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Analysis of Effects of 2003 and Full-Allocation Withdrawals in Critical Area 1, East-Central New Jersey

Open-File Report 2009–1104

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

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Analysis of Effects of 2003 and Full-Allocation Withdrawals in Critical Area 1, East-Central New Jersey

By Frederick J. Spitz

Abstract

Critical Area 1 in east-central New Jersey was mandated in the early 1980s to address large drawdowns caused by increases in groundwater withdrawals. The aquifers involved include the Englishtown aquifer system, Wenonah-Mount Laurel aquifer, and the Upper and Middle Potomac-Raritan-Magothy aquifers. Groundwater levels recovered as a result of mandated cutbacks in withdrawals that began in the late 1980s. Subsequent increased demand for water has necessitated an analysis to determine the effects of full-allocation withdrawals, which supplements an optimization analysis done previously. A steady-state regional groundwater flow model is used to evaluate the effects of 2003 withdrawals and full-allocation withdrawals (7.3 million gallons per day greater than for 2003) on simulated water-levels. Simulation results indicate that the range of available withdrawals greater than full-allocation withdrawals is likely between 0 and 12 million gallons per day. The estimated range of available withdrawals is based on: (1) an examination of hydraulic-heads resulting from each of the two simulations, (2) an examination of differences in heads between these two simulations, (3) a comparison of simulated heads from each of the two simulations with the estimated location of salty groundwater, and (4) a comparison of simulated 2003 water levels to observed 2003 water levels. The results of the simulations also indicate that obtaining most of the available water would require varying the distribution of withdrawals and (or) relaxing the mandated hydrologic constraints used to protect the water supply.

Introduction

In 1983, the decline of water levels in several New Jersey Coastal Plain aquifers due to withdrawals posed a threat of serious adverse effects on the water supply in some areas, including the depletion of the groundwater supply, saltwater intrusion, and reduction of groundwater flow to streams (N.J. Department of Environmental Protection, 1996). In response to these threats to water-resources, the N.J. Department of Environmental Protection (NJDEP) designated two Water Supply Critical Areas where excessive withdrawals create undue stress or long-term adverse effects on the water supply (Hoffman and Lieberman, 2000). Each Critical Area consists of a depleted zone corresponding to the 1983 potentiometric contour 30 ft below the National Geodetic Vertical Datum of 1929 (NGVD 29) for each of four affected aquifers and a 3-mile-wide threatened margin surrounding the depleted zone (Hoffman and Lieberman, 2000). The extent of Critical Area 1 in all figures of this report is a "composite" that includes the largest surface area of the depleted zones and threatened margins in the affected aquifers in Monmouth, Middlesex, and Ocean Counties. The four affected aquifers are the Wenonah-Mount Laurel aquifer, Englishtown aquifer system, Upper Potomac-Raritan-Magothy aquifer, and Middle Potomac-Raritan-Magothy aquifer, in order of increasing depth.

Groundwater levels recovered as a result of mandated cutbacks in withdrawals begun in the late 1980s. This recovery is documented in detail in Spitz and others (2008). Observed potentiometric surfaces for these aquifers in 2003 (dePaul and others, 2008) and locations of withdrawals are shown in figure 1. The extent of Critical Area 1 is also shown in this figure. Subsequent increased demand for water in Critical Area 1 has necessitated an analysis of the potential hydraulic effects of full-allocation withdrawals.

In this study, conducted by the U.S. Geological Survey (USGS) in cooperation with the NJDEP, the USGS Regional Aquifer System Analysis (RASA) model (Voronin, 2004) is used to simulate steady-state groundwater flow in Critical Area 1. Minor changes were made to the revised RASA model input data (Spitz and others, 2007) including conversion to a more recent version of the MODFLOW finite-difference ground-water flow model developed by the USGS (Harbaugh and others, 2000). The assumption that steady-state flow simulations provide an adequate representation of the flow system is based on cross sections showing that water-level altitudes in the four aquifers (Spitz and others, 2008, figs. 3a–6a) remained relatively stable from 1998 until 2003. Two withdrawal conditions are tested using the model: 2003 withdrawals and full-allocation withdrawals. Model results are presented as maps of hydraulic heads and head differences for these aquifers that compare the effects of 2003 and full-allocation withdrawals. Simulation results for each aquifer unit are evaluated in regard to the mandated hydrologic conditions for Critical Area protection: that the simulated

