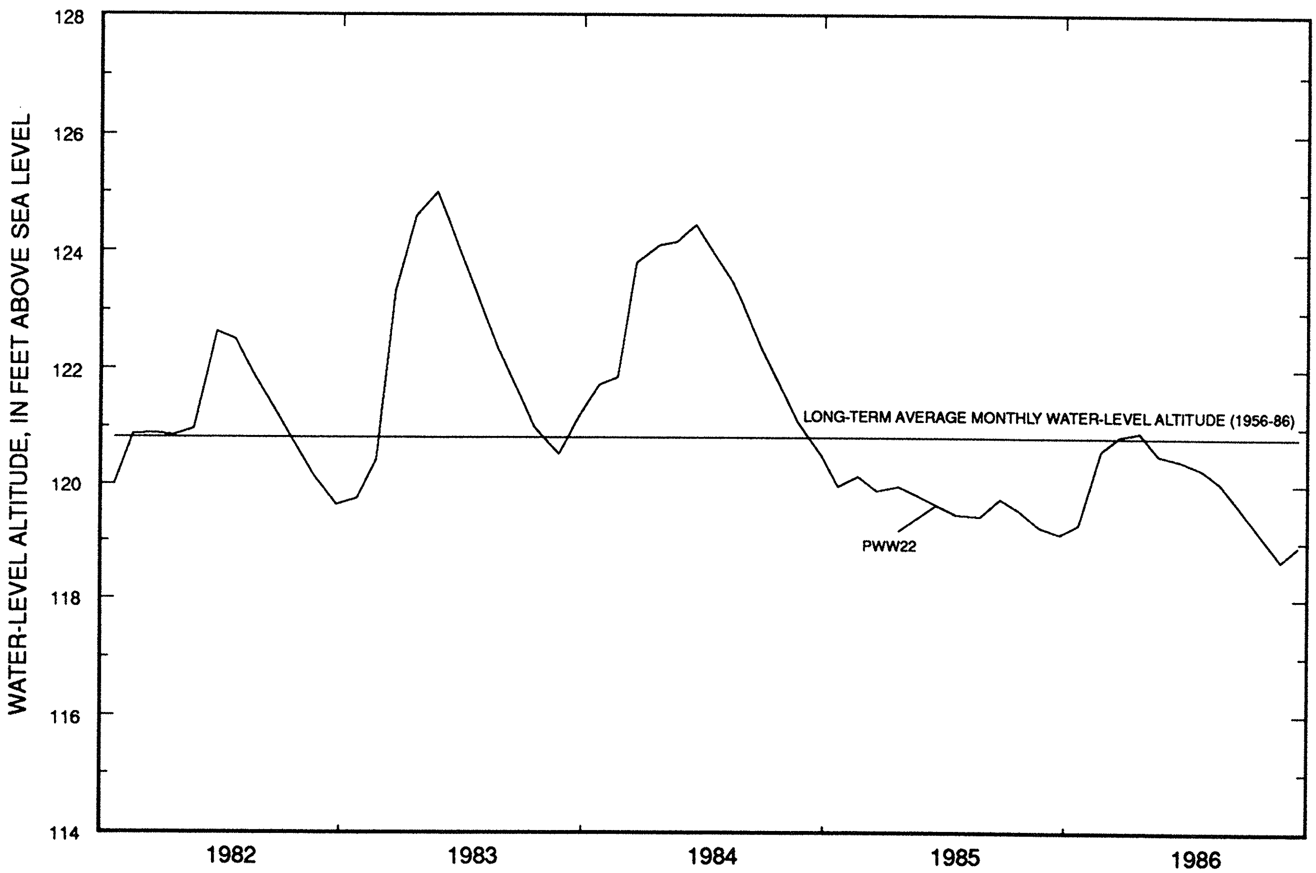

Figure 20.--Water-level altitude in observation well PWW-22, 1982-87.

Table 12.--*Calculated values of specific yield of Plymouth-Carver aquifer near observation well PWW-22*

Period of hydrograph recession	Water-level decline (ft)	Extrapolated decline during 1 year		Specific yield
		Feet	Inches	
May - December 1964	4.2	6.3	76	0.35
June - November 1983	4.5	9.0	108	.25
June - December 1984	4.6	7.9	94.8	.28

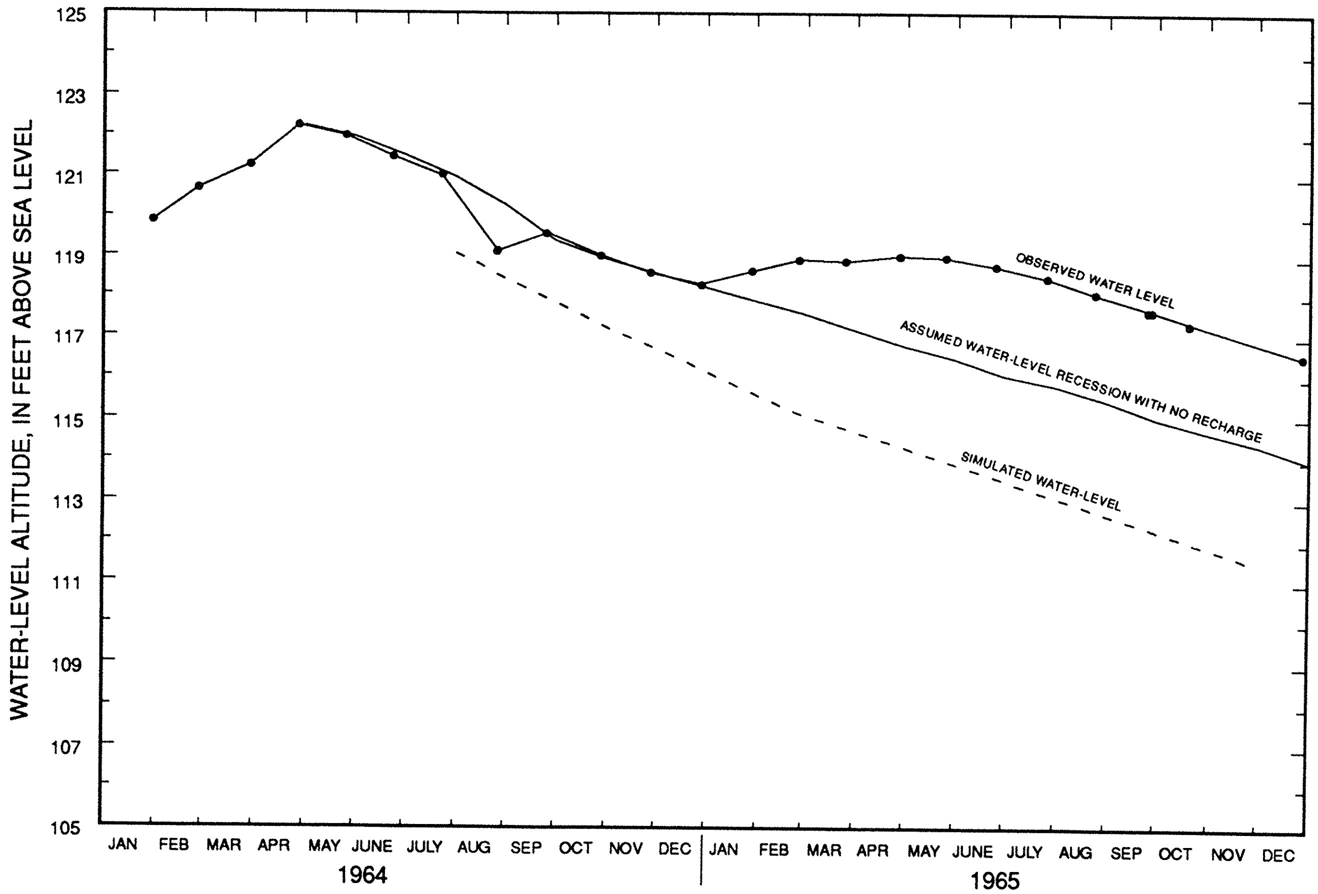

Figure 21.--Measured and simulated water levels in observation well PWW-22 during 1964-66 drought.

water levels in PWW-22 to rise from December 1983 through June 1984. During early July 1984, water levels in well PWW-22 were near the maximum attained during the 30 years of record (fig. 11). From July 1984 through January 1985, virtually no recharge occurred, and water levels in the well declined steadily. Other observation wells show a similar pattern of water-level fluctuation.

The water level in well PWW-22 in December 1983 was close to the long-term average water level in that well. As indicated on the hydrograph (fig. 20), the water level in PWW-22 rose about 3.6 ft from December 1983 through July 1984. Using this rise of 3.6 ft and the specific yield of 0.28 determined previously, the calculated recharge rate above the long-term average rate of 27 in/yr simulated in the calibrated model during those 7 months was 12.8 in. or 21.9 in/yr. Therefore, raising the water level 3.6 ft above the long-term average level requires simulation of the 27 in/yr of average recharge necessary to sustain long-term average conditions plus simulation of an additional 22 in/yr for those 7 months (for a total of 49 in/yr of recharge for 7 months). Following the 7-month recharge period, a 1-year period of no recharge was simulated. Measured and simulated water levels in 11 observation wells located throughout the basin are shown in figure 22. The generally good agreement between measured and simulated water levels indicates that the model closely simulates response to natural variation in recharge throughout the aquifer.

It is preferable to calibrate a model that is designed to simulate the effects of large-scale development of an aquifer with data collected during pumping of large-capacity wells or from large-scale pumping tests, because the stress on the aquifer during the pumping is similar to that which will be simulated. Because there is no large-scale pumping of the Plymouth-Carver aquifer, no data of this type are available to aid in calibration. Therefore, it is uncertain how well the model will simulate the effects of large-scale development of the aquifer.

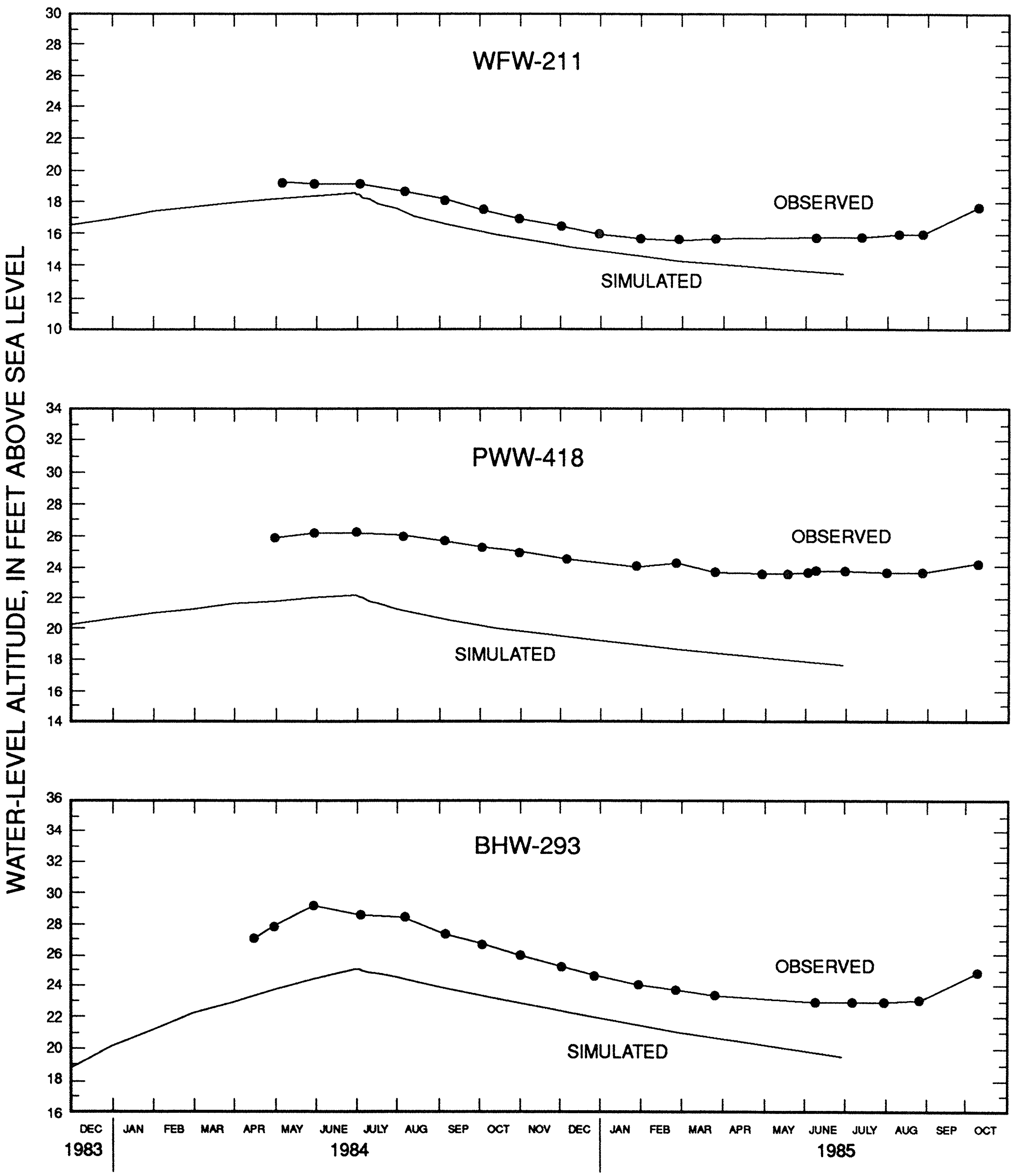

Figure 22.--Measured and simulated water-level altitudes in 11 observation wells screened in Plymouth-Carver aquifer, December 1983 through January 1986.

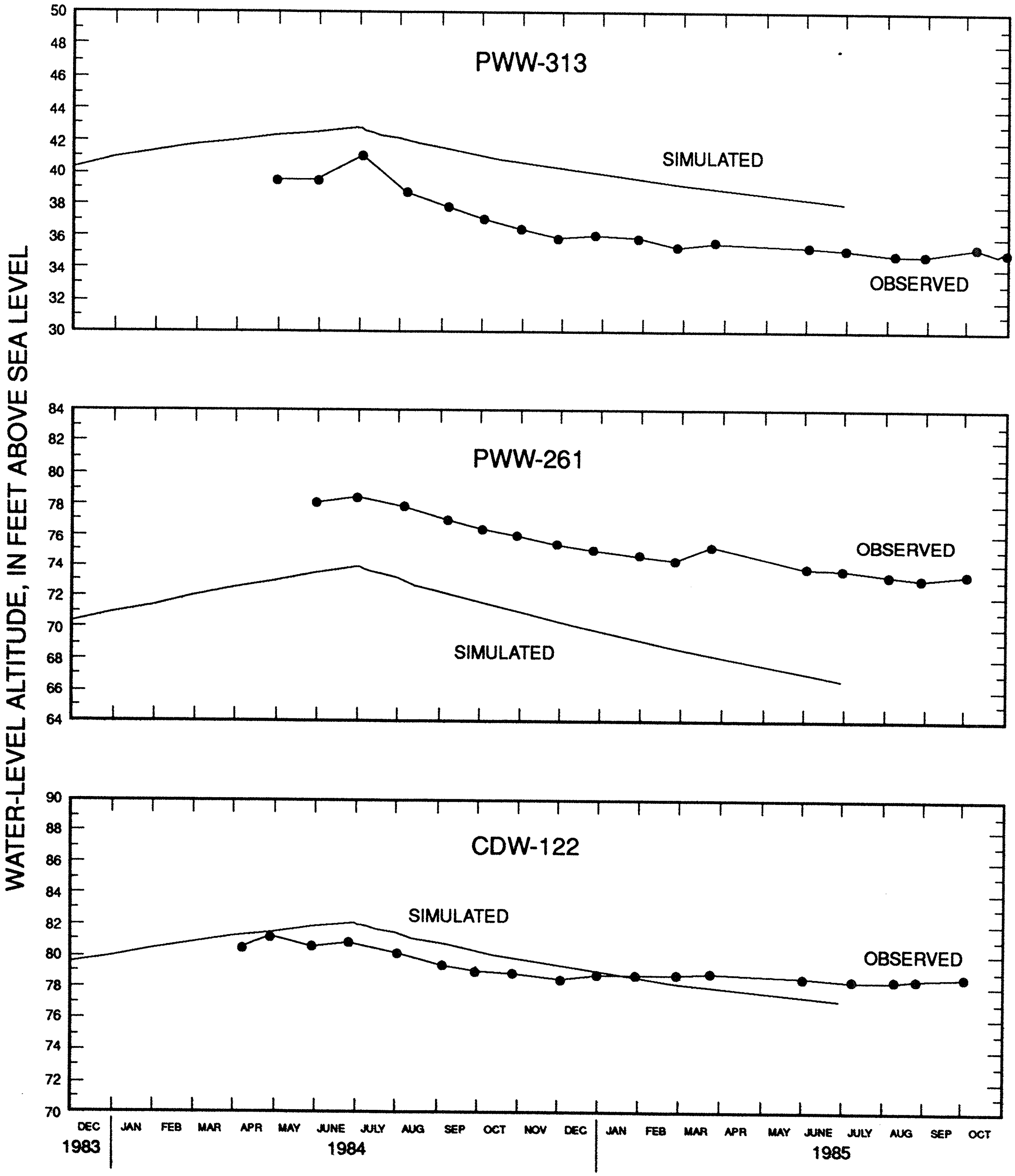

Figure 22.--Measured and simulated water-level altitudes in 11 observation wells screened in Plymouth-Carver aquifer, December 1983 through January 1986--Continued.

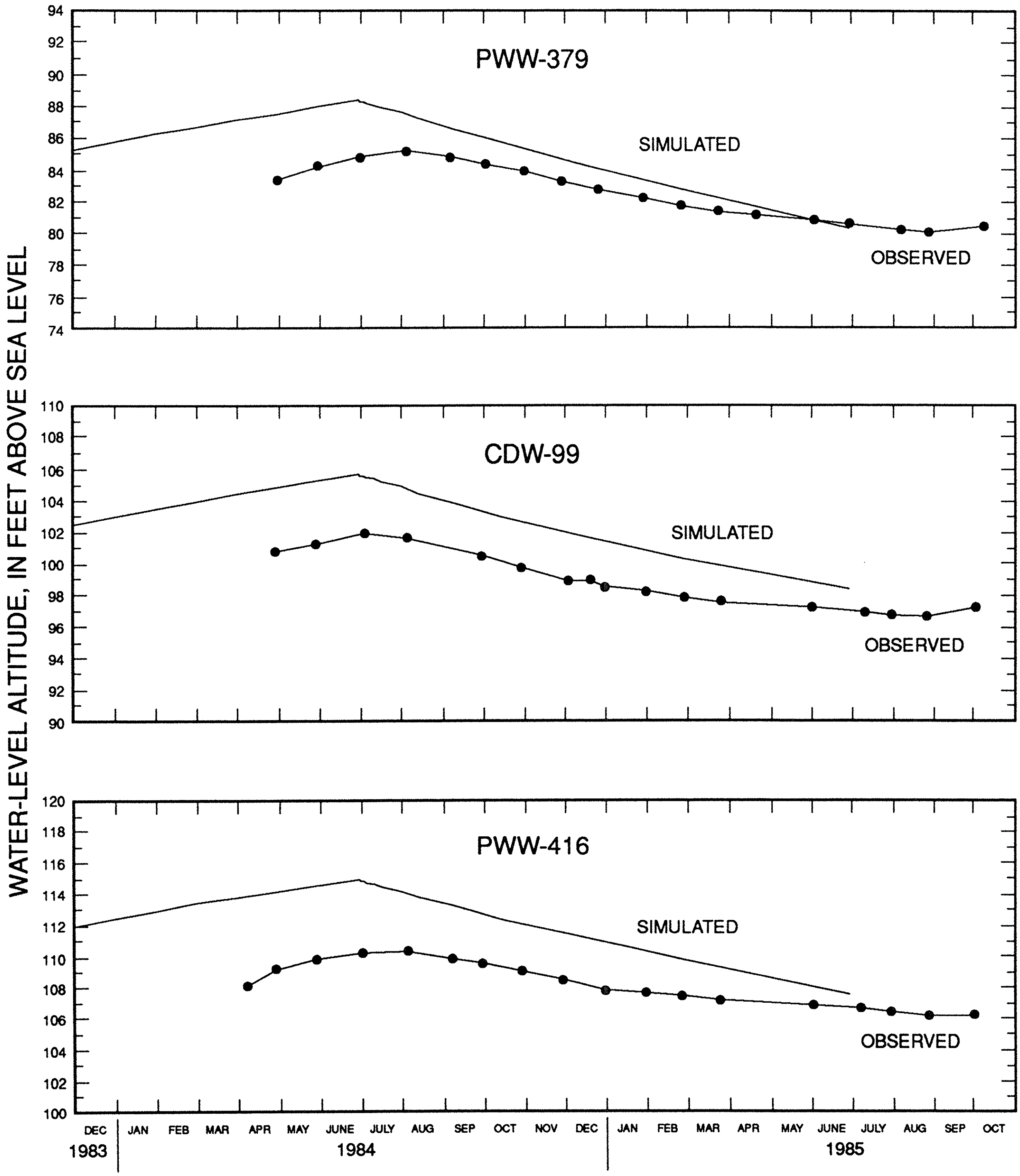

Figure 22.--Measured and simulated water-level altitudes in 11 observation wells screened in Plymouth-Carver aquifer, December 1983 through January 1986--Continued.

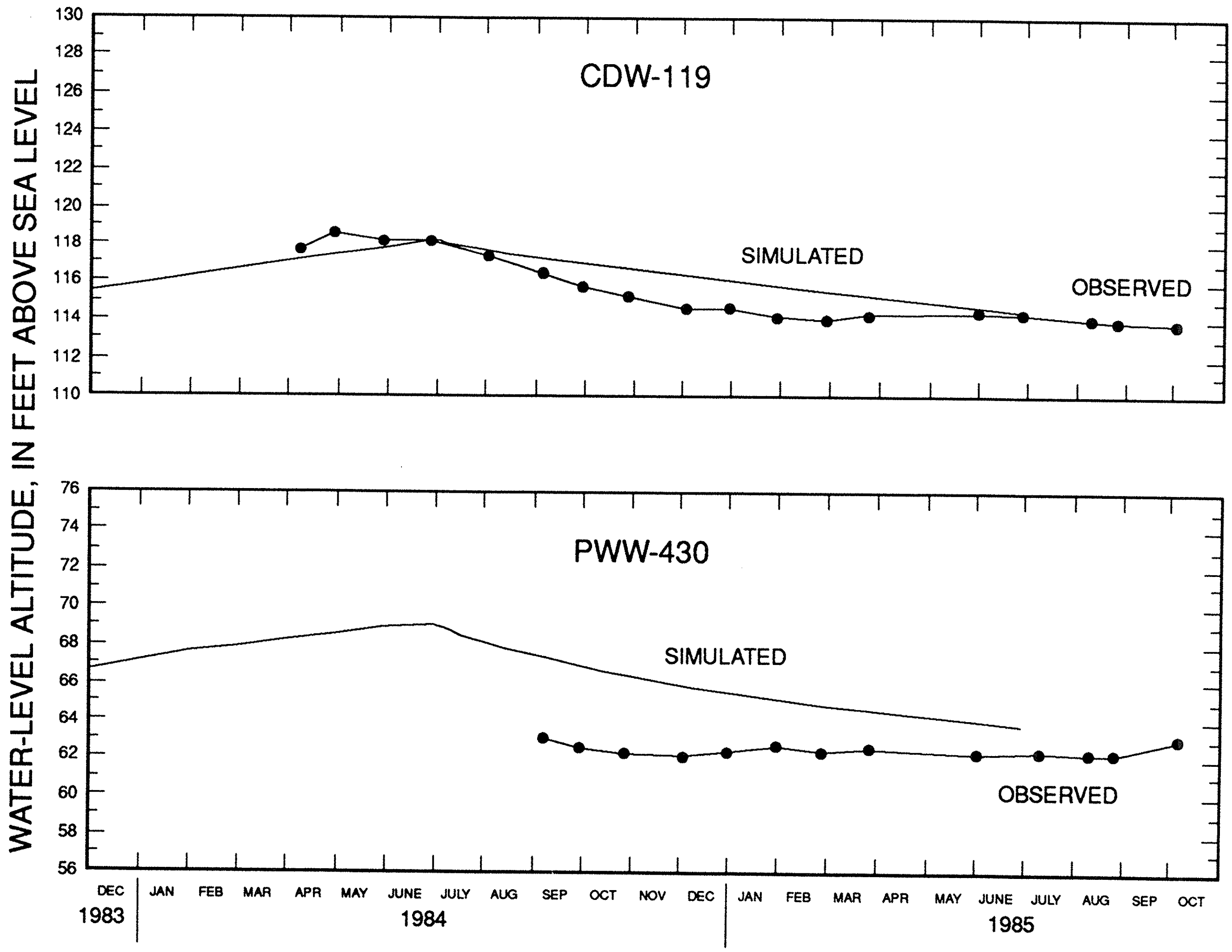

Figure 22.--Measured and simulated water-level altitudes in 11 observation wells screened in Plymouth-Carver aquifer, December 1983 through January 1986--Continued.

Table 13.--*Summary of water-level residuals for simulated recharge rates of 18, 24, 27, and 30 inches per year*

[ft, feet; in/yr, inches per year; total number of observations = 101]

	Water-level residuals (ft) for recharge rate (in/yr)			
	18	24	27	30
Absolute value of the mean of the water-level residuals[1], in feet	4.64	1.52	0.15	1.76
Mean of the absolute values of the water-level residuals, in feet	5.44	3.56	3.46	3.82
Standard deviation of the water-level residuals, in feet	5.03	4.52	4.42	4.54

[1]Water-level residual = Measured water level minus simulated water level.

Model Sensitivity to Variations in Input Parameters

A sensitivity analysis of the Plymouth-Carver ground-water-flow model was made determine the response of the model to changes in input parameters such as recharge rate, hydraulic conductivity and specific yield of the unconsolidated deposits, and streambed conductance. This analysis evaluated the degree to which errors in estimation of those factors affect the accuracy of the model. For example, assume that only small differences occur in simulated hydraulic heads and ground-water discharge between simulations in which the rate of recharge was 20 percent larger or smaller than that used for steady-state calibration, but that large differences occur in simulated hydraulic heads and ground-water discharge between simulations in which the recharge rate was 50 percent larger or smaller than that used for steady-state calibration. If the recharge rate used in the calibrated model is considered accurate within ± 10 percent, then the model would be insensitive to the recharge rate within this 20-percent range, and there would be no advantage to refining the recharge rate further for input to the model. However, if the recharge rate is considered accurate only within a range of ± 70 percent, the model would be sensitive to the recharge rate, and further data collection to improve definition of the recharge rate would be warranted.

Sensitivity analysis of the ground-water-flow model entailed uniformly increasing and decreasing values of input parameters and noting the response of water levels and rates of ground-water discharge to streams to the input variation. As was used during calibration, three statistical measures were used to evaluate the sensitivity of the model to changes in model inputs: (1) The absolute value of the mean of the residuals between measured and simulated water levels and ground-water discharge, (2) the mean of the absolute value of the residuals between measured and simulated water levels and ground-water discharge, and (3) the standard deviation of the residuals between measured and simulated water levels and ground-water discharge.

Average Annual Recharge

Sensitivity of the model to the average annual rate of recharge to the outwash-plain, morainal, and kame deposits was tested by simulating recharge rates of 18, 24, 27, and 30 in/yr. The rate of 27 in/yr was used for the calibrated steady-state model. The range of simulated recharge rates approximates the range of recharge rates estimated for glacial deposits in southeastern Massachusetts (Knott and Olimpio, 1986).

Results of the four simulations are summarized in tables 13, 14, and 15. Detailed information pertaining to the results summarized in tables 13 and 14 are provided in tables 23 and 24 at the end of the report. A comparison of water-level residuals for the four simulated rates of recharge is shown in table 13. Measured water levels in observation wells and ponds in the Plymouth-Carver aquifer and simulated water levels for these four recharge rates, and a comparison of the water-level residuals are shown in table 23. The

Table 14.--*Summary of ground-water-discharge residuals for simulated recharge rates of 18, 24, 27, and 30 inches per year*

[ft^3/s, cubic foot per second; in/yr, inches per year]

	Discharge residual (ft^3/s) for recharge rate (in/yr)			
	18	24	27	30
Absolute value of the mean of the discharge residuals[1], in cubic feet per second	7.3	2.8	0.5	2.0
Mean of the absolute values of the discharge residuals, in cubic feet per second	7.6	3.3	2.2	3.4
Standard deviation of the discharge residuals, in cubic feet per second	5.6	3.0	3.0	4.1

[1]Discharge residual = measured ground-water-discharge minus simulated ground-water-discharge.

absolute value of the mean of the water-level residuals (table 13), for example, for the four recharge rates are 4.64 ft for the rate of 18 in/yr, 1.52 ft for the rate of 24 in/yr, 0.15 ft for the rate of 27 in/yr, and 1.76 ft for the rate of 30 in/yr. All three statistical measures indicate that the recharge rate of 27 in/yr resulted in the best agreement between measured and simulated water levels; the most conclusive evidence is provided by the absolute value of the mean of the water level residuals.

As with the calibrated model, the ratio of the water-level residuals to the total relief in the water table (125 ft) was used to compare the significance of the differences in residuals. For example, the mean of the absolute values of the water-level residuals for the calibrated model was about 2.8 percent (3.46 ft/125 ft (table 13)) of the total relief of the water table, whereas the mean of the absolute value of the water-level residuals for the simulations with recharge rates of 18, 24, and 30 in/yr are 4.4, 2.8, and 3.1 percent of the total relief in the water table, respectively. A mean of the absolute values of the water-level residuals for the calibrated model that was less than about 5 percent of the total relief of the water table was considered to indicate excellent overall agreement between measured and simulated water levels, and a value less than about 10 percent was considered acceptable. Means of the absolute values of the water-level residuals were less than 5 percent of the total relief of the water table for all four recharge rates, indicating excellent overall agreement. Therefore, simulated water levels were insensitive to recharge rates from 18 through 30 in/yr.

Table 14 shows the ground-water-discharge residuals for the four simulated rates of recharge. Table 24 shows measured and simulated ground-water discharge to streams resulting from the four recharge rates summarized in table 14. The significance of the differences in the discharge residuals is determined by comparing the ratio of the residual to the total rate of ground-water-discharge to streams measured in the modeled area. As previously indicated total stream discharge from the modeled area on July 21-22, 1986, was about 139 ft^3/s (table 10). Consequently, the mean of the absolute value of the discharge residuals for the calibrated model was about 1.6 percent [2.2 ft^3/s ÷ 139 ft^3/s (table 10)] of the total ground-water discharge to streams in the modeled area, whereas the mean of the absolute value of the discharge residuals for the simulations with recharge rates of 18, 24, and 30 in/yr were 5.5, 2.4, and 2.4 percent of the total ground-water discharge, respectively. A value less than about 5 percent was considered to indicate excellent overall agreement between measured and simulated discharges, and a value less than about 10 percent was considered acceptable. Values for recharge rates of 24, 27, and 30 in/yr were less than 5 percent, and the value for a recharge rate of 18 in/yr was less than 10 percent, indicating excellent overall agreement for recharge rates of 24, 27, and 30 in/yr, and good agreement for a recharge rate of 18 in/yr. Therefore, the ground-water-discharge residuals indicated that ground-water discharge to streams in the model was insensitive to rates of recharge of 18 to 30 in/yr.

Comparison of the simulated ground-water budgets of the Plymouth-Carver aquifer for the four simulated recharge rates (table 15) indicates that the percentage of recharge that discharges to streams increased only from about 46 percent [((107.8 ft^3/s) ÷ (235.3 ft^3/s)) x 100] for a recharge rate of 18 in/yr to about 53 percent for a recharge rate of 30 in/yr [((192.0 ft^3/s)) ÷ (364.8 ft^3/s) x 100].

Horizontal Hydraulic Conductivity of Unconsolidated Deposits

Sensitivity of the model to the horizontal hydraulic conductivity of the outwash-plain, morainal, and kame deposits was tested by simulating the range of hydraulic-conductivity values that might prevail in the outwash plains and moraines of southeastern Massachusetts. The values tested were multiples of the values of hydraulic conductivity used for each model cell in the calibrated steady-state model. The multiples were 0.2, 0.5, 1.0, 2.0, and 5.0.