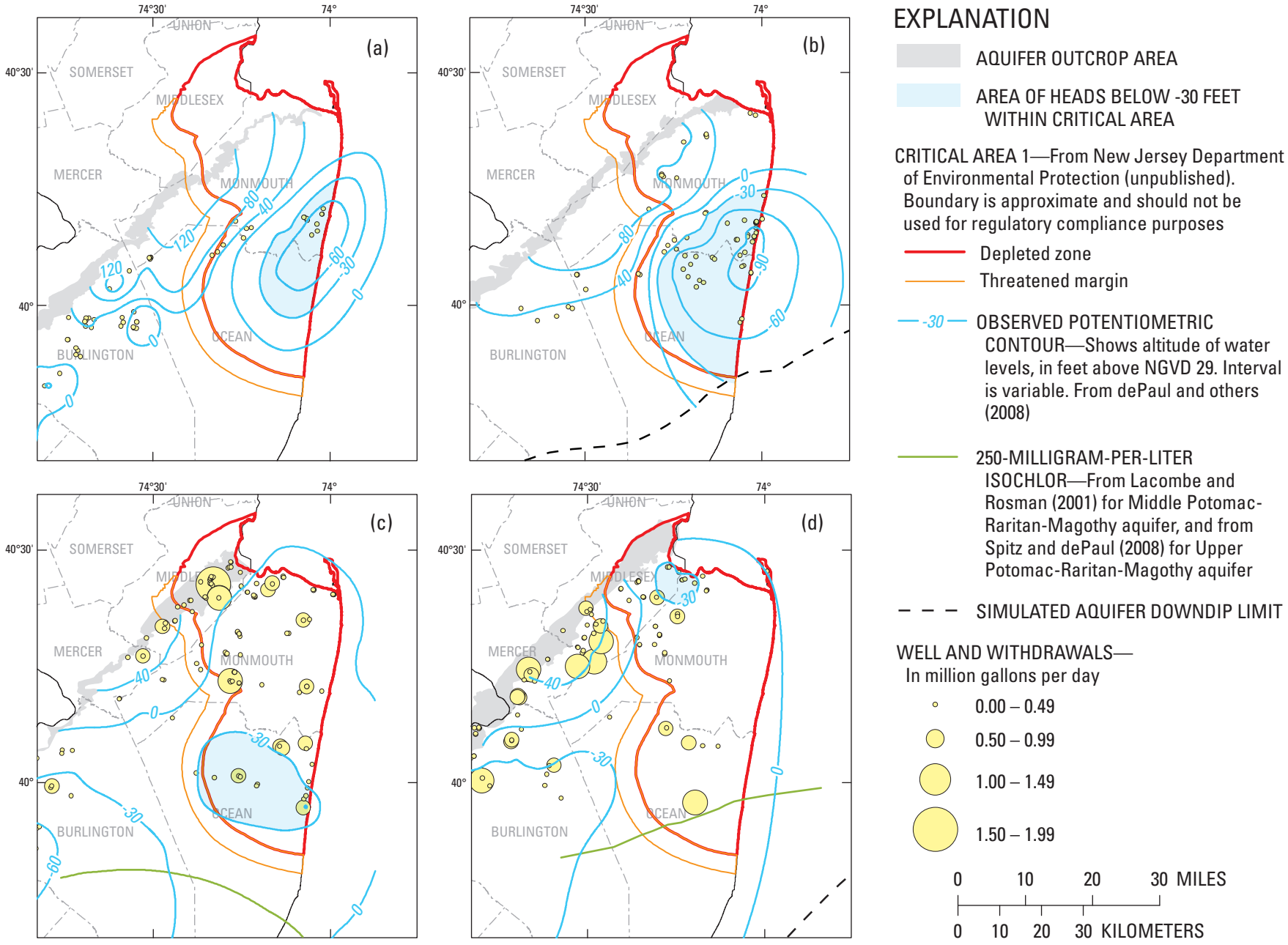

Figure 1. Observed potentiometric surface and distribution of withdrawals in 2003 in the (a) Wenonah-Mount Laurel aquifer, (b) Englishtown aquifer system, (c) Upper Potomac-Raritan-Magothy aquifer, and (d) Middle Potomac-Raritan-Magothy aquifer in Critical Area 1, east-central New Jersey.

-30-ft potentiometric contour not extend beyond the landward boundary of the depleted zone and (or) be at least 5 mi updip from the 250-mg/L isochlor.

The assumption that steady-state flow simulations provide an adequate representation of the flow system is based on cross sections showing that water-level altitudes in the four aquifers (Spitz and others, 2008, figs. 3a–6a) remained relatively stable from 1998 until 2003. Also, the 2003 and full-allocation withdrawal conditions do not cause appreciable drawdowns at the model boundaries.

This analysis is similar to that done for Critical Area 2 in southern New Jersey (Spitz and dePaul, 2008); that work can be consulted for additional details regarding the approach used and associated limitations. The optimization study of Critical Area 1 (Spitz and others, 2008) also can be consulted for background information on Critical Area 1. In that study, the maximum available managed withdrawals were estimated to be about 5 to 20 Mgal/d above 2003 withdrawals, but maximum available withdrawals greater than full-allocation levels were not evaluated. This study documents the simulated effects of full-allocation withdrawals and evaluates available withdrawals greater than full-allocation levels.

This report presents the results of an analysis of the effects of two selected withdrawal conditions within Critical Area 1 in east-central New Jersey. An existing regional groundwater-flow model is used to simulate the effects of 2003 and full-allocation withdrawals on water levels and in relation to saltwater intrusion within Critical Area 1. The results of the two simulations are compared to each other, to observed water levels for 2003, and to hydrologic criteria mandated for the Critical Area.

Evaluation of Effects of 2003 and Full-Allocation Withdrawals

In a manner similar to that of the Critical Area studies mentioned above, the USGS RASA model (Voronin, 2004) is used to simulate groundwater flow. The Wenonah-Mount Laurel aquifer, Englishtown aquifer system, Upper Potomac-Raritan-Magothy aquifer, and Middle Potomac-Raritan-Magothy aquifer in Critical Area 1 are hydraulically connected to aquifers and confining units beyond the extent of Critical Area 1. Therefore, to examine the effect of withdrawals on these aquifers in this area, the larger hydrologic system and associated stresses must be considered. Accordingly, a regional groundwater-flow model of the entire New Jersey Coastal Plain was used in this study. A brief description of this model is provided by Spitz and dePaul (2008). Results of simulations made using this model are provided in the following sections.

Two steady-state simulations are used to assess the effects of withdrawals on water levels in Critical Area 1 and incorporate: (1) 2003 withdrawals and (2) full-allocation withdrawals. The 2003 withdrawal simulation included 2003 withdrawals everywhere in the model. The full-allocation simulation included 2003 withdrawals from wells outside the critical area and full-allocation withdrawals from wells in the depleted zone and threatened margin of Critical Area 1 (Diane Zalaskus, N.J. Department of Environmental Protection, written commun., 2008). As the result of discussions with the NJDEP, the full-allocation simulation in this study differs from the full-allocation simulation done previously for Critical Area 2 (Spitz and dePaul, 2008) in that the Critical Area 2 full-allocation simulation included 2003 withdrawals from wells outside the critical area depleted zone and included full-allocation withdrawals only from wells in the depleted zone (and not from wells in the threatened margin).

Model results of both simulations are evaluated in terms of satisfying the mandated hydrologic conditions for Critical Area protection (New Jersey Administrative Code, 2005). Specifically, these conditions pertain to the location of the -30-ft potentiometric contour in each aquifer. For Critical Area protection, the -30-ft potentiometric contour should (1) not extend beyond the landward boundary of the depleted zone and (or) (2) be at least 5 mi updip from the 250-mg/L isochlor in the aquifers. Additional conditions considered relevant to Critical Area protection are evaluated below, including the changes in simulated heads and changes in the area within the depleted zone of heads below -30 ft resulting from the differences between the 2003 and full-allocation withdrawal conditions.

Results are also discussed in relation to the landward movement of the 250-mg/L isochlor, a line of equal chloride concentration, which is used to define saltwater intrusion. Drawdown at the downdip 250-mg/L isochlor, as well as the proximity to the -30-ft potentiometric contour, in the Upper and Middle Potomac-Raritan-Magothy aquifers are an indication of the susceptibility to saltwater intrusion. The locations of the isochlors in the aquifers have been modified from Gill and Farlekas (1976) and Lacombe and Rosman (2001) on the basis of water-quality data collected by dePaul and others (2008). These isochlors are mapped with limited areal extent. No data are available to indicate that saltwater intrusion is a major concern in the Wenonah-Mount Laurel aquifer and Englishtown aquifer system in Critical Area 1.

2003 Withdrawals

The RASA model is used to simulate 2003 withdrawals from all wells in the New Jersey Coastal Plain. These withdrawals from wells in Critical Area 1 are shown in figure 1 and listed in table 1. Simulated steady-state potentiometric surfaces from the RASA model based on 2003 withdrawals are shown in figure 2. The simulated -30-ft potentiometric contour for the Wenonah-Mount Laurel aquifer, Englishtown aquifer system, and Upper Potomac-Raritan-Magothy aquifer are located within the boundary of the depleted zone. For these aquifers, the areas in the depleted zone of heads below -30 ft range from 63.5 mi^2 (in the Wenonah-Mount Laurel aquifer) to 142 mi^2 (in the Upper Potomac-Raritan-Magothy aquifer). There is no area of heads below -30 ft in the Middle

Table 1. Withdrawals from, and model locations of, production wells in the depleted zone and threatened margin of Critical Area 1, east-central New Jersey.