Results of the five simulations are summarized in tables 16, 17, and 18. Detailed information pertaining to the results summarized in tables 16 and 17 are provided in tables 25 and 26 at the end of the report. Table 16 shows the water-level residuals for the five simulated hydraulic-conductivity values. Simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for the multiples of hydraulic conductivity, and comparison of the water-level residuals are given in table 25. Comparison of the three statistical measures for simulations indicates that the hydraulic-conductivity values used in the calibrated steady-state simulation (multiple of 1.0) resulted in the best match of residuals. An increase or a decrease in hydraulic conductivity increased the water-level residuals. For example, the standard deviation of the water-level residuals increased from

Table 15--*Simulated ground-water budgets of the Plymouth-Carver aquifer for average annual recharge rates of 18, 24, 27, and 30 inches per year*

[ft^3/s, cubic foot per second; in/yr, inches per year]

Inflow	Inflow (ft^3/s) for simulated recharge rate of (in/yr) 18	24	27	30	Outflow	Outflow (ft^3/s) for simulated recharge rate of (inches per year) 18	24	27	30
Recharge from precipitation	208.5	279.9	315.6	351.3	Ground-water discharge to the ocean and to constant-head boundaries on western and northwestern edges of modeled area	113.2	134.2	145.0	155.8
Leakage from streams and ponds into the aquifer	16.0	9.4	7.7	6.4	Ground-water discharge to streams	107.8	146.7	169.1	192.0
Flow into the aquifer from constant-head boundaries	10.8	8.5	7.7	7.0	Pumpage	[1]8.5	11.2	11.2	11.2
					Loss from cranberry bogs	5.8	5.8	5.8	5.8
Total inflow	235.3	297.8	331.0	364.7	Total outflow	235.3	297.9	331.1	364.8

[1]Some pumping wells go dry during simulation; once those wells go dry, no pumping from them is simulated.

Table 16.--*Summary of water-level residuals for multiples of the horizontal hydraulic conductivity of the unconsolidated deposits used in the calibrated, steady-state model.*

[ft, feet]

	Water-level residuals (ft) for indicated multiple of hydraulic conductivity				
	0.2	0.5	1.0	2.0	5.0
Absolute value of the mean of the water-level residuals[1], in feet	31.67	10.26	0.15	7.08	14.75
Mean of the absolute values of the water-level residuals, in feet	33.08	10.84	3.46	7.80	15.12
Standard deviation of the water-level residuals, in feet	22.53	8.01	4.42	6.39	10.32

[1]Water-level residual = Measured water level - simulated water level.

4.42 for a hydraulic-conductivity multiple of 1.0 to 6.39 ft and 10.32 ft for multiples of 2.0 and 5.0 respectively, and the standard deviation increased from 4.42 to 8.01 and 22.53 for hydraulic-conductivity multiples of 0.5 and 0.2, respectively.

The comparative significance of these differences in water-level residuals can be assessed using the ratio of the residual to the total relief in the water table. The mean of the absolute value of the water-level residuals for the calibrated model (hydraulic-conductivity multiple of 1.0) was about 2.8 percent (3.46 ft/125 ft) of the total relief of the water table, whereas the means of the absolute value of the water-level residuals for multiples of 0.2, 0.5, 2.0, and 5.0 were 26.5, 8.7, 6.2, and 12.1 percent, respectively, of the total relief in the water table. The results for hydraulic-conductivity multiples of 0.2 and 5.0 exceeded the 10-percent criterion considered to indicate a good overall agreement between measured and simulated water levels. Therefore, for these two multiples, the agreement is considered poor. The results for multiples of 0.5 and 2.0 were 5 to 10 percent--a range considered to indicate a good overall agreement. Simulated water levels were considerably more sensitive to variation in hydraulic conductivity of the outwash-plain and morainal deposits than to variation in recharge within the probable ranges of values of hydraulic conductivity and recharge that would occur in the study area. Therefore, in future studies in the area, additional investigation of the variation in hydraulic conductivity of the outwash-plain and morainal deposits is warranted.

Table 17 shows the ground-water-discharge residuals for the five simulated hydraulic conductivity values.

Table 17.--*Summary of ground-water-discharge residuals for multiples of the horizontal hydraulic conductivity of unconsolidated deposits used in the calibrated, steady-state model.*

[ft^3/s, cubic foot per second]

	Discharge residuals, (ft^3/s) for indicated multiple of hydraulic conductivity				
	0.2	0.5	1.0	2.0	5.0
Absolute value of the mean of the discharge residuals[1], in cubic feet per second	3.8	1.7	0.5	3.7	10.8
Mean of the absolute values of the discharge residuals, in cubic feet per second	3.8	2.5	2.2	4.5	12.4
Standard deviation of the discharge residuals, in cubic feet per second	3.5	3.0	3.0	4.4	10.2

[1]Discharge residual = measured ground-water discharge - simulated ground-water discharge.

Table 25 compares the measured and simulated ground-water discharge to streams resulting from the five multiples of hydraulic conductivity summarized in table 17. The same comparative significance of the differences in the discharge residuals was made by comparing the ratio of the residual to the total rate of ground-water discharge to streams measured in the modeled area. The mean of the absolute value of the discharge residuals for the calibrated model (multiple of 1.0) was about 1.6 percent (2.2 $ft^3/s \div$ 139 ft^3/s) (table 17) of the total ground-water-discharge to streams in the modeled area, whereas the mean of the absolute value of the discharge residuals for the simulations using hydraulic-conductivity multiples of 0.2, 0.5, 2.0, and 5.0 were 2.7, 1.8, 3.2, and 8.9 percent of the total ground-water discharge, respectively. Given the criteria used to assess the agreement between measured and simulated ground-water discharge, hydraulic conductivity multiples of 0.2, 0.5, and 2.0 resulted in excellent agreement, and a multiple of 5.0 resulted in good agreement. Therefore, ground-water discharge to streams in the model is insensitive to hydraulic conductivity values ranging from 0.2 to 5.0 times those used in the calibrated steady-state model. The reason why discharge values are not affected significantly throughout the range of hydraulic conductivity values tested probably is because those values are fairly high and, therefore, do not significantly restrict discharge.

Comparison of the ground-water budgets of the aquifer for the five hydraulic-conductivity simulations (table 18) indicates that the total simulated outflow from the modeled area for a multiple of 0.2 was only about 4 percent smaller than that of the calibrated model, and the simulated outflow for a multiple of 2.0 was about 12 percent larger. Total outflow for the hydraulic-conductivity multiple of 5.0 was about 51 percent larger than the outflow from the calibrated model.

Streambed Conductance

Sensitivity of the model to the streambed conductance was tested by simulating the range of anticipated values of streambed conductance that probably occurs in the study area. Simulations were done with streambed conductances that were multiples of 0.1, 0.2, 1.0, 5.0, and 10.0 of the values used in the calibrated steady-state model.

Results of the five simulations are summarized in tables 19, 20, and 21. Detailed information pertaining to the results summarized in tables 19 and 20 are provided in tables 27 and 28 at the end of the report. Table 19 shows the water-level residuals for the five multiples of streambed conductance. Table 27 shows simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for these multiples of streambed conductance, and a comparison of the water-level residuals. Statistical analysis indicated that there was little difference between residuals for multiples from 1.0 through 10. However, for streambed-conductance multiples less than 1.0, the water-level residuals increased as the multiple decreased. The insensitivity of the model to streambed-conductance multiples from 1.0 through 10 occurred because the streambed conductivity is sufficiently high that it does not impede ground-water discharge.

The mean of the absolute value of the water-level residuals for the calibrated model (multiple of 1.0) was about 2.8 percent (3.46 ft/125 ft (table 19) of the total relief of the water table. The means of the absolute values of the water-level residuals for simulations with streambed-conductance multiples of 0.1, 0.2, 5.0, and 10.0, were 7.4, 4.9, 2.7, and 2.7 percent, respectively, of the total relief in the water table. The sensitivity of simulated water levels increased as the streambed conductance decreased. However, the agreement between measured and simulated water levels was excellent for streambed-conductance multiples from 0.2 through 10.

Table 20 shows the ground-water-discharge residuals for the five simulated multiples of streambed conductance. Table 28 compares the measured and simulated ground-water discharge to streams resulting from the five multiples of streambed conductance. The same comparative significance of the differences in the discharge residuals was made by comparing the ratio of the residual to the total rate of ground-water discharge to streams measured in the modeled area (table 20). The mean of the absolute value of the discharge residuals for the calibrated model (multiple of 1.0) was about 1.6 percent (2.2 $ft^3/s \div$ 139 ft^3/s) of the total ground-water discharge to streams in the modeled area, whereas the mean of the absolute value of the discharge residuals for the simulations with streambed-conductance multiples of 0.1, 0.2, 5.0, and 10.0 were 2.6, 2.2, 1.9, and 2.2 percent of the total ground-water discharge, respectively. Simulations with streambed-conductance multiples from 0.1 through 10 of the calibrated-model values resulted in excellent agreement. Ground-water budgets for the five streambed-conductance simulations (table 21) show that the total outflow from the modeled area

Table 18.--*Simulated ground-water budgets of the Plymouth-Carver aquifer for multiples of horizontal hydraulic conductivity values used in the calibrated, steady-state model*

[ft^3/s, cubic foot per second]

Inflow	Inflow (ft^3/s) for indicated multiple of hydraulic conductivity					Outflow	Outflow (ft^3/s) for indicated multiple of hydraulic conductivity				
	0.2	0.5	1.0	2.0	5.0		0.2	0.5	1.0	2.0	5.0
Recharge from precipitation	315.6	315.6	315.6	315.6	315.6	Ground-water discharge to the ocean and to constant-head boundaries on western and northwestern edges of modeled area	95.5	116.9	145.0	194.6	320.7
Leakage from streams and ponds into the aquifer	.7	2.1	7.7	30.8	111.1	Ground-water discharge to streams	206.9	186.1	169.1	158.5	165.4
Flow into the aquifer from constant-head boundaries	.3	2.1	7.7	23.7	73.6	Pumpage	8.5	11.2	11.2	11.2	8.5
						Loss from cranberry bogs	5.8	5.8	5.8	5.8	5.8
Total inflow	316.6	319.8	331.0	370.1	500.3	Total outflow	316.7	320.0	331.1	370.1	500.4

Table 19.--*Summary of water-level residuals for multiples of streambed conductance used in the calibrated, steady-state model.*

[ft, feet]

	Water-level residuals (ft) for indicated multiple of streambed conductance				
	0.1	0.2	1.0	5.0	10.0
Absolute value of the mean of the water-level residuals[1], in feet	8.47	4.60	0.15	0.91	0.96
Mean of the absolute values of the water-level residuals, in feet	9.31	6.15	3.46	3.34	3.33
Standard deviation of the water-level residuals, in feet	7.05	5.60	4.42	4.18	4.15

[1] Water-level residual = measured water level - simulated water level.

changed by less than 5 percent throughout the range of multiples of 0.1 to 10.

Aquifer Specific Yield

Sensitivity of the model to specific yield also was tested. For this analysis, four model simulations were compared. In all four simulations, water-level declines during the 2-year period of no recharge that occurred during the 1964-66 drought were simulated. Results were compared to measured water-level declines in observation well PWW-22. The specific-yield values for the four simulations were 0.10, 0.20, 0.28 (the calibrated-model value) and 0.40. These values represent the maximum range of specific yields that would likely be found in outwash plain and morainal deposits in the study area. Results of the four simulations are shown in figure 23.

As shown in figure 23, a specific yield of 0.28 resulted in the best match between the slopes of measured and simulated water-level declines. On the basis of the calculated recession, the water-level decline in well PWW-22 would have been about 5.0 ft from August 1964 to August 1965 if no recharge had occurred (fig. 23). Simulated declines during that same period for the four values of specific yield of 0.10, 0.20, 0.28, and 0.40 were about 11.2, 7.5, 5.9, and 4.5 ft, respectively. Therefore, the model is relatively insensitive to values of specific yield ranging from about 0.20

Table 20.--*Summary of ground-water-discharge residuals for multiples of the streambed conductance used in the calibrated, steady-state model.*

[ft^3/s, cubic foot per second]

	Discharge residuals (ft^3/s) for indicated multiple of streambed conductance				
	0.1	0.2	1.0	5.0	10.0
Absolute value of the mean of the discharge residuals[1], in cubic feet per second	2.8	1.8	0.5	0.2	0.3
Mean of the absolute values of the discharge residuals, in cubic feet per second	3.6	3.0	2.2	2.7	3.0
Standard deviation of the discharge residuals, in cubic feet per second	3.8	3.5	3.0	3.4	3.8

[1] Discharge residual = measured ground-water discharge - simulated ground-water discharge.

Table 21.--*Comparison of simulated ground-water budgets of the Plymouth-Carver aquifer for multiples of streambed conductance used in the calibrated, steady-state model*

[ft^3/s, cubic foot per second]

Inflow	Inflow (ft^3/s) for indicated multiple of conductance					Outflow	Outflow (ft^3/s) for indicated multiple of conductance				
	0.1	0.2	1.0	5.0	10.0		0.1	0.2	1.0	5.0	10.0
Recharge from precipitation	315.6	315.6	315.6	315.6	315.6	Ground-water discharge to the ocean and to constant-head boundaries on western and northwestern edges of modeled area	165.6	156.2	145.0	145.3	147.4
Leakage from streams and ponds into the aquifer	0.2	0.9	7.7	21.1	27.4	Ground-water discharge to streams	139.8	150.3	169.1	182.3	186.6
Flow into the aquifer from constant-head boundaries	6.5	7.0	7.7	7.9	7.9	Pumpage	11.2	11.2	11.2	11.2	11.2
						Loss from cranberry bogs	5.8	5.8	5.8	5.8	5.8
Total inflow	322.3	323.5	331.0	344.6	350.9	Total outflow	322.4	323.5	331.1	344.6	351.0

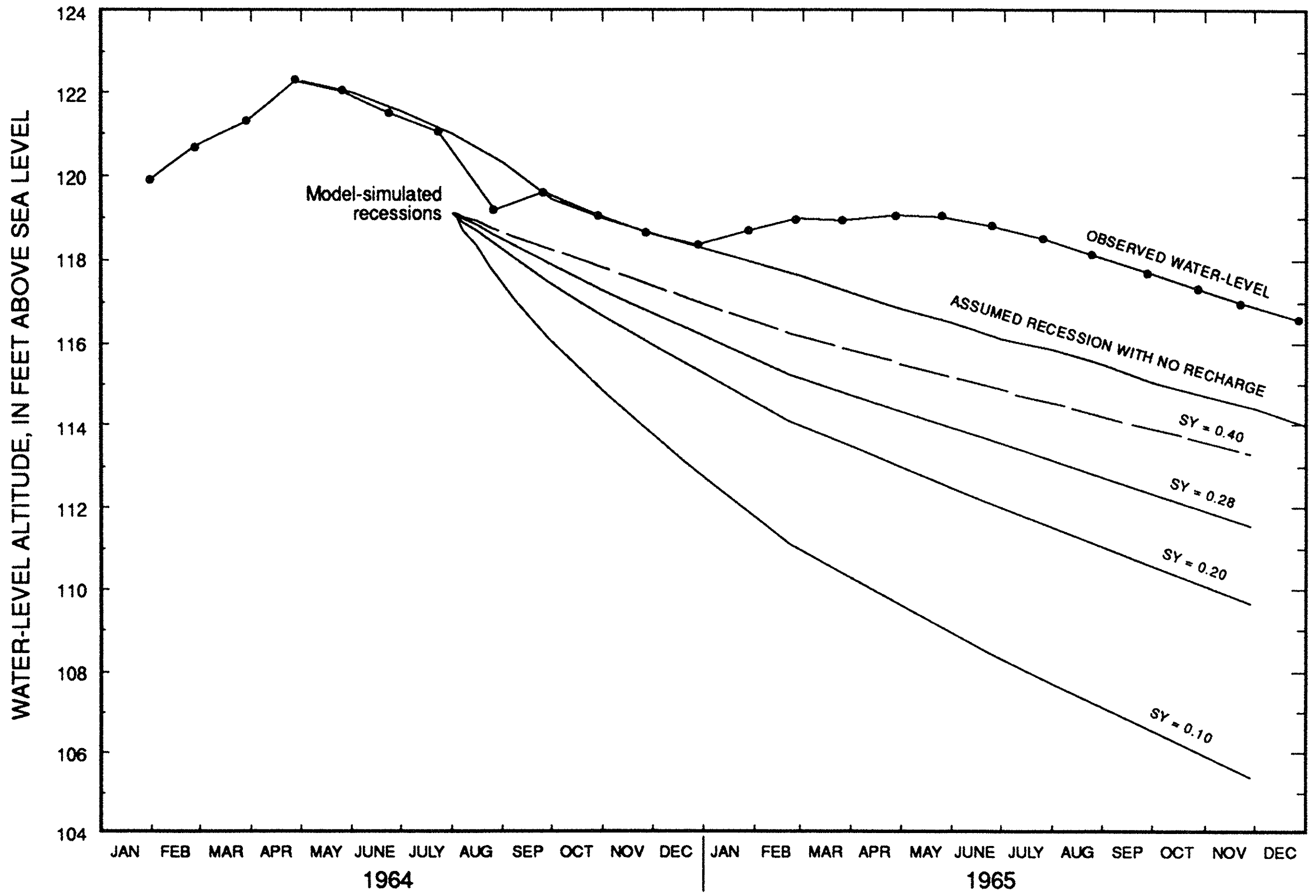

Figure 23.--Measured and simulated water-level declines in observation well PWW-22 for different values of specific yield in unconsolidated deposits.

through 0.40 in the vicinity of well PWW-22 for transient simulations of 1 year or less.