[Depths are below land surface; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; BWA, Bureau of Water Allocation; ft, feet; Mgal/d, million gallons per day; WD, Water Department; WC, Water Company; WSC, Water Supply Company; NJ, New Jersey; Co, Company; Inc, Incorporated; ---, not available]

Well owner	Local well name	Well depth (ft)	Depth to top of open interval[1] (ft)	Depth to bottom of open interval (ft)	NJDEP			USGS				
					BWA permit number	Well permit number	Full allocation[2] (Mgal/d)	Local well number[3]	Model layer[4]	Model row	Model column	2003 withdrawal (Mgal/d)
Atlantic Highlands Borough WD	PW 1	593	519	582	5325	49-00049	0.020	250006	8	35	232	0.000
	PW 4	550	510	543	5325	29-10478	0.295	250496	8	35	232	0.253
	Atlantic Highlands PW 5	548	506	548	5325	29-11230	0.009	250513	8	35	232	0.000
	Atlantic Highlands PW 6	251	198	248	5325	29-25383	0.000	250714	7	36	232	0.194
Avon By The Sea Borough WD	Avon PW 4	1,165	1,105	1,165	5132	29-07461	0.085	250013	8	59	213	0.085
	Avon PW 1	504	424	504	5132	49-00017	0.039	250014	6	59	213	0.031
	PW 2	501	419	501	5132	49-00018	0.031	250011	6	59	213	0.035
Bamm Hollow Country Club	Bhcc Irr 1	600	527	600	2151P	29-05164	0.041	250303	8	35	219	0.016
BadisheProduct	Ind 2	288	248	288	2307P	28-05896	0.183	230300	9	10	193	0.218
	Ind 3	276	230	276	2307P	28-10192	0.183	230492	9	10	193	0.075
Battleground Country Club	Battleground Cc Irr	569	539	569	2327P	28-06114	0.011	250220	8	30	195	0.015
Belmar Borough WD	PW 14	550	---	---	5138	29-10462	0.037	250497	7	60	211	0.010
	2 Elec(10)	581	---	---	5138	49-00023	0.126	250018	7	60	211	0.057
	PW 13	605	555	605	5138	29-06956	0.317	250023	7	60	211	0.225
	Belmar 3 Elec(12)	594	563	594	5138	29-00045	0.000	250016	7	60	211	0.089
Brick Township MUA	Forg Pond 9-73	1,779	1,441	1,779	5172	29-06841	0.221	290045	9	63	193	0.191
	Fp 10	1,832	1,607	1,827	5172	29-07791	0.209	290046	8	63	193	0.221
	Fp 11	1,800	1,565	1,800	5172	29-08356	0.709	290595	8	64	193	0.722
	PW 12	1,860	1,700	1,860	5172	29-12006	0.741	290779	8	63	193	0.835
Brielle Borough WD	Brielle PW 3	820	770	820	5279	29-05292	0.148	250028	7	64	201	0.139
	Brielle PW 2	750	690	750	5279	29-00069	0.081	250030	7	64	203	0.105
Brock Farms Inc.	Irr 1	700	---	---	MN0020	48-00197	0.071	250741	8	34	190	0.047
Duhernal Water Co	Duhernal Bf	300	240	300	2323P	48-00208	0.927	230171	9	13	205	0.572
	Ind Af	296	236	296	2323P	48-00213	0.536	230127	9	13	203	0.969
Englishtown Borough WD	Englishtown PW 2	384	363	384	5191	28-05400	0.227	250056	8	25	196	0.181
	Englishtown PW 3	621	540	621	5191	28-21488	0.019	250728	9	25	196	0.000
Farmingdale Borough WD	PW 4	470	410	470	5126	29-06088	0.010	250064	7	48	202	0.011
	Farmingdale PW 3	460	420	460	5126	29-04386	0.150	250063	7	48	202	0.000
Flock And Sons	Irr	682	649	677	MN0068	29-03972	0.030	250045	8	38	212	0.114
Freehold Borough WD	PW 3	567	468	567	5059	29-04419	0.219	250099	8	32	200	0.220
	PW 7	884	771	884	5059	29-13480	0.296	250561	9	32	200	0.300
	PW 6	943	835	943	5059	29-11217	0.269	250503	9	31	200	0.190
	PW 4	583	529	583	5059	29-05680	0.125	250098	8	32	200	0.075
	WaterWorks Rd 8	229	136	224	5059	29-25736	0.000	250730	7	32	200	0.358
	Well 9	208	161	208	5059	29-43832	0.000	250858	7	32	200	0.202

Table 1. Withdrawals from, and model locations of, production wells in the depleted zone and threatened margin of Critical Area 1, east-central New Jersey.—Continued

[Depths are below land surface; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; BWA, Bureau of Water Allocation; ft, feet; Mgal/d, million gallons per day; WD, Water Department; WC, Water Company; WSC, Water Supply Company; NJ, New Jersey; Co, Company; Inc, Incorporated; ---, not available]

Well owner	Local well name	Well depth (ft)	Depth to top of open interval[1] (ft)	Depth to bottom of open interval (ft)	NJDEP			USGS				
					BWA permit number	Well permit number	Full allocation[2] (Mgal/d)	Local well number[3]	Model layer[4]	Model row	Model column	2003 withdrawal (Mgal/d)
Freehold Township WD	7-74	580	478	575	5009	29-07494	0.096	250103	8	31	200	0.022
	Freehold PW 8	671	616	671	5009	29-11033	0.129	250502	8	37	198	0.033
	PW 9	676	617	676	5009	29-13609	0.157	250551	8	39	196	0.043
	10 Jackson Mill Rd	697	633	691	5009	29-14513	0.394	250722	8	39	195	0.182
	Koenig Lane T Plant 13	680	584	673	5009	29-24703	0.234	250726	8	37	198	0.118
	PW 3	212	150	212	5009	29-05302	0.752	250105	7	31	200	0.299
	Edwards Dr Plant 12	211	149	206	5009	29-24425	0.112	250727	7	31	200	0.152
	PW 14	993	927	988	5009	29-33928	0.000	250774	8	38	195	1.110
	PW 15	983	918	978	5009	29-33929	0.000	250775	8	38	195	0.320
	Jackson Mills T Plant 11	1,002	918	997	5009	29-24426	0.000	250725	9	39	195	0.422
Giamarese Farm	Irr 1	30	---	---	MI0008	48-00243	0.017	231257	9	5	200	0.001
Gordons Corner WC	PW 10	800	740	800	5185X	29-10864	0.309	250452	9	27	202	0.456
	Gordons 12	761	649	756	5185X	29-14303	0.309	250711	9	28	199	0.153
	PW 4	810	741	810	5185X	29-05548	0.309	250249	9	27	202	0.175
	PW 6	712	592	708	5185X	29-07402	0.309	250231	9	24	203	0.387
	Gordons PW 5	670	580	670	5185X	29-06353	0.309	250230	9	24	203	0.279
	Gordons Corner 9-A River Rd	556	446	551	5185X	29-17817	0.218	250724	8	29	207	0.085
	Gordons PW 7	594	524	594	5185X	29-05790	0.218	250244	8	30	206	0.162
	PW 11	576	479	576	5185X	29-12877	0.218	250564	8	29	206	0.187
Hominy Hills Golf Club	Glf Clb 2-1963	706	686	706	2180P	29-04068	0.024	250037	8	39	206	0.004
International Flavors & Frags	Ind 3R	316	277	316	2179P	29-08092	0.070	250456	8	24	226	0.000
	Ind 1	328	298	328	2179P	29-00126	0.070	250423	8	24	226	0.000
	Iff 2R	312	266	312	2179P	29-12732	0.070	250514	8	24	226	0.000
Jackson Township MUA	PW 3	559	513	559	5075	29-03797	0.069	290228	7	48	185	0.094
	PW 1	557	511	557	5075	29-03574	0.088	290229	7	50	188	0.062
Keansburg MUA	Keansburg PW 5A	350	290	350	5280	29-0129-7	0.827	250195	8	26	227	0.459
	PW 3	348	308	348	5280	49-00047	0.069	250196	8	26	228	0.122
	PW 6	362	302	362	5280	29-05333	0.000	250191	8	26	227	0.000
Keyport Borough WD	8 Perry St	555	500	555	5267	29-13329	0.200	250562	9	22	220	0.000
	Keyport PW 7	364	304	354	5267	29-08379	0.481	250197	8	22	220	0.184
Kid International	Ind 4-Deep	885	831	885	2064P	29-03492	0.048	250062	8	49	202	0.000
Knob Hill Country Club	1-74	710	465	495	2174P	28-08484	0.099	250457	8	27	192	0.016

Table 1. Withdrawals from, and model locations of, production wells in the depleted zone and threatened margin of Critical Area 1, east-central New Jersey.—Continued

[Depths are below land surface; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; BWA, Bureau of Water Allocation; ft, feet; Mgal/d, million gallons per day; WD, Water Department; WC, Water Company; WSC, Water Supply Company; NJ, New Jersey; Co, Company; Inc, Incorporated; ---, not available]

Well owner	Local well name	Well depth (ft)	Depth to top of open interval[1] (ft)	Depth to bottom of open interval (ft)	NJDEP			USGS				
					BWA permit number	Well permit number	Full allocation[2] (Mgal/d)	Local well number[3]	Model layer[4]	Model row	Model column	2003 withdrawal (Mgal/d)
Lakewood Township MUA	Lakewood PW 3	741	673	741	5079	29-05110	0.131	290433	7	62	187	0.085
	Lakewood PW 1	817	752	817	5079	29-05721	0.062	290430	7	63	185	0.084
	Lakewood PW 7	1,625	1,410	1,620	5079	29-09259	0.464	290588	9	59	190	0.444
Lavallette Borough WD	PW 3	1,808	1,120	1,180	5136	3300001	0.065	290452	7	77	188	0.000
Marlboro S Hosp	Institutional 12	593	508	593	5384	29-00073	0.008	250259	8	28	210	0.000
	Institutional 15	810	730	810	5384	29-05023	0.061	250262	9	28	211	0.017
Marlboro Township MUA	1-Prod	716	647	716	5055	29-06360	0.516	250269	9	26	210	0.500
	4A-Prod	720	638	720	5055	29-12777	0.343	250543	9	26	210	0.412
	3-Prod	710	624	710	5055	29-11251	0.330	250549	9	25	211	0.235
	2-Prod	700	632	698	5055	29-06361	0.328	250268	9	26	210	0.090
Matawan Borough WD	Matawan PW 3	271	231	271	5320	29-01731	0.258	250284	8	20	216	0.236
	PW 4	266	220	266	5320	29-05288	0.288	250283	8	20	216	0.283
Middlesex Water Co	Tamarack 1-75	107	87	107	2209P	28-08704	0.084	230058	9	6	200	0.002
Navesink, C C	1-78	615	551	612	2169P	29-09335	0.064	250459	8	38	227	0.040
Nestle Co	Ind 1	607	557	607	2034P	49-00006	0.529	250068	8	36	199	0.687
	Ind 2	614	564	614	2034P	29-01797	0.106	250069	8	36	200	0.013
	Ind 3	650	576	650	2034P	29-05963	0.142	250070	8	35	199	0.000
NJ/American WC	Aberdeen PW 3	425	345	425	5018X	29-05350	0.173	250288	8	25	217	0.000
	PW 2	354	316	354	5018X	29-03818	0.173	250293	8	24	217	0.000
	PW 4	372	322	372	5018X	29-10810	0.062	250499	8	25	217	0.000
	Aberdeen PW 1	414	341	414	5018X	29-03729	0.062	250292	8	25	217	0.000
NJ/American WC	Aldrich Wc 4/Htmua 4	550	363	550	5078X	29-05346	0.344	250165	7	50	193	0.375
	Aldrich PW 2	440	354	440	5078X	29-03105	0.089	250168	6	48	195	0.214
	H-1 Yellow Brick Rd[5]	860	---	---	5078X	29-07784	0.243	250493	8	46	201	0.243
	Aldrich Wc 3/Htmua	396	336	396	5078X	29-04381	0.089	250166	6	47	194	0.000
NJ/American WC	PW 7	129	118	129	5052	28-01612	0.237	230100	8	14	195	0.198
	Jamesburg 6	120	99	120	5052	28-01426	0.326	230098	8	14	195	0.303
NJ/American WC	Lakewood PW 6	582	520	582	5078X	29-03324	0.264	290450	7	53	189	0.330
	Lakewood PW 8	758	600	758	5078X	29-04834	0.264	290438	7	56	186	0.221
	Lakewood PW 10	1,607	1,357	1,602	5078X	29-06549	0.767	290440	9	56	187	0.820
	Lakewood PW 9	698	569	698	5078X	29-05496	0.264	290449	7	56	191	0.275
	Lakewood PW 7	757	697	757	5078X	29-04304	0.264	290434	7	59	185	0.275
NJ/American WC	Jumping Br 4	1,065	1,013	1,065	5018X	29-00137	0.372	250334	8	55	211	0.000
	1 Gondola Rsvr	1,154	999	1,149	5018X	29-15170	0.372	250721	8	55	208	0.246

Table 1. Withdrawals from, and model locations of, production wells in the depleted zone and threatened margin of Critical Area 1, east-central New Jersey.—Continued

[Depths are below land surface; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; BWA, Bureau of Water Allocation; ft, feet; Mgal/d, million gallons per day; WD, Water Department; WC, Water Company; WSC, Water Supply Company; NJ, New Jersey; Co, Company; Inc, Incorporated; ---, not available]