Simulation of Effects of Ground-Water Development Alternatives

Four hypothetical ground-water development alternatives were simulated with the model. The alternatives were designed to illustrate a variety of possible applications of the model as a tool for water-resource management in the study area. The alternatives discussed are only a few of the many possible alternatives for development and management of the aquifer; their inclusion in this report is not an endorsement of them. The alternatives simulate the effects of (1) Long-term drought on water levels at average 1980-85 pumping rates, (2) large-scale ground-water development in the northern part of the aquifer in which (2a) all pumping is consumptive or (2b) the water pumped is recharged artificially into the aquifer through infiltration ponds after treatment, (3) large-scale regional ground-water development, and (4) the effect of ground-water development on streamflow.

Simulation of Long-Term Drought

Beginning in about 1964, virtually no recharge occurred in the study area for 2 years. During this period, eastern Massachusetts experienced one of the worst droughts of the century (R.B. Lautzenheizer, State Climatologist, New England Climatic Service, written commun., 1988). The general effect of this period of no recharge on water levels in the Plymouth-Carver aquifer is shown on the long-term hydrograph of water-level fluctuations in observation well PWW-22 (fig. 11).

The model was used to simulate water-level declines in the Plymouth-Carver aquifer during a 2-year period of no recharge similar to that which occurred during the 1964-66 drought. The initial water levels for this simulation were the calibrated steady-state water levels, which approximated long-term average water levels in the aquifer. The pumping rate used was the average annual rate of pumping from public-supply and industrial wells during 1980-85; this was the same pumping rate that was used in the calibrated, steady-state model. Also simulated as part of the calibrated model was the long-term annual rate of loss of water attributable to cranberry-bog operations (table 7).

Simulated water-level declines at the end of the 2-year period are shown in figure 24. Water-level declines exceeded 5 ft throughout most of the aquifer and exceeded 10 ft in the central and northwestern parts of the aquifer. Total ground-water discharge to streams at the beginning of the simulation was 169.1 ft^3/s (table 11). By the end of the 2-year period of no recharge, ground-water discharge to streams had decreased by 54 percent to 77.4 ft^3/s.

Simulation of Large-Scale Pumping with and without Artificial Recharge

The effects of large-scale pumping with and without artificial recharge were evaluated by simulating two conditions: (1) All pumping is consumptive (no artificial recharge); and (2) all pumping in excess of the rate used in the calibrated steady-state model is recharged artificially after treatment back into the aquifer through infiltration ponds.

For both simulations, four arbitrarily selected wells were pumped at twice their rated capacities until steady-state conditions were achieved; these four wells were PWW-15, PWW-411, PWW-422, and PWW-541 (table 8, fig. 14). Pumping from these four wells was simulated in the calibrated steady-state model at 0.03, 0.9, 1.0, and 0.3 Mgal/d, respectively (table 8) (1 ft^3/s = 0.6462 Mgal/d). Pumping rates from these four wells, with and without artificial recharge, were 2.0, 5.8, 3.2, and 1.6 Mgal/d, (twice their rated capacities) respectively. The increases in pumping for these four wells from the rates simulated in the calibrated steady-state model were 2.0, 4.9, 2.2, and 1.3 Mgal/d, respectively. Total pumpage in the two simulations exceeded pumping in the calibrated steady-state model by 10.4 Mgal/d (16.1 ft^3/s).

Water-level declines attributable to pumping the four wells with all pumping consumptive (without artificial recharge) were 2 ft or more over an area of about 25 mi^2 (fig. 25). Water-level declines in the immediate vicinity of all four wells exceeded 8 ft. Ground-water discharge to streams in the modeled area decreased from 169.1 ft^3/s in the calibrated steady-state model to 158.4 ft^3/s.

In the pumping simulation with artificial recharge, all the water pumped in excess (10.4 Mgal/d) of that in the calibrated steady-state model was recharged artificially into a 2,000- by 2,000-ft area about 3,000 ft north of well PWW-422. The thickness of the unsaturated zone near the simulated recharge area ranges from about 40 to 65 ft. Simulated artificial recharge to the aquifer at a rate of 10.4 Mgal/d caused the water table directly beneath the recharge area to rise more than 40 ft (negative water-level declines in fig. 26). The combination of pumping and artificial recharge decreased ground-water discharge to streams by about 3.4 ft^3/s (from 169.1 ft^3/s in the calibrated steady-state model to 165.7 ft^3/s) but increased ground-water discharge to the ocean by 6 ft^3/s. Although the net withdrawal of water in this simulation was the same as that in the calibrated steady-state model, the ground-water-flow pattern in the aquifer was changed by redistributing natural ground-water discharge from the modeled area.

Simulation of Large-Scale Regional Withdrawal

Large-scale ground-water development of the aquifer was simulated for two hypothetical situations: (1) Increased pumping from 21 existing wells simulated in the calibrated steady-state model, and (2) increased pumping from 21 existing wells simulated in the calibrated steady-state model plus pumping from 15 additional wells located throughout the aquifer. Nearly every well simulated in the calibrated steady-state model was pumped at its design capacity for these simulations. Each of the 15 additional wells was pumped at a rate of 1 Mgal/d. Total pumping from wells simulated in the steady-state model was 17.8 Mgal/d, and total pumping from existing wells plus the 15 additional wells was 32.8 Mgal/d. Pumping in excess of that in the steady-state model was 10.6 Mgal/d for the simulation of increased pumping

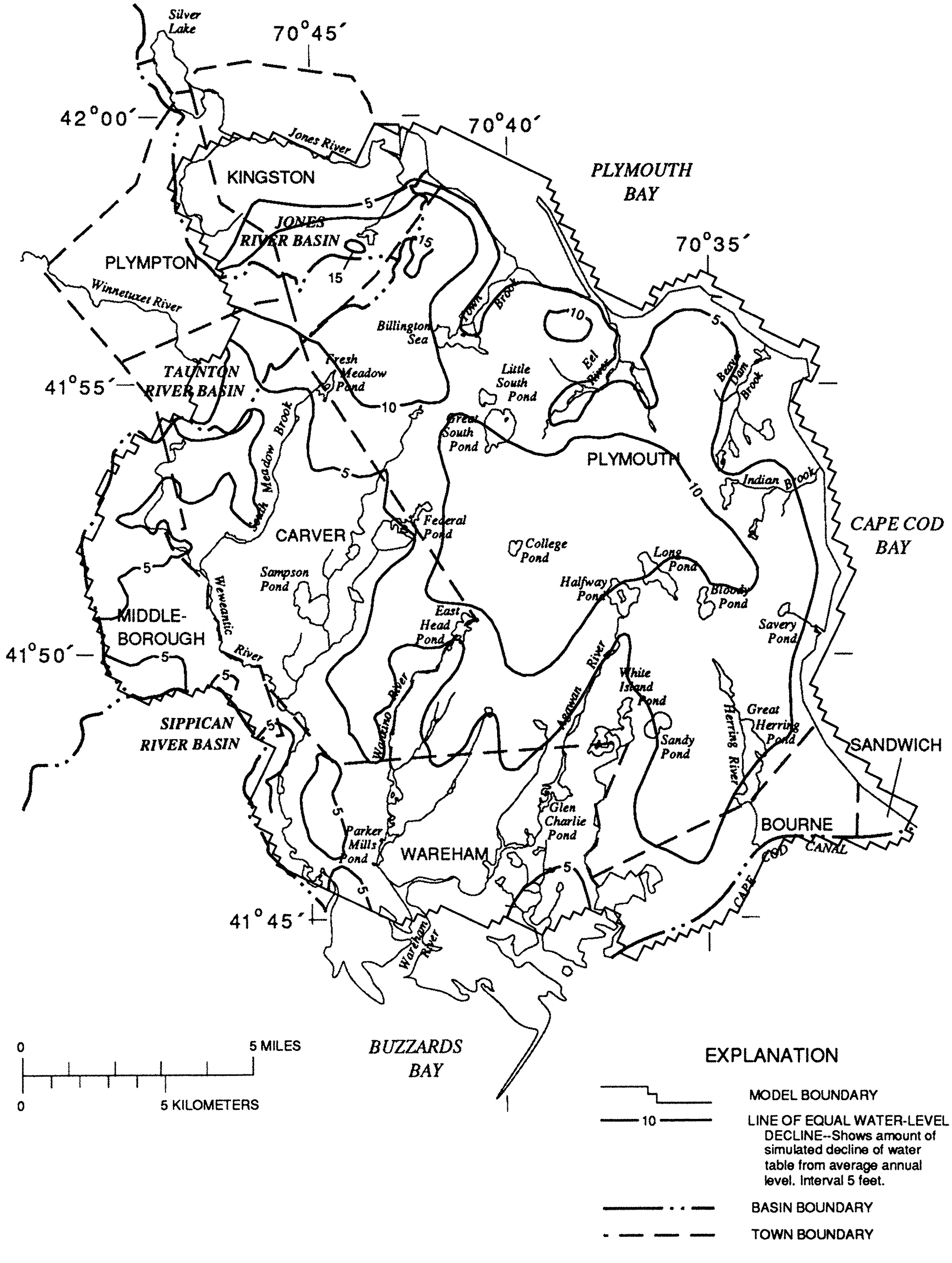

Figure 24.--Simulated water-level declines in Plymouth-Carver aquifer after 2-year period of no recharge.

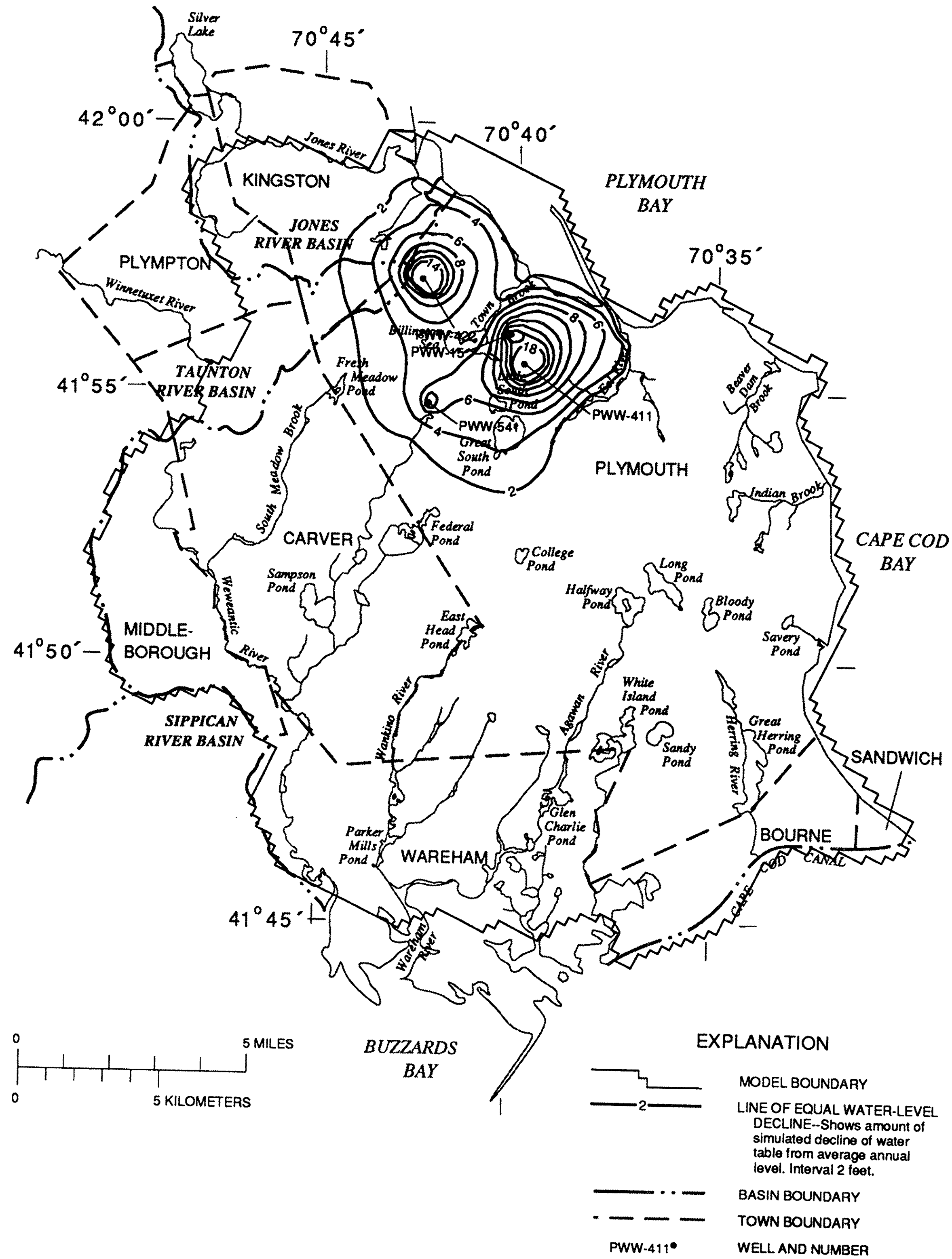

Figure 25.--Water-level declines in Plymouth-Carver aquifer for pumping simulation without artificial recharge and with twice the rated pumping capacity at four selected wells.

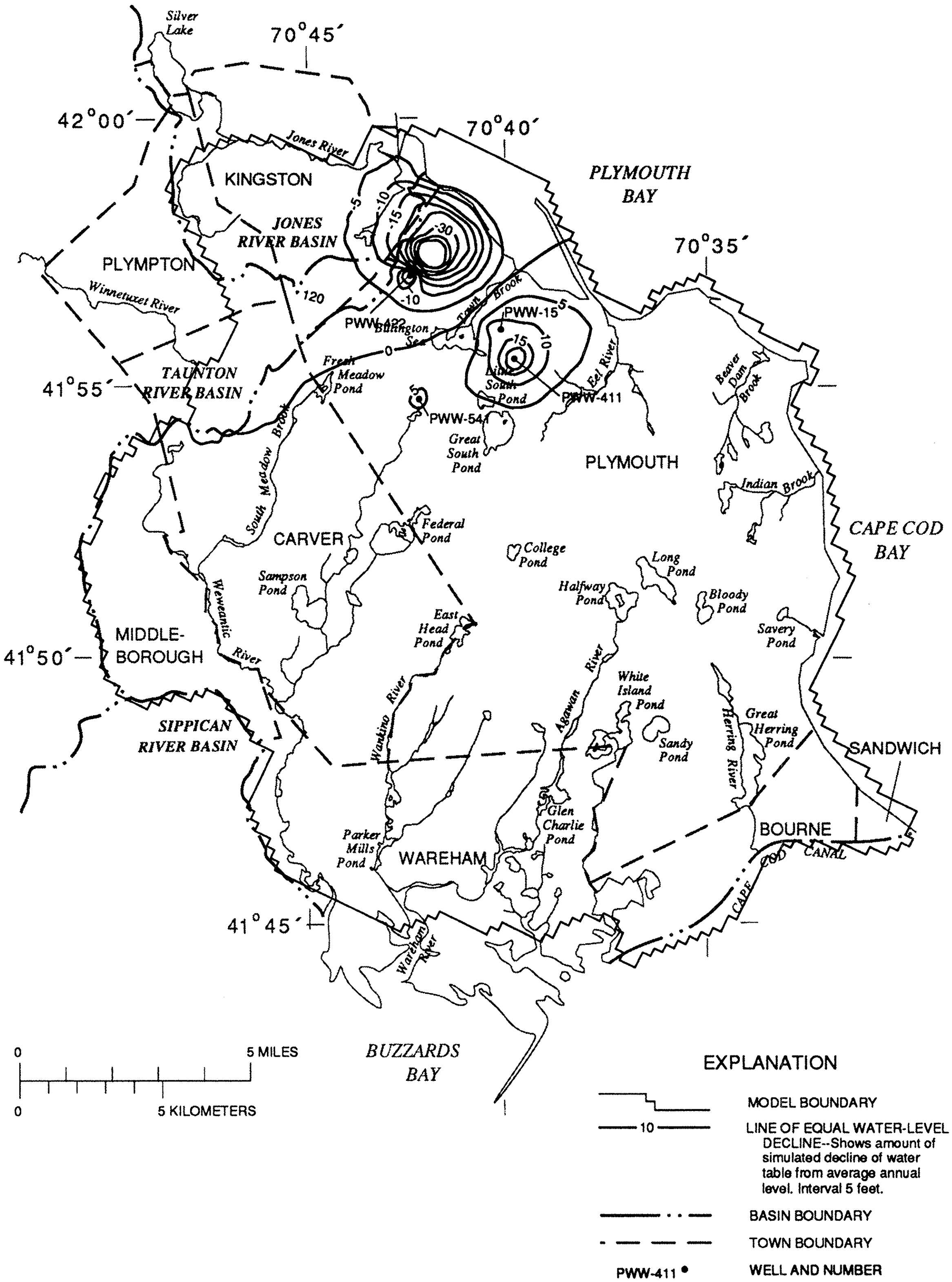

Figure 26.--Water-level declines in Plymouth-Carver aquifer for pumping simulation with artificial recharge and a pumping rate of 10.4 million gallons per day at four selected wells.

from existing wells and 25.6 Mgal/d for the simulation of increased pumping from existing wells and 15 additional wells.

Pumping the existing wells at nearly design capacity caused local water-level declines of more than 10 ft around some of the wells (fig. 27), but water-level declines were less than 2 ft throughout most of the aquifer. The additional 15 Mgal/d pumped from the 15 new wells significantly increased the area where water-level declines were more than 2 ft (fig. 28).

Simulation of Effect of Ground-Water Development on Streamflow

The model was used to simulate the effect of ground-water development on streamflow. This hypothetical situation demonstrates how the model might be used to aid agricultural water-use planning, development, and management.

A hypothetical well field is to be located in Myles Standish State Forest (fig. 2), along the eastern side of the Crane Brook basin (fig. 29). This basin contains 1,209 acres of cranberry bogs. The bog owners are concerned that withdrawals from the proposed well field may not leave enough water available for optimum cranberry production.

Maximum water demand for cranberry culture occurs in mid-December when all of the bogs are flooded simultaneously to prevent freezing of the plants. The flooding normally is completed in 5 to 10 days. On the basis of data from the U.S. Soil Conservation Service (U.S. Department of Agriculture, 1986), it was determined that 915 Mgal (183 Mgal/d for 5 days or 92 Mgal/d for 10 days) of water is required to flood the bogs in the basin. During years of normal precipitation, 95 percent of the streamflow in this basin is ground-water discharge. In some years, almost 100 percent of streamflow in December is ground-water discharge.

The model was used to simulate the effects of pumping from the proposed well field on streamflow during normal and extreme-drought conditions. Twelve wells were simulated in the well field (fig. 29). Four wells (1-4) were used to pump 2 Mgal/d; eight wells (1-8) were used to pump 4 Mgal/d, and 12 wells were used to pump 6 Mgal/d. Table 22 shows the simulated streamflow (ground-water discharge) resulting from these hypothetical situations.

During years of normal precipitation when streamflow is mainly ground-water discharge, 88 percent of the water required for a 10-day winter flood (94 percent for a 5-day flood) comes from storage in ponds, reservoirs, or ground water. During drought and well-field pumping conditions, streamflow is reduced, so more water must come from storage reservoirs. No attempt is made here to distribute the need for flood water or assess the adequacy of existing storage reservoirs to meet these demands. In general, the effects of pumping will be greatest near, and just downstream from, the well field. Figure 30 shows simulated streamflow in Crane Brook, from Federal Pond to the confluence with Sampson Brook (fig. 29), during various climatic and pumping conditions.

The model was not calibrated with any streamflow data from Sampson Brook, so the relative magnitudes of stream discharges after pumping may not be accurate. However, the simulation results provide an indication of the relative effects of several possible sets of climatic and pumping conditions on stream discharge in the subbasin.

Appraisal and Limitations of the Model

The ground-water-flow model discussed in this report simulated the three-dimensional distribution of regional water levels in the Plymouth-Carver aquifer and the distribution of regional ground-water discharge to streams and the ocean. The model was constructed using all available information on the geohydrologic characteristics of the aquifer. From a regional perspective, the model accurately simulated ground-water flow. However, measured water levels in the aquifer and ground-water discharge to streams differed somewhat from those simulated because of uncertainties regarding local aquifer geometry and hydraulic properties and because it was not possible to include all complexities of the aquifer in the model. The calibrated steady-state model simulated water levels in the aquifer and ground-water discharge to streams during periods when hydrologic conditions approximate the long-term average. Several hypothetical ground-water development and management alternatives were simulated to illustrate a variety of possible applications of the model as a tool for water-resources management in the study area. The alternatives discussed in this report are only a few of the many possible alternatives for development and management of the aquifer.

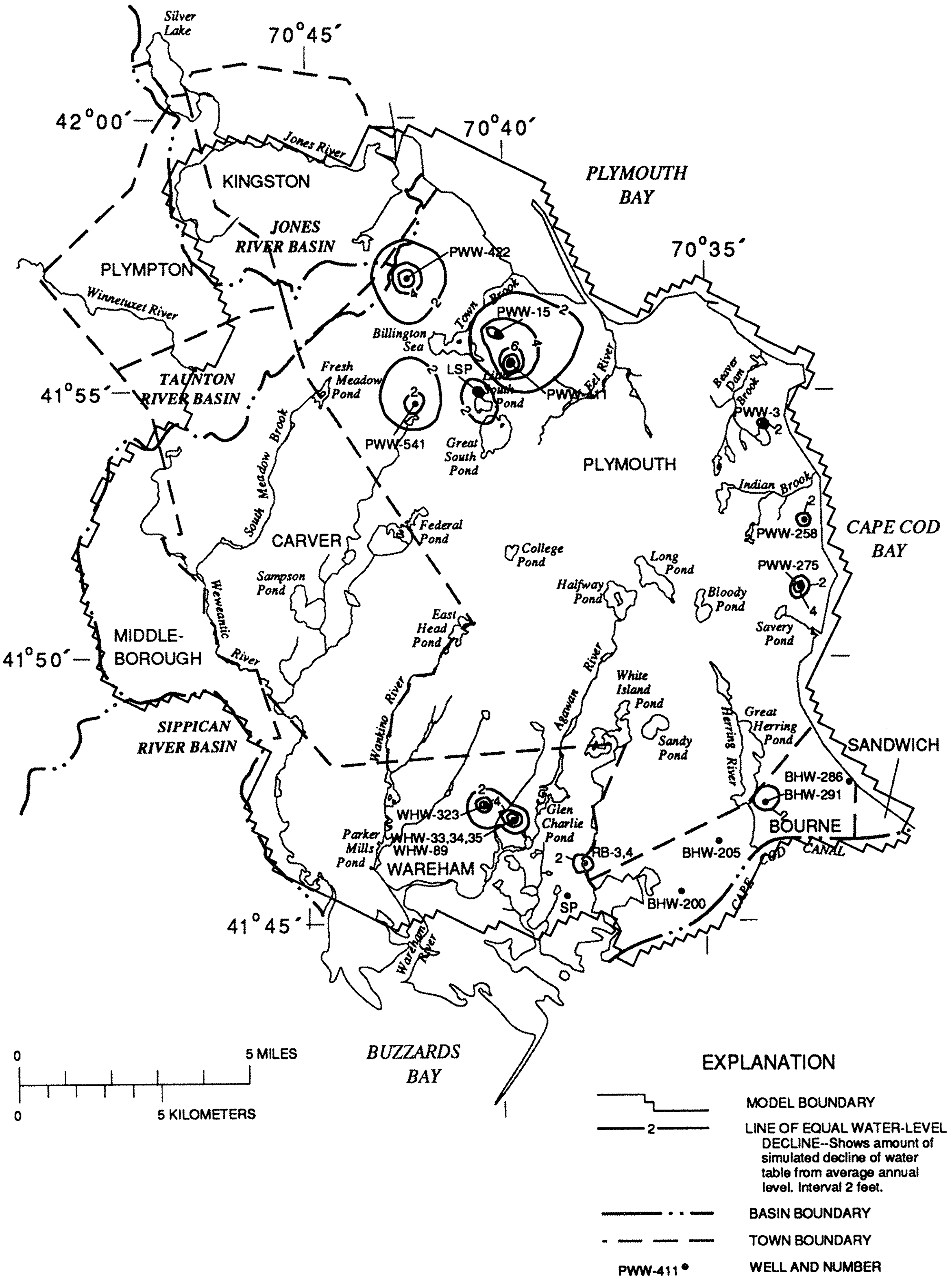

Figure 27.--Water-level declines in Plymouth-Carver aquifer for simulation of increased pumping from existing wells.

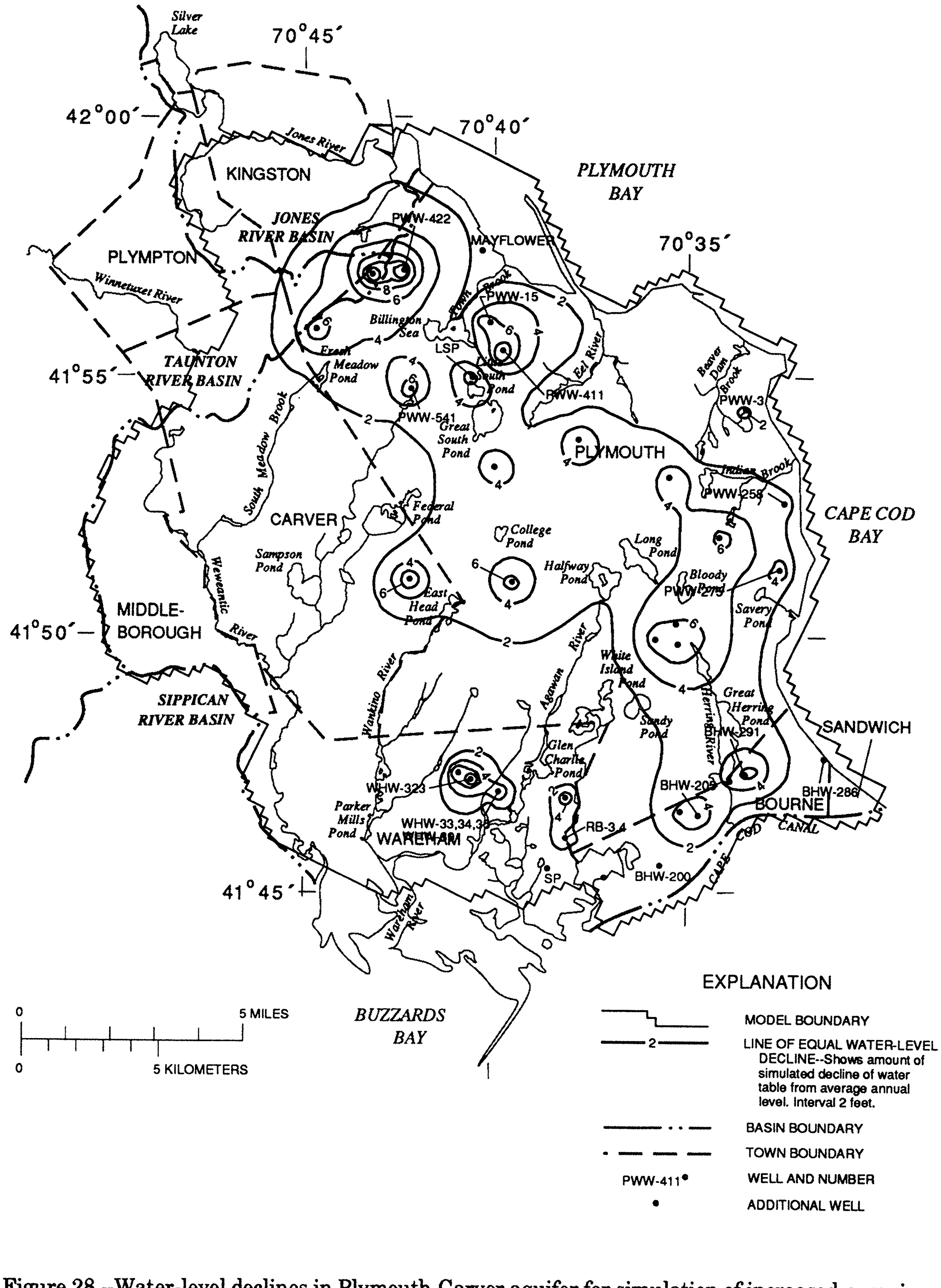

Figure 28.--Water-level declines in Plymouth-Carver aquifer for simulation of increased pumping from existing wells and 15 additional wells.

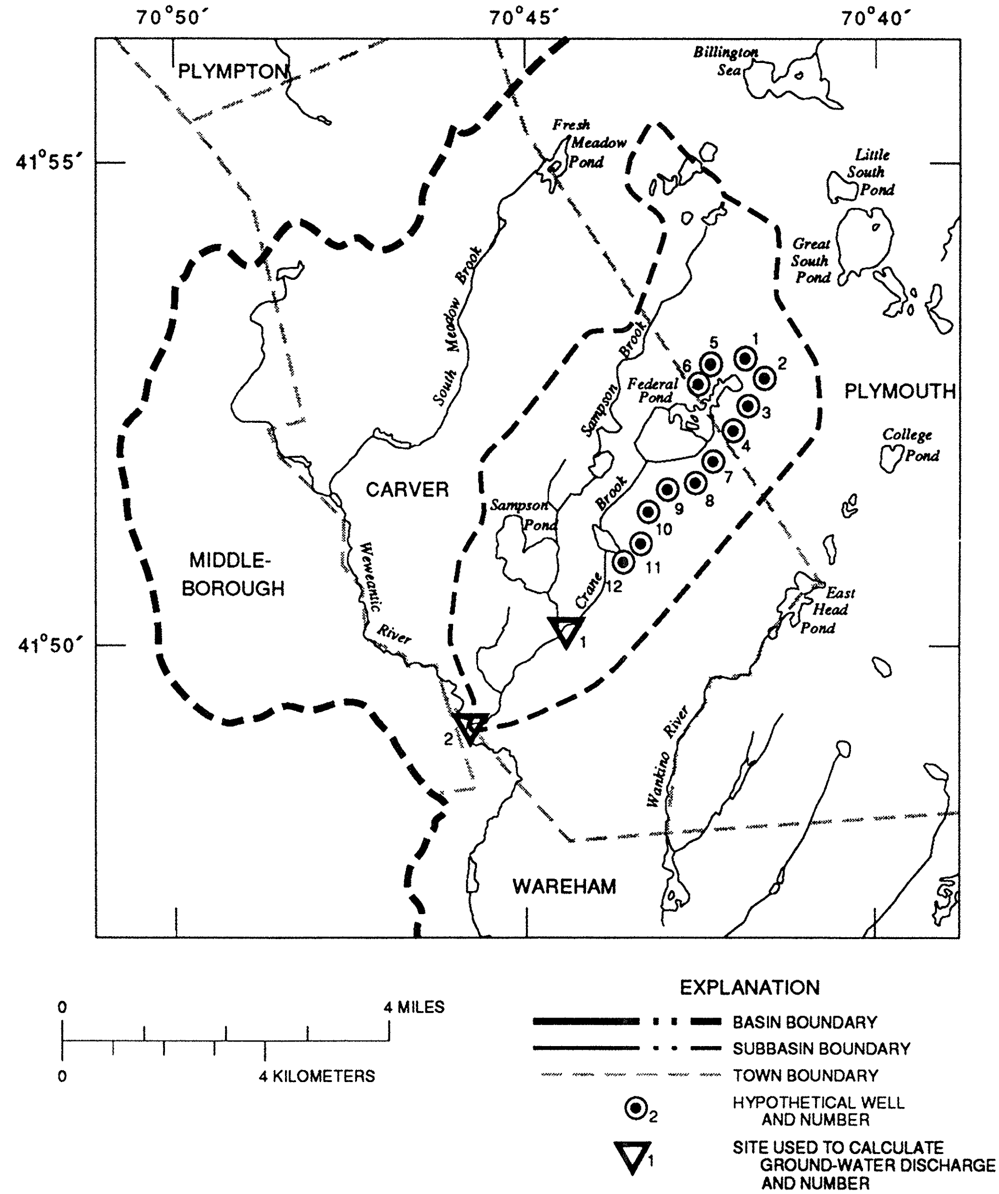

Figure 29.--Crane Brook basin, hypothetical well field, and sites used to calculate ground-water discharge.

The model was designed for use in estimating the regional effects of ground-water development on ground-water levels and streamflow. The model was not designed for precise simulation of well interference on a small scale or for well-field design. However, the model can provide information on hydraulic-boundary conditions for use in more detailed models of smaller areas within the Plymouth-Carver aquifer.