Well owner	Local well name	Well depth (ft)	Depth to top of open interval[1] (ft)	Depth to bottom of open interval (ft)	NJDEP			USGS				
					BWA permit number	Well permit number	Full allocation[2] (Mgal/d)	Local well number[3]	Model layer[4]	Model row	Model column	2003 withdrawal (Mgal/d)
	Jumping Br 6	1,080	1,000	1,075	5018X	29-11335	0.372	250501	8	55	211	0.811
NJ/American WC	[6]Bay Head 12	834	750	834	5062X	49-00002	0.128	290005	7	70	200	0.073
	Bay Head 6	818	778	818	5062X	29-00087	0.052	290006	7	70	200	0.131
	Mantoloking 17	1,369	1,263	1,368	5062X	29-03142	0.052	290504	8	73	197	0.000
Old Bridge MUA	11-1972	120	80	120	5340	28-07470	0.448	230145	8	15	206	0.363
	Browntown 3	480	435	480	5340	29-04997	0.738	230146	9	18	209	0.739
	Browntown 4	475	425	475	5340	29-04998	0.409	230147	9	18	209	0.225
	PW R6	355	255	350	5340	28-20449	0.095	231158	9	15	206	0.116
	PW 12	337	230	337	5340	28-14095	0.202	230782	9	15	206	0.283
	Browntown 1	249	199	249	5340	49-29698	1.130	230142	8	18	209	1.166
	Browntown 2	250	190	248	5340	29-03635	0.851	230135	8	18	209	1.161
	10-1972	120	90	120	5340	28-07471	0.348	230156	8	15	206	0.077
Parkway WC	Parkway 1 A	649	594	644	5184	29-16728	0.062	250710	7	59	195	0.062
Perth Amboy City	Ranney Collector 1	66	51	66	5006	28-18659	3.607	231271	8	13	209	2.572
	Runyon PW-6R	85	60	80	5006	28-32915	0.322	231396	8	13	210	0.282
	PW 7	82	67	82	5006	29-12352	1.367	230571	8	14	211	1.798
	PW 5	80	50	80	5006	28-05579	0.501	230195	8	13	210	0.439
	Runyon 8R	85	70	85	5006	29-12353	0.984	230735	8	14	210	0.329
Point Pleasant Borough WD	Pt Pleasant PW 3	798	748	798	5150	49-00075	0.159	290532	7	67	200	0.159
	Pt Pleasant PW 5	1,342	1,256	1,342	5150	29-03345	0.974	290531	8	67	199	0.868
Red Bank Borough	Red Bank PW6	705	605	700	5085	29-49204	0.022	250823	8	40	223	0.025
	4-75/Rb 5	769	668	759	5085	29-07941	0.999	250360	8	41	225	0.230
Rumson Country Club	Irr 2	333	268	333	2293P	29-04513	0.041	250365	7	43	228	0.030
Sayreville Borough Water Dept	PW S	286	213	286	5313	29-10499	0.360	230554	9	13	218	0.360
	Q-1973	136	78	136	5313	29-06767	0.244	230403	8	13	218	0.000
	PW R	111	70	111	5313	29-10500	0.244	230549	8	13	218	0.000
	Sayreville PW T	137	102	132	5313	29-11861	0.244	230569	8	13	217	0.000
	Morgan P	288	254	288	5313	29-05352	0.360	230401	9	14	218	0.000

Table 1. Withdrawals from, and model locations of, production wells in the depleted zone and threatened margin of Critical Area 1, east-central New Jersey.—Continued

[Depths are below land surface; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; BWA, Bureau of Water Allocation; ft, feet; Mgal/d, million gallons per day; WD, Water Department; WC, Water Company; WSC, Water Supply Company; NJ, New Jersey; Co, Company; Inc, Incorporated; ---, not available]

Well owner	Local well name	Well depth (ft)	Depth to top of open interval[1] (ft)	Depth to bottom of open interval (ft)	NJDEP			USGS				
					BWA permit number	Well permit number	Full allocation[2] (Mgal/d)	Local well number[3]	Model layer[4]	Model row	Model column	2003 withdrawal (Mgal/d)
Schweitzer, P J	Ind 12	280	210	280	2348P	28-12880	0.804	230568	9	13	205	0.724
	Ind 10	73	62	72	2348P	28-10177	0.455	230493	8	12	204	0.208
	Ind 11	63	53	63	2348P	28-10685	0.548	230522	8	12	205	0.259
	Ind 4R	59	49	59	2348P	28-03886	0.951	230461	8	12	205	0.336
	Ind 3R	68	58	68	2348P	28-03670	0.749	230459	8	12	204	0.287
	Ind 9	63	53	63	2348P	28-03887	0.466	230460	8	12	205	0.195
	Ind 1R	275	235	275	2348P	28-01955	0.062	230456	9	13	204	0.000
	Ind 8	278	226	276	2348P	48-00193	0.742	231389	9	13	205	0.728
	Ind 5R	---	---	---	2348P	28-39618	0.216	231344	8	13	204	0.000
	Ind 6	73	53	73	2348P	48-00003	0.000	230457	8	12	204	0.414
Sea Girt Borough WD	Sea Girt PW 5	710	660	710	5237	29-04102	0.011	250374	7	64	206	0.015
Shorelands WC	W Keansburg 4	690	635	690	5066	29-05942	0.217	250153	9	26	222	0.239
	W Keansburg 6	712	---	---	5066	29-13277	0.245	250545	9	26	222	0.271
	W Keansburg 3	430	400	430	5066	29-04207	0.474	250154	8	26	222	0.633
	W Keansburg 2	352	312	352	5066	29-03096	0.454	250112	8	25	224	0.506
	W Keansburg 1	366	326	366	5066	29-02400	0.418	250111	8	25	224	0.443
	W Keans 5	700	650	700	5066	29-0929-5	0.283	250467	9	26	221	0.236
South River Borough WD	Radial Collector	33	16	33	5171	48-00343	0.082	231262	8	11	208	0.021
	PW 6	213	155	208	5171	28-11524	0.187	230551	9	10	208	0.232
	PW 2	198	173	198	5171	28-00332	0.006	230434	9	11	208	0.003
	South River PW 5	187	132	182	5171	28-09722	0.460	230438	9	10	209	0.386
Spotswood WD	PW 3	91	64	78	5177	28--07928	0.140	230442	8	12	200	0.029
	PW 5	97	83	97	5177	28-10465	0.277	230494	8	13	202	0.290
	PW 4F	287	198	282	5177	28-09559	0.136	230499	9	13	203	0.135
Spring Lake Borough WD	PW 1	711	631	711	5089	49-00014	0.009	250383	7	63	208	0.000
	PW 2	707	640	700	5089	49-00015	0.077	250384	7	63	208	0.058
	PW 4	670	600	670	5089	29-04721	0.180	250386	7	61	210	0.138
Spring Lake Heights Borough WD	PW 1	600	570	600	5266	29-00180	0.040	250387	6	61	207	0.000
	Spring Lake Hgts PW 4	564	485	561	5266	29-07506	0.040	250391	6	62	209	0.000
	Spring Lake Hgts PW 2	711	660	711	5266	29-00398	0.111	250389	7	61	207	0.108
	PW 3	680	630	680	5266	29-05075	0.104	250388	7	62	207	0.083
United Water NJ	Lambs Rd 1	641	585	641	5080	21-07184	0.064	250214	8	30	191	0.000
	PW 2	642	505	636	5080	28-14142	0.064	250705	8	28	191	0.054

Table 1. Withdrawals from, and model locations of, production wells in the depleted zone and threatened margin of Critical Area 1, east-central New Jersey.—Continued

[Depths are below land surface; NJDEP, New Jersey Department of Environmental Protection; USGS, U.S. Geological Survey; BWA, Bureau of Water Allocation; ft, feet; Mgal/d, million gallons per day; WD, Water Department; WC, Water Company; WSC, Water Supply Company; NJ, New Jersey; Co, Company; Inc, Incorporated; ---, not available]