The model only approximates hydrologic conditions in the aquifer and has several limitations. One major limitation is that stream stage is held constant in the model during a simulation, even though actual stream stage changes continuously over time, and a stream may even dry up. Therefore, although an actual stream may go dry as a result of pumping, the simulated stream will continue to supply water to the wells at a rate partly dependent on the assigned stream stage. Because of this, simulated hydraulic heads in the aquifer could be higher than actual hydraulic heads, and simulated drawdowns in wells could be less than actual drawdowns.

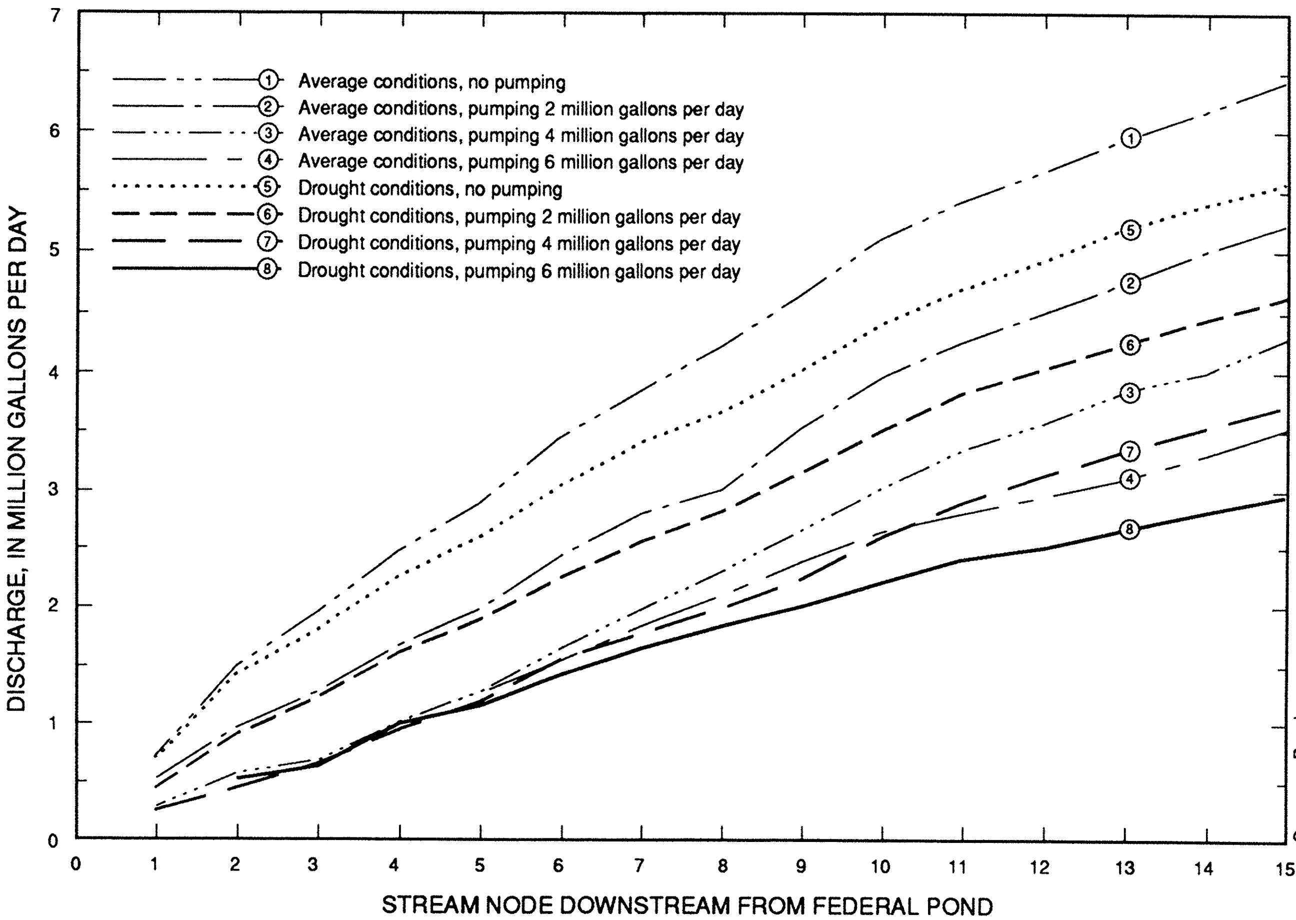

Figure 30.--Simulated streamflow in Crane Brook from Federal Pond to confluence with Sampson Brook.

A second major limitation of the model is the simplified representation of the distribution of vertical and horizontal hydraulic conductivity in the outwash-plain and morainal deposits. Lithologic logs of the aquifer suggest that these deposits become siltier with depth and that the horizontal hydraulic conductivity of these deposits, therefore, decreases with depth. This decrease was simulated in the model by assigning horizontal hydraulic conductivities for the outwash-plain and morainal deposits of 250, 150, 50, and 50 ft/d to model layers 1, 2, 3, and 4, respectively. At some locations, however, the deposits do not become siltier with depth, and the horizontal hydraulic conductivity remains high throughout the vertical section. Simulation of pumping from model layers 3 and 4 at these locations may result in overestimation of drawdown near the pumped well and underestimation of drawdown far from the pumped well. A possible refinement of the model would be to alter the horizontal hydraulic-conductivity matrices for each layer to account for areas where lithologic logs suggest that the deposits do not become siltier with depth.

Another limitation of the model is that the assigned values for the storage coefficient and specific yield are the same throughout the modeled area, although the actual values probably vary from location to location in the aquifer. Another possible refinement to the model would be to determine the areal variation in these values by field investigation and then vary values of storage coefficient and specific yield areally in the model accordingly. This would enable more accurate simulation of local transient response to variations in recharge and pumping.

A fourth limitation of the model is that it does not simulate the saltwater-freshwater interface along the coast. Therefore, the model does not provide a means of simulating the extent of saltwater intrusion due to pumping near the coast or to simulate changes in the salinity of water from the pumped wells.

Table 22.--*Simulated ground-water discharge to Crane Brook for various climatic and pumping conditions*

[Mgal/d, million gallons per day]

Climatic condition[1]	Well field pumping rate (Mgal/d)	Simulated ground-water discharge (Mgal/d)	
		S-1 (fig. 29)	S-2 (fig. 29)
Average	0	6.4	10.7
Average	2	5.2	9.3
Average	4	4.3	7.9
Average	6	3.5	7.1
Maximum drought	0	5.6	8.0
Maximum drought	2	4.7	6.9
Maximum drought	4	3.7	5.5
Maximum drought	6	3.0	4.7

[1]Average climatic conditions used in steady-state simulation; maximum drought used in transient simulation.
[2]Maximum drought refers to the conditions measured during 1964-66.

SUMMARY AND CONCLUSIONS

The Plymouth-Carver aquifer has an areal extent of 140 mi^2 and is composed predominantly of glacial sand and gravel. The area served by the aquifer is experiencing rapid population growth and increasing pressure to develop the aquifer as a regional source of water. Development decisions require an understanding of the regional behavior of the aquifer system.

The mostly unconfined Plymouth-Carver aquifer is underlain by granitic bedrock. The altitude of the bedrock surface ranges from 100 ft above sea level to about 200 ft below sea level. Surficial glacial deposits, mostly sand and gravel, are greater than 200 ft thick at some locations. The saturated thickness of the aquifer ranges from less than 20 to slightly greater than 200 ft. The hydraulic conductivity of sand and gravel deposits, as determined by aquifer tests, ranges from 55 to 313 ft/d. There is some evidence from lithologic logs that aquifer deposits are finer and siltier with depth. Some limited areas of artesian or perched-water-table conditions are caused by confining units.

The major source of aquifer recharge is precipitation. Recharge to the sand and gravel deposits, as determined from Eel River streamflow data, is 24.2 in/yr, but is probably somewhat higher than that. The altitude of the water table ranges from sea level to slightly higher than 125 ft above sea level. In general, groundwater flows radially from water-table highs and discharges to streams and the ocean.

In 1985, the withdrawal of water from the Plymouth-Carver aquifer averaged 59.6 Mgal/d. Agricultural use for cranberry culture accounted for 82 percent of total water use; public supplies accounted for 12 percent.

A three-dimensional, finite-difference ground-water-flow model was used to simulate regional flow in the aquifer. The model was designed to estimate the regional effects of ground-water development and should not be used for detailed analysis of hydrologic conditions in a small area. The model was calibrated to, and closely duplicates, measured water levels and groundwater discharge to streams. However, some inaccuracies are present because of uncertainties in aquifer geometry and hydraulic properties and from simplification of the modeled distribution of some hydraulic properties. The sensitivity of the model to changes in input values for recharge, hydraulic conductivity, specific yield, and streambed conductance was tested. The model was insensitive to rates of recharge of 18 to 30 in/yr. The model was more sensitive to hydraulic conductivity; simulations with horizontal hydraulic-conductivity multiples of 0.2 or less, and 5.0 or greater gave unacceptable results. Model sensitivity increased as streambed conductance decreased; however, good water-level agreement was achieved using streambed-conductance multipliers from 0.2 through 10. Specific yields of 0.20 to 0.40 provided close agreement of simulated water-level declines to the assumed decline at observation well PWW-22 during August 1965 through August 1966 if there had been no recharge during that period.

Four hypothetical ground-water development alternatives were simulated to demonstrate the use of the model. Simulation of a 2-year period of no recharge (an approximation of the maximum recorded drought) resulted in water-level declines larger than 5 ft throughout most of the study area and larger than 10 ft in the central and northwestern parts. Ground-water discharge to streams decreased 54 percent from average.

In a second simulation, four wells in the northern part of the area were pumped at 12.6 Mgal/d (10.4 Mgal/d larger than steady-state rates). When this pumping was treated as being consumptive (no artificial recharge), water levels declined 2 ft or more in an area of 25 mi^2, and ground-water discharge to streams decreased 6 percent from average. When the same amount was pumped and then recharged to the aquifer, water levels beneath a simulated infiltration pond rose more than 40 ft. Total ground-water discharge remained equal to steady-state discharge but was redistributed.

In a third simulation, all of the 21 existing production wells were pumped at nearly design capacity, a rate 10.6 Mgal/d greater than steady-state pumping. This rate then was increased to 25.6 Mgal/d greater than steady state by pumping from existing wells and from 15 additional wells distributed throughout the aquifer. Pumping from the existing wells at design capacity resulted in water-level declines of less than 2 ft throughout most of the aquifer. Increased pumping from the 15 additional wells substantially increased the area where water-level declines exceeded 2 ft.

In a final simulation, a well field close to a stream that drains the aquifer was pumped at 2, 4, and 6 Mgal/d. At a pumping rate of 6 Mgal/d, ground-water discharge to the stream decreased 34 percent during periods of normal precipitation and 56 percent during drought conditions.

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APPENDIX:
Results of Sensitivity Analyses of Ground-Water Flow Model

Table 23.--*Measured and simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for average annual recharge rates of 18, 24, 27, and 30 inches per year*

[ft, feet; in/yr, inches per year]

Model Row	Model Column (fig. 16)	Model Layer	Well or pond (fig. 18)	Water level (ft) Measured	Simulated for recharge rate (in/yr) 18	24	27	30
8	78	1	PWW-501	5.88	0.78	0.91	0.97	1.03
19	40	1	PWW-502	81.63	77.55	80.14	81.86	83.24
19	48	1	PWW-261	74.05	64.77	67.99	70.30	72.46
20	44	1	PWW-503	77.41	71.74	76.33	76.09	77.74
22	77	1	PWW-313	38.59	35.25	39.12	39.25	40.49
23	67	1	PWW-241	67.73	57.86	63.06	64.29	66.19
23	77	1	PWW-285	36.60	37.05	43.67	41.49	42.87
24	49	1	PWW-215	81.90	78.84	83.10	84.14	86.64
24	52	1	PWW-516	77.03	76.48	79.25	81.38	83.44
24	66	1	PWW-242	72.59	60.91	67.77	67.56	69.52
24	73	1	PWW-245	57.79	49.98	53.82	55.66	57.42
25	28	1	PWW-413	123.73	109.35	117.07	119.03	122.22
25	72	1	PWW-240	71.78	56.61	58.99	63.91	66.15
26	46	1	PWW-504	99.03	88.35	83.38	90.99	94.03
27	66	1	PWW-243	79.20	69.26	76.19	77.59	80.15
28	38	1	PWW-505	118.30	102.52	107.33	110.40	113.09
28	47	1	PWW-306	101.66	91.98	94.78	97.65	100.42
28	68	1	PWW-244	87.20	69.81	74.98	78.93	81.75
29	46	1	PWW-305	102.07	93.14	97.95	98.99	101.77
30	26	1	PWW-517	123.73	115.07	120.26	122.93	125.48
30	52	1	PWW-506	98.88	90.77	94.95	97.77	100.49
30	66	1	PWW-379	82.05	75.78	82.23	85.35	88.33
34	34	1	PWW-22	120.98	111.92	116.68	119.18	121.52
34	53	1	PWW-315	102.71	94.82	100.52	103.69	106.74
35	71	1	PWW-509	70.45	69.32	75.74	78.82	81.73
36	24	1	CDW-119	114.70	111.67	114.08	115.84	117.21
37	46	1	PWW-507	112.95	105.36	110.19	112.74	115.24
38	78	1	PWW-414	64.07	59.69	64.12	68.56	71.28
39	50	1	PWW-416	108.18	103.01	109.01	111.75	114.63
40	82	1	PWW-518	52.39	48.20	53.52	56.53	59.11
41	92	1	PWW-319	21.04	15.53	16.98	19.23	20.42
42	29	1	CDW-120	92.60	97.00	99.20	98.53	99.04
42	92	1	PWW-418	22.16	18.28	19.07	22.54	23.90
44	31	1	CDW-121	103.23	99.50	100.06	102.31	103.23
44	82	1	PWW-253	46.59	47.22	52.23	54.62	56.96
46	61	1	PWW-510	98.53	90.23	96.80	99.92	102.94
46	84	1	PWW-251	43.60	42.19	46.87	49.10	51.29
47	56	1	PWW-511	101.01	95.47	102.69	104.38	107.18
49	83	1	PWW-513	47.75	44.73	48.81	50.76	52.68
51	40	1	BHW-126	99.95	87.02	87.82	87.98	88.30
51	50	1	CDW-99	98.92	96.53	100.37	103.27	105.39
51	59	1	PWW-415	91.34	88.62	93.15	96.06	98.38
53	82	1	PWW-514	48.22	45.35	48.25	49.64	51.03
53	84	1	PWW-520	47.02	41.97	45.72	46.88	48.45
54	55	1	CDW-123	83.97	86.03	90.01	89.90	91.16

Table 23.--*Measured and simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for average annual recharge rates of 18, 24, 27, and 30 inches per year*--Continued

Model Row	Model Column	Model Layer (fig. 16)	Well or pond (fig. 18)	Water level (ft) Measured	Simulated for recharge rate (in/yr) 18	24	27	30
54	56	1	PWW-521	89.77	85.38	87.55	88.64	89.73
56	52	1	CDW-125	79.66	85.56	88.40	89.74	91.07
57	84	1	PWW-519	46.61	38.22	41.67	42.69	44.11
58	58	1	PWW-431	75.15	76.57	78.98	80.19	81.35
59	63	1	PWW-512	69.78	65.32	67.82	69.07	70.28
61	87	1	PWW-368	28.98	26.38	28.47	30.64	31.98
61	93	1	BHW-293	25.22	15.66	17.49	19.65	20.90
63	56	1	PWW-430	61.56	64.40	65.93	66.69	67.43
64	37	1	CDW-122	76.10	78.01	78.73	80.67	81.50
64	53	1	CDW-86	64.80	64.15	65.35	66.41	67.12
65	36	1	CDW-201	78.14	74.74	77.82	76.65	77.25
65	57	1	PWW-236	55.71	58.09	59.98	60.72	61.57
66	53	1	CDW-85	62.84	59.48	59.85	62.02	62.80
66	55	1	PWW-369	56.02	54.39	54.98	56.13	56.69
66	61	1	PWW-238	55.51	51.85	53.43	54.20	54.96
66	64	1	WFW-296	45.48	44.54	46.44	45.55	45.88
68	57	1	PWW-237	51.09	50.56	50.45	52.64	53.30
69	61	1	WFW-295	45.81	42.77	45.16	44.37	44.89
69	64	1	WFW-297	39.49	37.56	38.36	38.75	39.14
70	57	1	WFW-245	46.21	43.05	45.56	44.75	45.28
70	79	1	WFW-211	16.49	16.73	16.02	18.25	18.74
8	73	1	BARTLETT POND	6.53	2.89	3.05	3.13	3.21
16	78	1	FRESH POND	14.24	13.65	14.43	14.81	15.19
20	75	1	BEAVER POND	20.66	32.84	33.81	34.29	34.75
20	81	1	SHALLOW POND	31.19	20.41	22.68	23.79	24.83
21	33	1	LITTLE MUDDY POND	108.70	91.10	97.81	101.29	104.60
21	57	1	RUSSELL MILL POND	51.79	57.30	57.95	58.32	58.68
21	74	1	ISLAND POND	42.28	39.93	40.00	40.03	40.06
24	43	1	BRIGGS RESERVOIR	87.41	85.55	88.05	90.35	92.50
24	48	1	COOKS POND	87.08	81.25	83.52	86.24	88.82
24	87	1	LILLY POND	11.09	8.79	10.50	11.33	12.12
28	41	1	MICAJAH POND	108.20	98.11	102.49	105.30	107.98
28	58	1	ISLAND POND	88.79	82.25	86.97	89.47	91.88
28	83	1	MOREY POND	48.74	34.76	39.45	41.67	43.69
30	93	1	BLACK POND	4.43	0.	0.	0.	0.00
31	20	1	UNNAMED POND WEST OF CEDAR SWAMP	122.44	116.83	119.09	120.25	121.41
33	59	1	CROOKED POND	95.78	88.67	95.05	98.32	101.44
34	89	1	SAVERY POND	26.08	19.09	22.55	24.22	25.83
37	48	1	WIDGEON POND	108.17	103.73	108.98	111.79	114.52
38	46	1	CURLEW POND	108.00	105.68	110.38	112.84	115.24
39	47	1	ROCKY POND	107.52	104.98	109.88	112.43	114.90
40	82	1	GRASSY POND	51.16	47.93	53.52	56.18	58.74
41	58	1	COLLEGE POND	103.58	96.00	103.04	106.49	109.81
42	88	1	HODGES POND	33.52	30.20	34.48	36.52	38.52
48	26	1	VAUGHN POND	101.81	100.03	102.01	102.97	103.91