Well owner	Local well name	Well depth (ft)	Depth to top of open interval[1] (ft)	Depth to bottom of open interval (ft)	NJDEP			USGS				
					BWA permit number	Well permit number	Full allocation[2] (Mgal/d)	Local well number[3]	Model layer[4]	Model row	Model column	2003 withdrawal (Mgal/d)
United Water NJ	Toms River PW 30	1,875	1,700	1,875	5000X	33-10224	1.724	290626	9	70	177	1.447
Wall Township WD	Imperial 3	455	425	455	5149	29-09107	0.034	250465	7	57	209	0.009
	Rt 34	649	549	649	5149	29-05289	0.135	250441	7	55	205	0.194
	Imperial 2	662	627	657	5149	49-00032	0.060	250442	7	57	209	0.085
	West Belmar	575	440	575	5149	29-02868	0.039	250440	6	60	210	0.018
	Allenwood 1	[7]757	[8]689	740	5149	29-02869	0.115	250428	7	60	204	0.146
	Rosehill 2A	456	421	451	5149	29-17963	0.192	250698	6	56	209	0.063
	Allenwood 2	710	658	710	5149	29-02870	0.149	250427	7	60	203	0.196
	Imperial 1	465	435	465	5149	29-02871	0.078	250443	6	57	209	0.031

[1]Model layer is assigned on the basis of aquifer if open-interval data are not available.

[2]Annual current base allocation (Diane Zalaskus, NJDEP, written commun., 2008). Prorated on the basis of 2001–03 reported use; therefore, value is based on multiple years.

[3]Number of wells associated with BWA permit is based on USGS and NJDEP water-use data.

[4]Certain model cells may contain more than one well. Layer 6 is the Wenonah-Mount Laurel aquifer, layer 7 is the Englishtown aquifer system, layer 8 is the Upper Potomac-Raritan-Magothy aquifer, and layer 9 is the Middle or Undifferentiated Potomac-Raritan-Magothy aquifer.

[5]Well I-975/Yellow Brk Well in Spitz and others (2008).

[6]Well Bay Head 5 in Spitz and others (2008).

[7]Well depth corrected from 740 ft shown in Spitz and others (2008).

[8]Depth to top of open interval corrected from 623 ft shown in Spitz and others (2008).

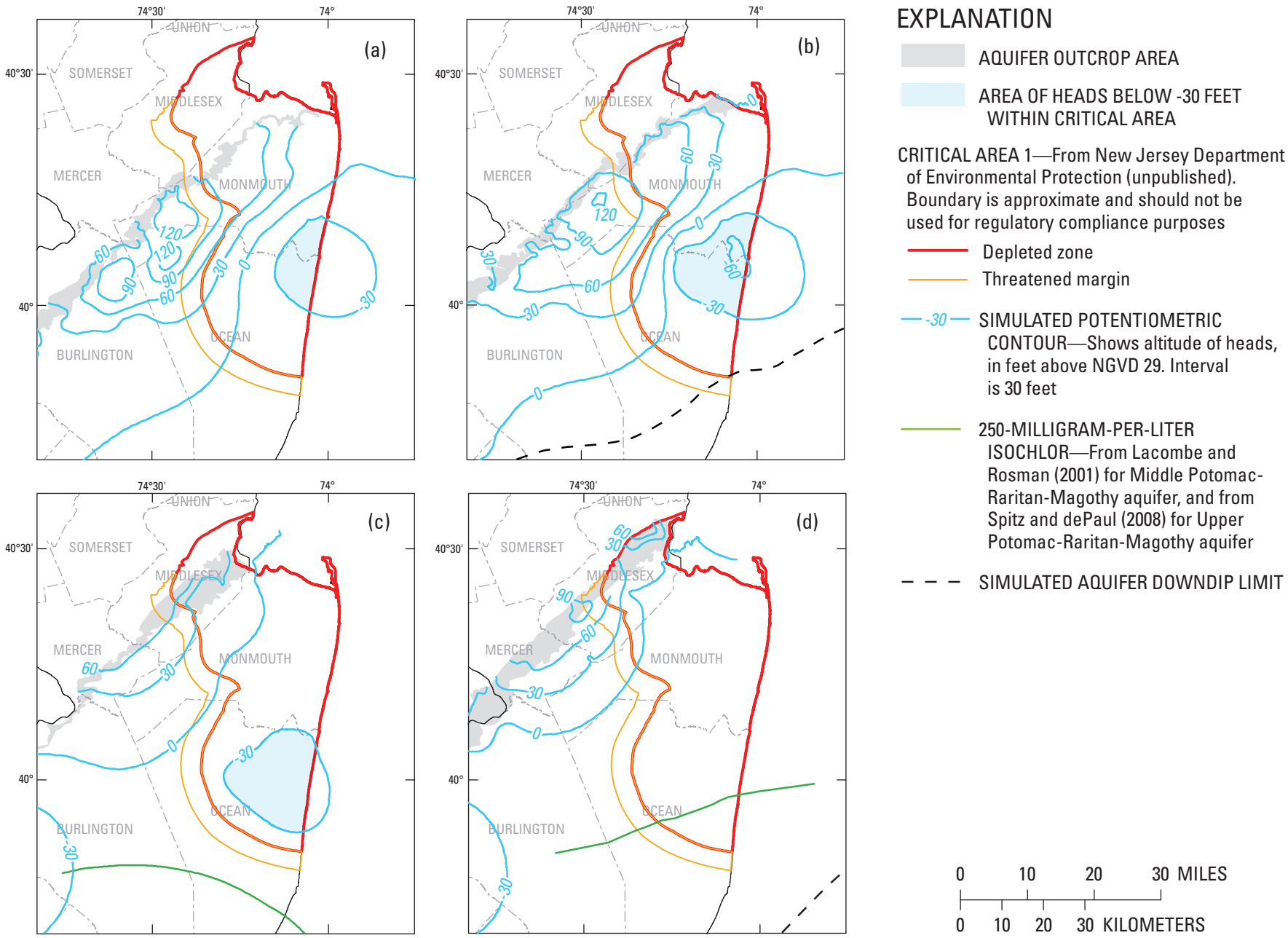

Figure 2. Simulated potentiometric surface for 2003 withdrawals in the (a) Wenonah-Mount Laurel aquifer, (b) Englishtown aquifer system, (c) Upper Potomac-Raritan-Magothy aquifer, and (d) Middle Potomac-Raritan-Magothy aquifer in Critical Area 1, east-central New Jersey.

Potomac-Raritan-Magothy aquifer. The -30-ft potentiometric contour generally is located about 15 mi updip from the 250-mg/L isochlor in the Upper Potomac-Raritan-Magothy aquifer.

Full-Allocation Withdrawals

The RASA model also is used to simulate full-allocation withdrawals from wells associated with NJDEP Bureau of Water Allocation (BWA) permits within the depleted zone in Critical Area 1. Current full-allocation withdrawals for BWA permits in Critical Area 1 were provided by NJDEP (Diane Zalaskus, N.J. Department of Environmental Protection, written commun., 2008). The procedure used to assign full-allocation withdrawals to wells is as follows. Wells associated with each BWA permit were determined by using USGS water-use databases and NJDEP Permit Requirements documents. Withdrawals during 2001–03 for each well associated with a BWA permit were used to prorate the full-allocation withdrawals by well.