Table 23.--*Measured and simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for average annual recharge rates of 18, 24, 27, and 30 inches per year*--Continued

Model Row (fig. 16)	Model Column	Model Layer	Well or pond (fig. 18)	Water level (ft) Measured	Simulated for recharge rate (in/yr) 18	24	27	30
49	83	1	LITTLE DUCK POND	47.07	44.73	48.81	50.76	52.68
57	83	1	LITTLE ROCKY POND	46.87	39.44	42.10	43.38	44.65
59	67	1	UNNAMED POND SOUTH-EAST OF CHARGE POND	57.00	56.21	58.96	60.25	61.56
59	89	1	HORSE POND	40.64	25.92	29.30	30.93	32.50
64	50	1	GOLDEN FIELD POND	74.04	71.96	74.36	75.49	76.58
64	90	1	GOAT PASTURE POND	20.76	13.47	15.69	16.78	17.82
65	36	1	BATES POND	79.08	76.29	77.82	78.54	79.23
65	39	1	POND NEAR HUCKLE-BERRY CORNER	72.91	72.94	73.98	74.48	74.96
65	42	1	POND ON CRANE BROOK	67.63	68.39	68.56	68.65	68.73
65	89	1	ELLIS POND	16.17	11.17	12.93	13.80	14.63
77	54	1	UNNAMED POND AT INTERSECTION OF I-195 AND I-25	38.83	34.12	34.70	34.93	35.17
Absolute value of the mean of the water-level residuals[1], in feet					4.64	1.52	0.15	1.76
Mean of the absolute values of the water-level residuals, in feet					5.44	3.56	3.46	3.82
Standard deviation of the water-level residuals, in feet					5.03	4.52	4.42	4.54

Total number of observations = 101.

[1]Water-level residual = Measured water level - simulated water level.

Table 24.--*Measured and simulated ground-water discharge to streams in the Plymouth-Carver aquifer for average annual recharge rates of 18, 24, 27, and 30 inches per year*

[ft^3/s, cubic foot per second, in/yr, inches per year]

Stream-measurement site (plate 1)	Date of measurement (month-day-year)	Discharge[1] (ft^3/s) Measured	Simulated using recharge rate in/yr 18	24	27	30
Town Brook at Plymouth upstream upstream of site 2 (01105874)	07-21-86	14.6				
	07-22-86	15.3	3.4	6.8	9.0	11.3
Eel River near Plymouth upstream of site 4 (01105876)	07-21-86	23.2	14.1	19.5	22.7	25.8
Eel River at Sandwich Road near Plymouth upstream of site 4a	07-22-86	14.9	7.9	11.3	13.4	15.4
Eel River tributary near Plymouth upstream of site 4b	07-22-86	7.87	1.3	2.7	3.4	4.2
Beaver Brook at White Horse Beach upstream of site 5 (01105878)	07-21-86	12.7				
	07-22-86	11.8	9.0	12.8	14.7	16.7
Indian Brook at Manomet Beach upstream of site 6	07-21-86	1.18	-.72	-.72	-.72	-.72
Herring River between outlet from Great Herring Pond and Cape Cod Canal between site 8a and 8	07-21-86	- .93	-1.2	-1.0	-.91	-.82
Red Brook near Buzzards Bay upstream of site 13	07-21-86	6.13	1.1	4.3	5.9	7.6
Agawam River at East Wareham upstream of site 16	07-21-86	33.5	18.7	26.7	30.7	34.8
Wankinco River at East Wareham upstream of site 21	07-21-86	18.6	9.9	16.7	18.7	23.4
Weweantic River at South Wareham upstream of site 22	07-21-86	81.2				
	07-22-86	11.9	30.5	43.9	51.0	57.8
Agawam River between site 16 and the confluence of the Agawam and Wankinco Rivers	07-21-86	2.1	4.3	5.0	5.4	5.8
Agawam River just upstream of the confluence with Wankinco River, Wareham	07-21-86	35.6	23.0	31.8	36.1	40.5
Absolute value of the mean of the discharge residuals[2], in feet			7.3	2.8	0.5	2.0
Mean of the absolute values of the discharge residuals, in feet			7.6	3.3	2.2	3.4
Standard deviation of the discharge residuals, in feet			5.6	3.0	3.0	4.1

[1]Negative discharge means that water moves from the stream into the underlying aquifer.

[2]Discharge residual = measured ground-water discharge - simulated ground-water discharge.

Table 25.--*Measured and simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for multiples of the horizontal hydraulic conductivity of unconsolidated deposits used in the calibrated, steady-state model*

[ft, feet]

Model Row	Model Column (fig.16)	Model Layer	Well or pond (fig. 18)	Water level (ft) Measured	Multiple of hydraulic conductivity 0.2	0.5	1.0	2.0	5.0
8	78	1	PWW-501	5.88	2.85	1.44	0.97	0.75	0.63
19	40	1	PWW-502	81.63	104.47	89.06	81.86	73.93	63.67
19	48	1	PWW-261	74.05	108.29	80.79	70.30	62.32	53.85
20	44	1	PWW-503	77.41	102.00	83.65	76.09	68.57	59.12
22	77	1	PWW-313	38.59	62.99	47.39	39.25	33.37	28.33
23	67	1	PWW-241	67.73	101.73	76.76	64.29	54.48	44.18
23	77	1	PWW-285	36.60	67.77	50.53	41.49	34.89	29.17
24	49	1	PWW-215	81.90	129.75	96.49	84.14	74.53	64.03
24	52	1	PWW-516	77.03	120.54	92.20	81.38	73.18	63.48
24	66	1	PWW-242	72.59	105.79	80.35	67.56	57.37	46.47
24	73	1	PWW-245	57.79	93.80	67.90	55.66	47.06	38.99
25	28	1	PWW-413	123.73	191.02	141.93	119.03	104.67	94.16
25	72	1	PWW-240	71.78	111.93	79.50	63.91	52.78	40.94
26	46	1	PWW-504	99.03	146.65	103.50	90.99	80.61	70.47
27	66	1	PWW-243	79.20	131.56	95.14	77.59	64.77	52.09
28	38	1	PWW-505	118.30	163.26	127.07	110.40	97.30	82.82
28	47	1	PWW-306	101.66	153.09	112.79	97.65	85.88	73.06
28	68	1	PWW-244	87.20	138.82	98.45	78.93	64.90	50.05
29	46	1	PWW-305	102.07	154.52	114.35	98.99	87.02	75.20
30	26	1	PWW-517	123.73	181.43	141.19	122.93	111.47	103.24
30	52	1	PWW-506	98.88	151.85	113.64	97.77	85.68	71.91
30	66	1	PWW-379	82.05	148.80	105.95	85.35	70.59	55.16
34	34	1	PWW-22	120.98	167.61	134.55	119.18	107.89	95.91
34	53	1	PWW-315	102.71	166.57	123.28	103.69	89.18	73.49
35	71	1	PWW-509	70.45	140.51	98.96	78.82	64.29	48.94
36	24	1	CDW-119	114.70	146.21	124.82	115.84	110.50	106.31
37	46	1	PWW-507	112.95	163.16	128.56	112.74	100.29	85.87
38	78	1	PWW-414	64.07	126.62	87.48	68.56	55.13	41.18
39	50	1	PWW-416	108.18	172.24	130.89	111.75	97.56	82.35
40	82	1	PWW-518	52.39	112.85	74.77	56.53	44.02	31.92
41	92	1	PWW-319	21.04	48.02	27.98	19.23	13.96	9.79
42	29	1	CDW-120	92.60	102.89	99.59	98.53	97.91	96.81
42	92	1	PWW-418	22.16	55.24	32.61	22.54	16.40	11.49
44	31	1	CDW-121	103.23	117.95	106.84	102.31	99.34	95.96
44	82	1	PWW-253	46.59	106.04	71.04	54.62	43.59	32.80
46	61	1	PWW-510	98.53	164.65	120.91	99.92	84.99	68.61
46	84	1	PWW-251	43.60	98.18	64.75	49.10	38.83	29.31
47	56	1	PWW-511	101.01	164.03	123.64	104.38	90.70	76.04
49	83	1	PWW-513	47.75	94.27	64.51	50.76	41.82	33.41
51	40	1	BHW-126	99.95	90.20	88.78	87.98	87.09	84.46
51	50	1	CDW-99	98.92	147.68	117.52	103.27	93.24	82.00
51	59	1	PWW-415	91.34	145.43	111.82	96.06	84.82	71.31
53	82	1	PWW-514	48.22	82.49	59.73	49.64	43.30	37.36
53	84	1	PWW-520	47.02	83.90	58.52	46.88	39.55	32.99
54	55	1	CDW-123	83.97	111.08	96.70	89.90	84.29	73.89

Table 25.--*Measured and simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for multiples of the horizontal hydraulic conductivity of unconsolidated deposits used in the calibrated, steady-state model*--Continued

Model Row	Model Column (fig.16)	Model Layer	Well or pond (fig. 18)	Water level (ft) Measured	Multiple of hydraulic conductivity 0.2	0.5	1.0	2.0	5.0
54	56	1	PWW-521	89.77	95.97	92.38	88.64	84.13	73.83
56	52	1	CDW-125	79.66	115.72	97.86	89.74	83.88	74.65
57	84	1	PWW-519	46.61	76.73	53.40	42.69	35.98	30.08
58	58	1	PWW-431	75.15	103.93	87.44	80.19	74.89	65.84
59	63	1	PWW-512	69.78	92.20	76.24	69.07	63.73	55.20
61	87	1	PWW-368	28.98	62.95	40.77	30.64	24.38	19.25
61	93	1	BHW-293	25.22	47.94	29.04	19.65	13.74	9.32
63	56	1	PWW-430	61.56	80.64	70.65	66.69	64.19	59.97
64	37	1	CDW-122	76.10	96.09	85.35	80.67	77.85	75.77
64	53	1	CDW-86	64.80	78.57	69.86	66.41	64.37	61.30
65	36	1	CDW-201	78.14	88.56	80.08	76.65	74.70	73.43
65	57	1	PWW-236	55.71	77.16	65.45	60.72	57.88	54.02
66	53	1	CDW-85	62.84	74.97	65.69	62.02	59.99	57.57
66	55	1	PWW-369	56.02	64.51	58.23	56.13	55.18	53.57
66	61	1	PWW-238	55.51	68.53	58.39	54.20	51.48	47.62
66	64	1	WFW-296	45.48	48.20	46.50	45.55	44.55	42.11
68	57	1	PWW-237	51.09	63.98	55.68	52.64	51.12	49.23
69	61	1	WFW-295	45.81	53.67	47.03	44.37	42.68	40.38
69	64	1	WFW-297	39.49	43.84	40.21	38.75	37.74	36.07
70	57	1	WFW-245	46.21	53.55	47.02	44.75	43.75	42.82
70	79	1	WFW-211	16.49	28.51	20.95	18.25	16.88	15.93
8	73	1	BARTLETT POND	6.53	3.65	3.38	3.13	2.90	2.71
16	78	1	FRESH POND	14.24	17.95	15.83	14.81	14.22	13.82
20	75	1	BEAVER POND	20.66	40.94	36.55	34.29	32.48	30.41
20	81	1	SHALLOW POND	31.19	41.43	30.42	23.79	18.99	15.25
21	33	1	LITTLE MUDDY POND	108.70	166.72	122.43	101.29	86.79	73.11
21	57	1	RUSSELL MILL POND	51.79	58.04	58.19	58.32	57.97	55.38
21	74	1	ISLAND POND	42.28	40.15	40.12	40.03	39.81	39.11
24	43	1	BRIGGS RESERVOIR	87.41	127.54	101.09	90.35	80.80	69.52
24	48	1	COOKS POND	87.08	133.42	98.78	86.24	76.30	65.60
24	87	1	LILLY POND	11.09	24.73	16.05	11.33	7.87	5.28
28	41	1	MICAJAH POND	108.20	156.74	121.05	105.30	92.62	78.78
28	58	1	ISLAND POND	88.79	137.02	104.28	89.47	78.54	65.86
28	83	1	MOREY POND	48.74	65.23	52.38	41.67	31.08	21.61
30	93	1	BLACK POND	4.43	0	0	0	0	0
31	20	1	UNNAMED POND WEST OF CEDAR SWAMP	122.44	151.39	129.10	120.25	115.51	112.50
33	59	1	CROOKED POND	95.78	163.74	119.21	98.32	83.18	66.91
34	89	1	SAVERY POND	26.08	60.36	35.57	24.22	16.88	10.96
37	48	1	WIDGEON POND	108.17	168.04	129.42	111.79	98.39	83.22
38	46	1	CURLEW POND	108.00	161.25	128.06	112.84	100.84	86.75
39	47	1	ROCKY POND	107.52	163.24	128.40	112.43	100.20	86.28
40	82	1	GRASSY POND	51.16	112.20	74.29	56.18	43.79	31.79
41	58	1	COLLEGE POND	103.58	176.98	129.34	106.49	90.06	72.06
42	88	1	HODGES POND	33.52	82.46	51.07	36.52	27.19	19.20
48	26	1	VAUGHN POND	101.81	118.48	107.76	102.97	99.87	97.04

Table 25.--*Measured and simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for multiples of the horizontal hydraulic conductivity of unconsolidated deposits used in the calibrated, steady-state model*--Continued

Model Row	Model Column (fig.16)	Model Layer	Well or pond (fig. 18)	Water level (ft) Measured	Multiple of hydraulic conductivity 0.2	0.5	1.0	2.0	5.0
49	83	1	LITTLE DUCK POND	47.07	94.27	64.51	50.76	41.82	33.41
57	83	1	LITTLE ROCKY POND	46.87	74.47	52.97	43.38	37.45	32.15
59	67	1	UNNAMED POND SOUTH-EAST OF CHARGE POND	57.0	85.65	67.98	60.25	55.11	48.47
59	89	1	HORSE POND	40.64	67.22	42.78	30.93	23.47	17.52
64	50	1	GOLDEN FIELD POND	74.04	97.15	82.18	75.49	71.18	66.10
64	90	1	GOAT PASTURE POND	20.76	42.15	24.62	16.78	12.08	8.59
65	36	1	BATES POND	79.08	92.34	82.63	78.54	76.14	74.51
65	39	1	POND NEAR HUCKLE-BERRY CORNER	72.91	83.00	76.88	74.48	73.06	72.04
65	42	1	POND ON CRANE BROOK	67.63	68.51	68.57	68.65	68.75	68.87
65	89	1	ELLIS POND	16.17	34.69	20.12	13.80	10.08	7.33
77	54	1	UNAMED POND AT INTERSECTION OF I-195 AND I-25	38.83	36.68	35.89	34.93	33.41	28.82
Absolute value of the mean of the water-level residuals[1], in feet					31.67	10.26	0.15	7.08	14.75
Mean of the absolute values of the water-level residuals, in feet					33.08	10.84	3.46	7.80	15.12
Standard deviation of the water-level residuals, in feet					22.53	8.01	4.42	6.39	10.32

Total number of observations = 101.