A total of 171 wells are associated with 57 BWA permits (table 1) in Critical Area 1. Full-allocation withdrawals are approximately 47.7 Mgal/d, 7.3 Mgal/d (11.25 cubic feet per second) greater than 2003 withdrawals of 40.4 Mgal/d for these wells. Approximately 95 percent of this difference is due to withdrawals from the Upper and Middle Potomac-Raritan-Magothy aquifers--80 percent from the Upper Potomac-Raritan-Magothy aquifer and 15 percent from the Middle Potomac-Raritan-Magothy aquifer. The difference between 2003 and full-allocation withdrawals for individual wells can be determined from table 1. Full-allocation withdrawals are greater than or equal to 2003 withdrawals for 116 wells of the 171 wells in Critical Area 1.

Simulated steady-state potentiometric surfaces from the RASA model run based on full-allocation withdrawals are shown in figure 3. Similar to the 2003 withdrawal simulation results (fig. 2), the simulated -30-ft potentiometric contour remains within the boundary of the depleted zone in the Wenonah-Mount Laurel aquifer, Englishtown aquifer system, and Upper Potomac-Raritan-Magothy aquifer. The contour is within 1 mi of the boundary of the depleted zone in the latter aquifer in Ocean County. For these three aquifers, the areas within the depleted zone with simulated heads below -30 ft range from 99.2 mi^2 (in the Wenonah-Mount Laurel aquifer) to 179.2 mi^2 (in the Upper Potomac-Raritan-Magothy aquifer). Unlike the 2003 withdrawal simulation, a small area (less than 2 mi^2) of heads below -30 ft develops in the Middle Potomac-Raritan-Magothy aquifer. The simulated -30-ft potentiometric contour generally is located about 10 mi updip from the 250-mg/L isochlor in the Upper Potomac-Raritan-Magothy aquifer, but is only about 2.5 mi from the isochlor in the Middle Potomac-Raritan-Magothy aquifer.

Comparison of Results

The differences between simulated heads from the 2003 and the full-allocation withdrawal simulations in Critical Area 1 are shown in figure 4. Compared to the 2003 simulated results, the full-allocation simulation results exhibit large areas 5- to 15-ft lower heads in the Wenonah-Mount Laurel aquifer and Englishtown aquifer system and very small areas of about 10-ft lower heads in the Upper Potomac-Raritan-Magothy and Middle Potomac-Raritan-Magothy aquifers. A small area where full-allocation simulated heads are less than 5 ft higher than the 2003 simulated heads occurs in three of the aquifers in central Monmouth County in areas where full-allocation withdrawals are less than 2003 withdrawals. However, this result may reflect limited accuracy of the withdrawal data. The area within the depleted zone of heads below -30 ft is greater for the full-allocation simulation than for the 2003 withdrawal simulation in all of the aquifers. The smallest increase of less than 2 mi^2 occurred in the Middle Potomac-Raritan-Magothy aquifer and the largest increase of 37.2 mi^2 in the Upper Potomac-Raritan-Magothy aquifer. Also, in the full-allocation simulation, the -30-ft potentiometric contour in the Upper Potomac-Raritan-Magothy aquifer is about 1 mi from the southern landward boundary of the depleted zone, and in the Middle Potomac-Raritan-Magothy aquifer is within 2.5 mi of the 250-mg/L isochlor in that aquifer.

Comparison with Observed Data

The simulated 2003 hydraulic heads are as much as 40 ft higher than the observed 2003 water levels. This is a limiting factor when analyzing water levels under full allocation withdrawal conditions, but adjustments which address this limitation can be made to account for the differences. For example, if simulated full-allocation heads are adjusted by subtracting the difference between the simulated and observed 2003 heads, the area with heads below -30 ft in the Wenonah-Mount Laurel aquifer would cover a larger part of the depleted zone; the area with heads below -30 ft in the Englishtown aquifer system would be closer to the boundary of the depleted zone; the area with heads below -30 ft in the Upper Potomac-Raritan-Magothy aquifer would extend beyond the boundary of the depleted zone; and a larger area with heads below -30 ft in the Middle Potomac-Raritan-Magothy aquifer would develop in the depleted zone. Also, the observed -30-ft potentiometric contours in the Upper and Middle Potomac-Raritan-Magothy aquifers in Burlington County in Critical Area 2 (Spitz and dePaul, 2008, fig. 3) are within 10 mi of the boundary of Critical Area 1 (fig. 1). The decline in simulated water levels caused by full-allocation withdrawals in Critical Area 1 could be 0 to 5 ft greater if the simulated effects of full-allocation withdrawals in Critical Area 2 (Spitz and dePaul, 2008, fig. 9) are included.

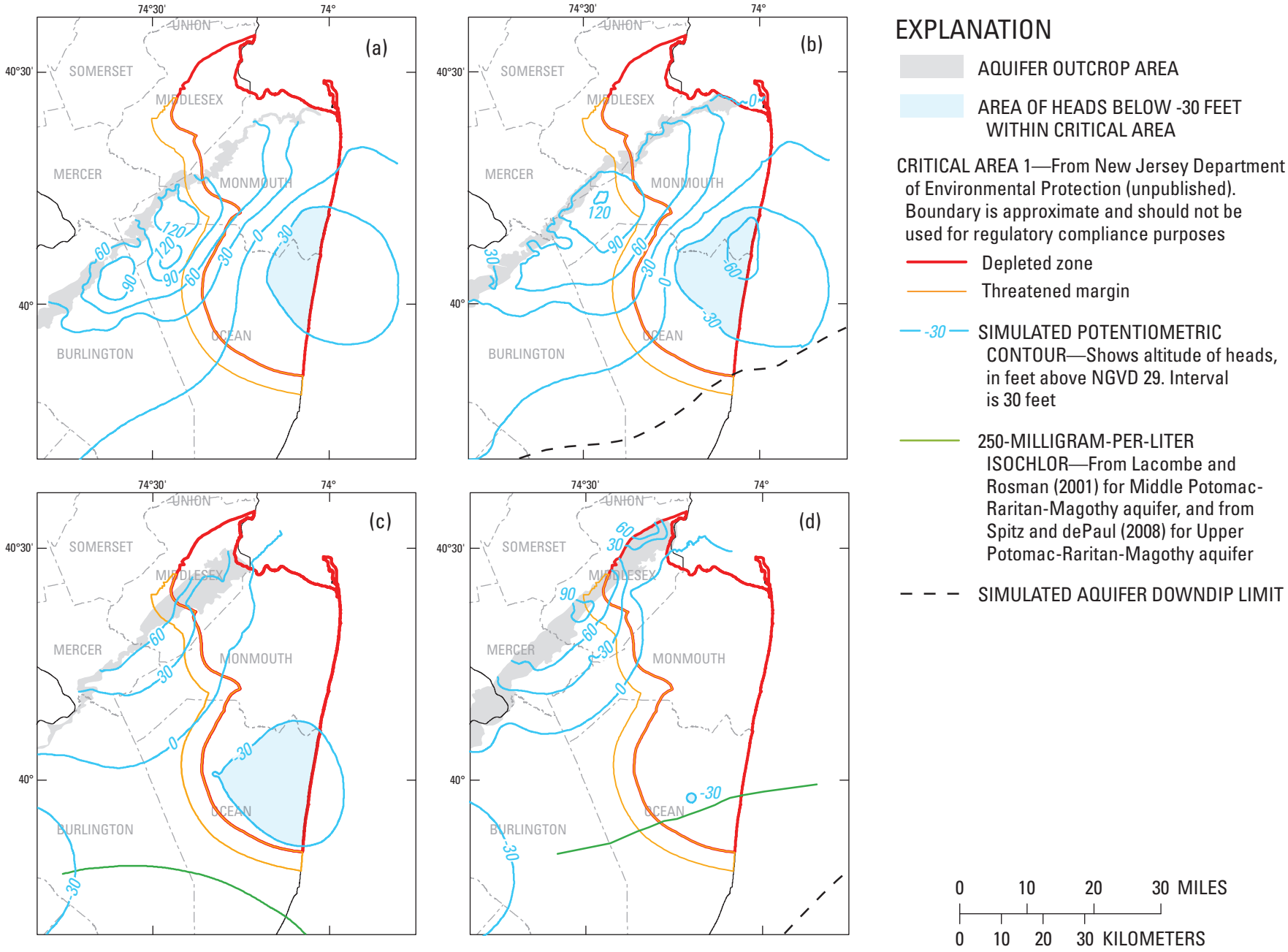

Figure 3. Simulated potentiometric surface for full-allocation withdrawals in the (a) Wenonah-Mount Laurel aquifer, (b) Englishtown aquifer system, (c) Upper Potomac-Raritan-Magothy aquifer, and (d) Middle Potomac-Raritan-Magothy aquifer in Critical Area 1, east-central New Jersey.

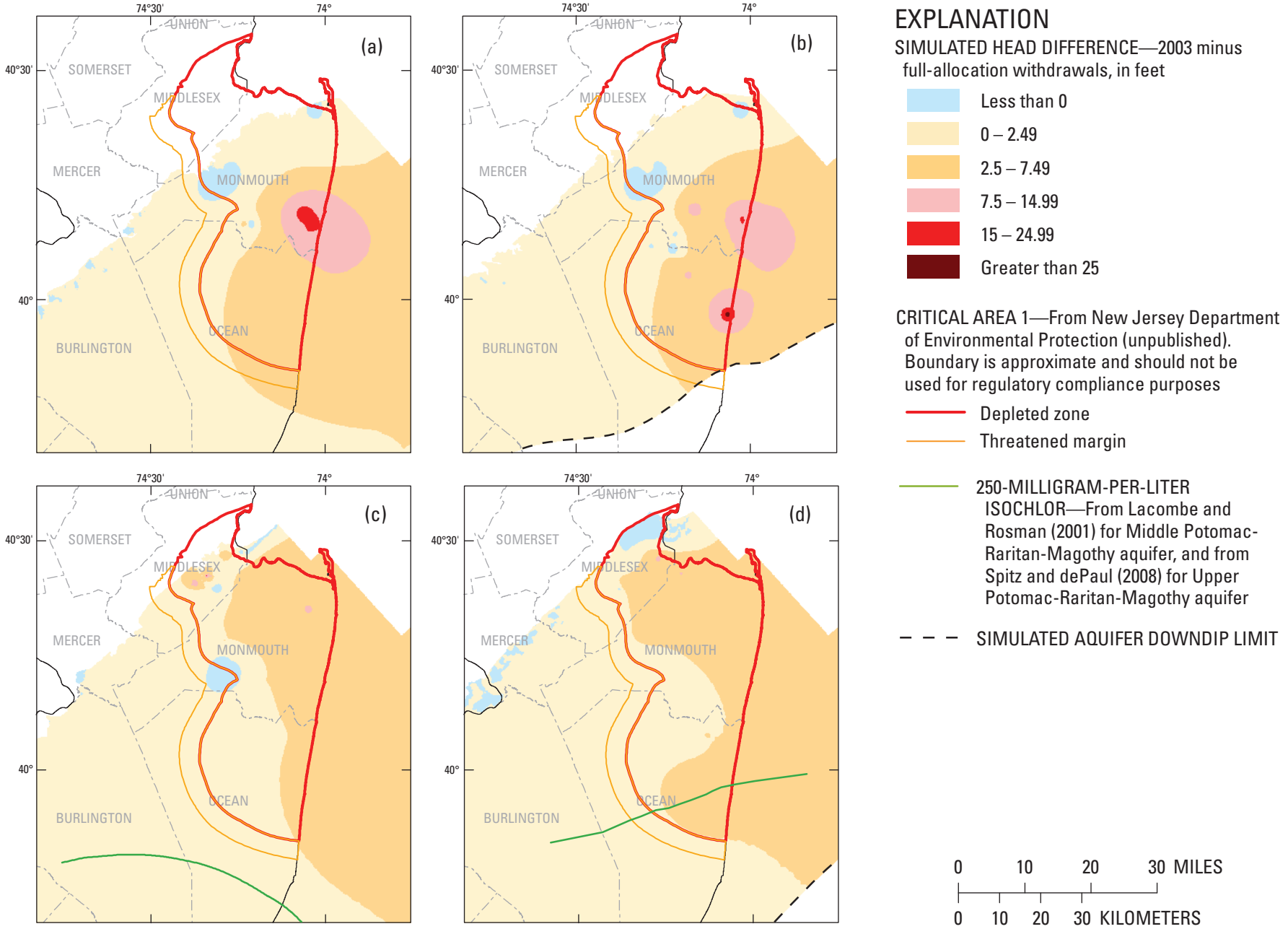

Figure 4. Simulated head difference between 2003 and full-allocation withdrawals in the (a) Wenonah-Mount Laurel aquifer, (b) Englishtown aquifer system, (c) Upper Potomac-Raritan-Magothy aquifer, and (d) Middle Potomac-Raritan-Magothy aquifer in Critical Area 1, east-central New Jersey.

Conclusions

The previous optimization study of Critical Area 1 (Spitz and others, 2008) indicates that, on the basis of the management models designed for that study, the amount of available withdrawals in Critical Area 1 generally ranges from 5 to 20 Mgal/d. The previous study also found that withdrawing the most available water would necessitate varying the distribution of withdrawals and (or) relaxing the hydrologic constraints used to protect the water supply. These previous optimization results in combination with the simulation results from this study indicate that the range of available withdrawals greater than full-allocation withdrawals is less than the range of available withdrawals greater than 2003 withdrawals--more likely 0 to 12 Mgal/d. This range of available withdrawals greater than full-allocation withdrawals is computed by subtracting 7.3 Mgal/d (the difference between full-allocation and 2003 withdrawals) from the withdrawal range (5 to 20 Mgal/d) determined through optimization. The location of the -30-ft potentiometric contour from the full-allocation simulation supports the conclusion that withdrawing the most available water would require varying the distribution of withdrawals and (or) relaxing the mandated hydrologic constraints used to protect the water supply. The effect of withdrawals in Critical Area 2 on water levels in Critical Area 1 is also important in evaluating available Critical Area 1 withdrawals.

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