[1]Water-level residual = Measured water level - simulated water level.

Table 26.--*Measured and simulated ground-water discharge to streams in the Plymouth-Carver aquifer for multiples of the horizontal hydraulic conductivity of unconsolidated deposits from that in the calibrated, steady-state model*

Stream-measurement site (plate 1)	Date of measurement (month-day-year)	Discharge[1] (ft^3/s) Measured	Simulated using multiple of hydraulic conductivity 0.2	0.5	1.0	2.0	5.0
Town Brook at Plymouth upstream upstream of site 2 (01105874)	07-21-86 07-22-86	14.6 15.3	16.8	12.9	9.0	3.8	-3.9
Eel River near Plymouth upstream of site 4 (01105876)	07-21-86	23.2	27.8	25.0	22.7	18.5	10.1
Eel River at Sandwich Road near Plymouth upstream of site 4a	07-22-86	14.9	17.1	15.3	13.4	8.7	-3.2
Eel River tributary near Plymouth upstream of site 4b	07-22-86	7.87	7.2	5.4	3.4	1.0	-2.0
Beaver Brook at White Horse Beach upstream of site 5 (01105878)	07-21-86 07-22-86	12.7 11.8	14.7	15.4	14.7	11.4	-3.4
Indian Brook at Manomet Beach upstream of site 6	07-21-86	1.18	4.9	1.2	-.72	-.72	-.72
Herring River between outlet from Great Herring Pond and Cape Cod Canal between site 8a and 8	07-21-86	-.93	3.9	.41	-.91	-1.1	-1.2
Red Brook near Buzzards Bay upstream of site 13	07-21-86	6.13	12.0	9.7	5.9	-1.1	-22.1
Agawam River at East Wareham upstream of site 16	07-21-86	33.5	33.8	32.9	30.7	26.5	18.2
Wankinco River at East Wareham upstream of site 21	07-21-86	18.6	27.3	24.2	18.7	13.0	0.32
Weweantic River at South Wareham upstream of site 22	07-21-86 07-22-86	81.2 11.9	58.4	54.6	51.0	46.6	39.3
Agawam River between site 16 and the confluence of the Agawam and Wankinco Rivers	07-21-86	2.1	3.6	4.3	5.4	7.6	13.3
Agawam River just upstream of the confluence with Wankinco River, Wareham	07-21-86	35.6	37.3	36.8	36.1	34.0	31.6
Absolute value of the mean of the discharge residuals[2], in feet			3.8	1.7	0.5	3.7	10.8
Mean of the absolute values of the discharge residuals, in feet			3.8	2.5	2.2	4.5	12.4
Standard deviation of the discharge residuals, in feet			3.5	3.0	3.0	4.4	10.2

[1]Negative discharge means that water moves from the stream into the underlying aquifer.

[2]Discharge residual = measured ground-water discharge - simulated ground-water discharge.

Table 27.-- *Measured and simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for multiples of streambed conductance used in the calibrated steady-state model*

Model Row (fig. 16)	Model Column	Model Layer	Well or pond (fig. 18)	Water level, in feet: Measured	Multiple of streambed conductance: 0.1	0.2	1.0	5.0	10.0
8	78	1	PWW-501	5.88	1.26	1.15	0.97	0.93	0.92
19	40	1	PWW-502	81.63	90.52	86.03	81.86	81.23	81.16
19	48	1	PWW-261	74.05	81.52	76.26	70.30	68.76	68.53
20	44	1	PWW-503	77.41	86.44	81.42	76.09	74.87	74.68
22	77	1	PWW-313	38.59	43.01	41.26	39.25	39.68	40.42
23	67	1	PWW-241	67.73	72.14	68.52	64.29	63.69	63.89
23	77	1	PWW-285	36.60	45.22	43.48	41.49	41.98	42.73
24	49	1	PWW-215	81.90	95.74	90.49	84.14	82.25	81.96
24	52	1	PWW-516	77.03	94.09	88.37	81.38	79.37	79.08
24	66	1	PWW-242	72.59	75.76	71.96	67.56	66.94	67.14
24	73	1	PWW-245	57.79	60.76	58.43	55.66	55.28	55.45
25	28	1	PWW-413	123.73	123.57	121.38	119.03	118.44	118.35
25	72	1	PWW-240	71.78	69.95	67.26	63.91	63.30	63.43
26	46	1	PWW-504	99.03	102.73	97.55	90.99	88.87	88.54
27	66	1	PWW-243	79.20	85.76	82.14	77.59	76.49	76.49
28	38	1	PWW-505	118.30	118.83	114.88	110.40	109.18	109.02
28	47	1	PWW-306	101.66	108.46	103.68	97.65	95.72	95.43
28	68	1	PWW-244	87.20	86.40	83.19	78.93	77.82	77.79
29	46	1	PWW-305	102.07	109.59	104.89	98.99	97.13	96.85
30	26	1	PWW-517	123.73	128.35	125.82	122.93	122.15	122.05
30	52	1	PWW-506	98.88	109.44	104.50	97.77	95.40	95.03
30	66	1	PWW-379	82.05	93.47	90.03	85.35	83.96	83.84
34	34	1	PWW-22	120.98	128.20	124.03	119.18	117.93	117.77
34	53	1	PWW-315	102.71	114.26	109.75	103.69	101.59	101.30
35	71	1	PWW-509	70.45	86.67	83.53	78.82	77.19	77.04
36	24	1	CDW-119	114.70	123.14	119.81	115.84	114.79	114.64
37	46	1	PWW-507	112.95	122.95	118.31	112.74	111.13	110.91
38	78	1	PWW-414	64.07	75.50	72.78	68.56	67.18	67.10
39	50	1	PWW-416	108.18	121.64	117.20	111.75	110.02	109.80
40	82	1	PWW-518	52.39	61.84	59.76	56.53	55.64	55.69
41	92	1	PWW-319	21.04	20.67	20.07	19.23	19.17	19.30
42	29	1	CDW-120	92.60	117.13	108.74	98.53	96.12	95.82
42	92	1	PWW-418	22.16	24.23	23.53	22.54	22.47	22.62
44	31	1	CDW-121	103.23	118.69	110.90	102.31	100.42	100.19
44	82	1	PWW-253	46.59	60.12	58.00	54.62	53.65	53.70
46	61	1	PWW-510	98.53	109.06	105.17	99.92	98.20	97.95
46	84	1	PWW-251	43.60	53.56	51.79	49.10	48.46	48.57
47	56	1	PWW-511	101.01	113.80	109.65	104.38	102.72	102.45
49	83	1	PWW-513	47.75	55.35	53.47	50.76	50.14	50.21
51	40	1	BHW-126	99.95	102.32	94.16	87.98	87.84	87.94
51	50	1	CDW-99	98.92	113.83	108.80	103.27	101.79	101.55
51	59	1	PWW-415	91.34	106.36	101.83	96.06	94.10	93.83
53	82	1	PWW-514	48.22	53.64	51.88	49.64	49.21	49.25
53	84	1	PWW-520	47.02	50.29	48.76	46.88	46.67	46.80
54	55	1	CDW-123	83.97	102.25	96.71	89.90	87.60	87.26
54	56	1	PWW-521	89.77	102.77	97.02	88.64	84.65	83.89
56	52	1	CDW-125	79.66	100.57	95.03	89.74	88.58	88.44
57	84	1	PWW-519	46.61	45.63	44.24	42.69	42.66	42.84
58	58	1	PWW-431	75.15	91.74	86.18	80.19	78.80	78.64
59	63	1	PWW-512	69.78	81.07	75.75	69.07	67.34	67.12

Table 27.-- ***Measured and simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for multiples of streambed conductance used in the calibrated steady-state model***

Model Row (fig. 16)	Model Column	Model Layer	Well or pond (fig. 18)	Water level, in feet: Measured	Multiple of streambed conductance 0.1	0.2	1.0	5.0	10.0
61	87	1	PWW-368	28.98	32.94	31.97	30.64	30.57	30.81
61	93	1	BHW-293	25.22	20.44	20.06	19.65	20.18	20.67
63	56	1	PWW-430	61.56	80.64	73.91	66.69	65.03	64.82
64	37	1	CDW-122	76.10	91.62	85.26	80.67	79.73	79.60
64	53	1	CDW-86	64.80	80.37	73.49	66.41	64.87	64.68
65	36	1	CDW-201	78.14	87.40	81.07	76.65	75.81	75.70
65	57	1	PWW-236	55.71	74.68	68.07	60.72	59.05	58.84
66	53	1	CDW-85	62.84	76.22	69.39	62.02	60.32	60.10
66	55	1	PWW-369	56.02	72.83	65.17	56.13	53.89	53.59
66	61	1	PWW-238	55.51	66.72	60.73	54.20	52.81	52.64
66	64	1	WFW-296	45.48	57.35	51.52	45.55	44.67	44.61
68	57	1	PWW-237	51.09	68.26	61.05	52.64	50.72	50.48
69	61	1	WFW-295	45.81	56.17	50.26	44.37	43.35	43.24
69	64	1	WFW-297	39.49	49.59	44.09	38.75	37.91	37.84
70	57	1	WFW-245	46.21	59.54	52.84	44.75	42.87	42.64
70	79	1	WFW-211	16.49	22.52	20.94	18.25	17.14	16.97
8	73	1	BARTLETT POND	6.53	5.69	4.54	3.13	2.96	2.97
16	78	1	FRESH POND	14.24	22.13	19.36	14.81	13.46	13.32
20	75	1	BEAVER POND	20.66	39.74	37.36	34.29	33.67	33.73
20	81	1	SHALLOW POND	31.19	26.46	25.22	23.79	24.87	26.28
21	33	1	LITTLE MUDDY POND	108.70	107.58	104.50	101.29	100.50	100.38
21	57	1	RUSSELL MILL POND	51.79	75.81	67.83	58.32	55.73	55.37
21	74	1	ISLAND POND	42.28	41.84	40.64	40.03	40.00	40.00
24	43	1	BRIGGS RESERVOIR	87.41	100.29	95.67	90.35	88.61	88.29
24	48	1	COOKS POND	87.08	97.63	92.49	86.24	84.34	84.04
24	87	1	LILLY POND	11.09	12.15	11.74	11.33	11.93	12.47
28	41	1	MICAJAH POND	108.20	114.35	110.15	105.30	103.91	103.71
28	58	1	ISLAND POND	88.79	102.17	97.00	89.47	86.70	86.31
28	83	1	MOREY POND	48.74	44.29	42.99	41.67	43.38	44.80
30	93	1	BLACK POND	4.43	0	0	0	0	0
31	20	1	UNNAMED POND WEST OF CEDAR SWAMP	122.44	122.19	121.27	120.25	119.99	119.96
33	59	1	CROOKED POND	95.78	108.39	104.18	98.32	96.25	95.98
34	89	1	SAVERY POND	26.08	26.18	25.37	24.22	24.12	24.30
37	48	1	WIDGEON POND	108.17	121.84	117.31	111.79	110.11	109.89
38	46	1	CURLEW POND	108.00	123.25	118.51	112.84	111.19	110.97
39	47	1	ROCKY POND	107.52	122.90	118.14	112.43	110.71	110.48
40	82	1	GRASSY POND	51.16	61.50	59.43	56.18	55.28	55.33
41	58	1	COLLEGE POND	103.58	115.50	111.63	106.49	104.80	104.54
42	88	1	HODGES POND	33.52	39.51	38.30	36.52	36.21	36.36
48	26	1	VAUGHN POND	101.81	118.49	111.10	102.97	101.06	100.81
49	83	1	LITTLE DUCK POND	47.07	55.35	53.47	50.76	50.14	50.21
57	83	1	LITTLE ROCKY POND	46.87	46.44	44.98	43.38	43.32	43.45
59	67	1	UNNAMED POND SOUTH-EAST OF CHARGE POND	57.0	72.25	67.42	60.25	58.07	57.83
59	89	1	HORSE POND	40.64	32.67	31.91	30.93	31.20	31.68
64	50	1	GOLDEN FIELD POND	74.04	86.02	80.37	75.49	74.57	74.45
64	90	1	GOAT PASTURE POND	20.76	17.82	17.38	16.78	16.84	17.02
65	36	1	BATES POND	79.08	89.33	82.98	78.54	77.70	77.59

Table 27.--*Measured and simulated water levels in observation wells and ponds in the Plymouth-Carver aquifer for multiples of streambed conductance used in the calibrated steady-state model*

Model Row (fig. 16)	Model Column	Model Layer	Well or pond (fig. 18)	Water level, in feet: Measured	Multiple of streambed conductance: 0.1	0.2	1.0	5.0	10.0
65	39	1	POND NEAR HUCKLEBERRY CORNER	72.91	85.04	78.97	74.48	73.42	73.28
65	42	1	POND ON CRANE BROOK	67.63	78.68	72.49	68.65	68.11	68.05
65	89	1	ELLIS POND	16.17	14.80	14.39	13.80	13.77	13.89
77	54	1	UNNAMED POND AT INTERSECTION OF I-195 AND I-25	38.83	41.62	37.64	34.93	34.85	34.91
Absolute value of the mean of the water-level residuals[1], in feet					8.47	4.60	0.15	0.91	0.96
Mean of the absolute values of the water-level residuals, in feet					9.31	6.15	3.46	3.34	3.33
Standard deviation of the water-level residuals, in feet					7.05	5.60	4.42	4.18	4.15

Total number of observations = 101.

[1]Water-level residual = Measured water level - simulated water level.

Table 28.--*Measured and simulated ground-water discharge to streams in the Plymouth-Carver aquifer for multiples of streambed conductance from that in the calibrated steady-state model*

[ft^3, cubic foot per second]

Stream-measurement site (plate 1)	Date of measurement (month-day-year)	Discharge[1] (ft^3) Measured	Multiple of streambed conductance 0.1	0.2	1.0	5.0	10.0
Town Brook at Plymouth upstream of site 2 (01105874)	07-21-86 07-22-86	14.6 15.3	6.3	7.5	9.0	9.5	9.6
Eel River near Plymouth upstream of site 4 (01105876)	07-21-86	23.2	18.0	20.3	22.7	23.2	23.2
Eel River at Sandwich Road near Plymouth upstream of site 4a	07-22-86	14.9	8.8	10.7	13.4	14.4	14.5
Eel River tributary near Plymouth upstream of site 4b	07-22-86	7.87	3.5	3.7	3.4	3.0	2.9
Beaver Brook at White Horse Beach upstream of site 5 (01105878)	07-21-86 07-22-86	12.7 11.8	10.6	12.1	14.7	16.2	16.7
Indian Brook at Manomet Beach upstream of site 6	07-21-86	1.18	-.21	-.44	-.72	-3.1	-5.1
Herring River between outlet from Great Herring Pond and Cape Cod Canal between site 8a and 8	07-21-86	-.93	-.09	-.19	-.91	-3.2	-4.5
Red Brook near Buzzards Bay upstream of site 13	07-21-86	6.13	7.7	7.0	5.9	5.6	5.5
Agawam River at East Wareham upstream of site 16	07-21-86	33.5	25.3	26.5	30.7	33.0	33.4
Wankinco River at East Wareham upstream of site 21	07-21-86	18.6	18.5	19.5	18.7	19.9	19.8
Weweantic River at South Wareham upstream of site 22	07-21-86 07-22-86	81.2 11.9	46.0	48.9	51.0	51.2	51.3

Table 28.--*Measured and simulated ground-water discharge to streams in the Plymouth-Carver aquifer for multiples of streambed conductance from that in the calibrated steady-state model*--Continued

Stream-measurement site (plate 1)	Date of measurement (month-day-year)	Discharge[1] (ft^3) Measured	Discharge[1] (ft^3) Multiple of streambed conductance 0.1	0.2	1.0	5.0	10.0
Agawam River between site 16 and the confluence of the Agawam and Wankinco Rivers	07-21-86	2.1	5.1	5.4	5.4	5.4	5.3
Agawam River just upstream of the confluence with Wankinco River, Wareham	07-21-86	35.6	30.4	31.7	36.1	38.4	38.8
Absolute value of the mean of the discharge residuals[2], in feet			2.8	1.8	.5	.2	.3
Mean of the absolute values of the discharge residuals, in feet			3.6	3.0	2.2	2.7	3.0
Standard deviation of the discharge residuals, in feet			3.8	3.5	3.0	3.4	3.8

[1] Negative discharge means that water moves from the stream into the underlying aquifer.

[2] Discharge residual = measured ground-water discharge - simulated ground-water discharge.

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