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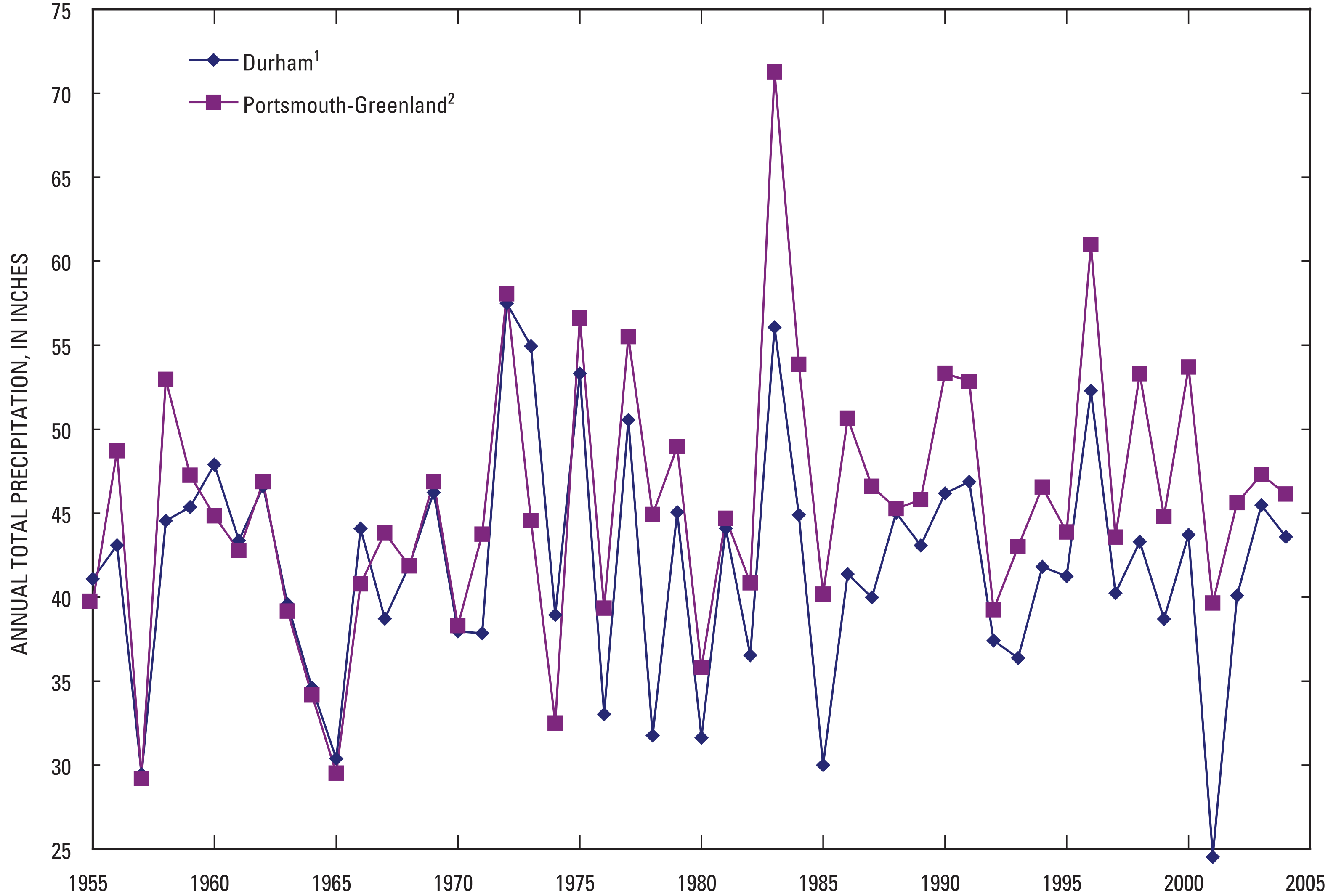
Appendix 1. Climate

Figures

Appendix 1. Climate

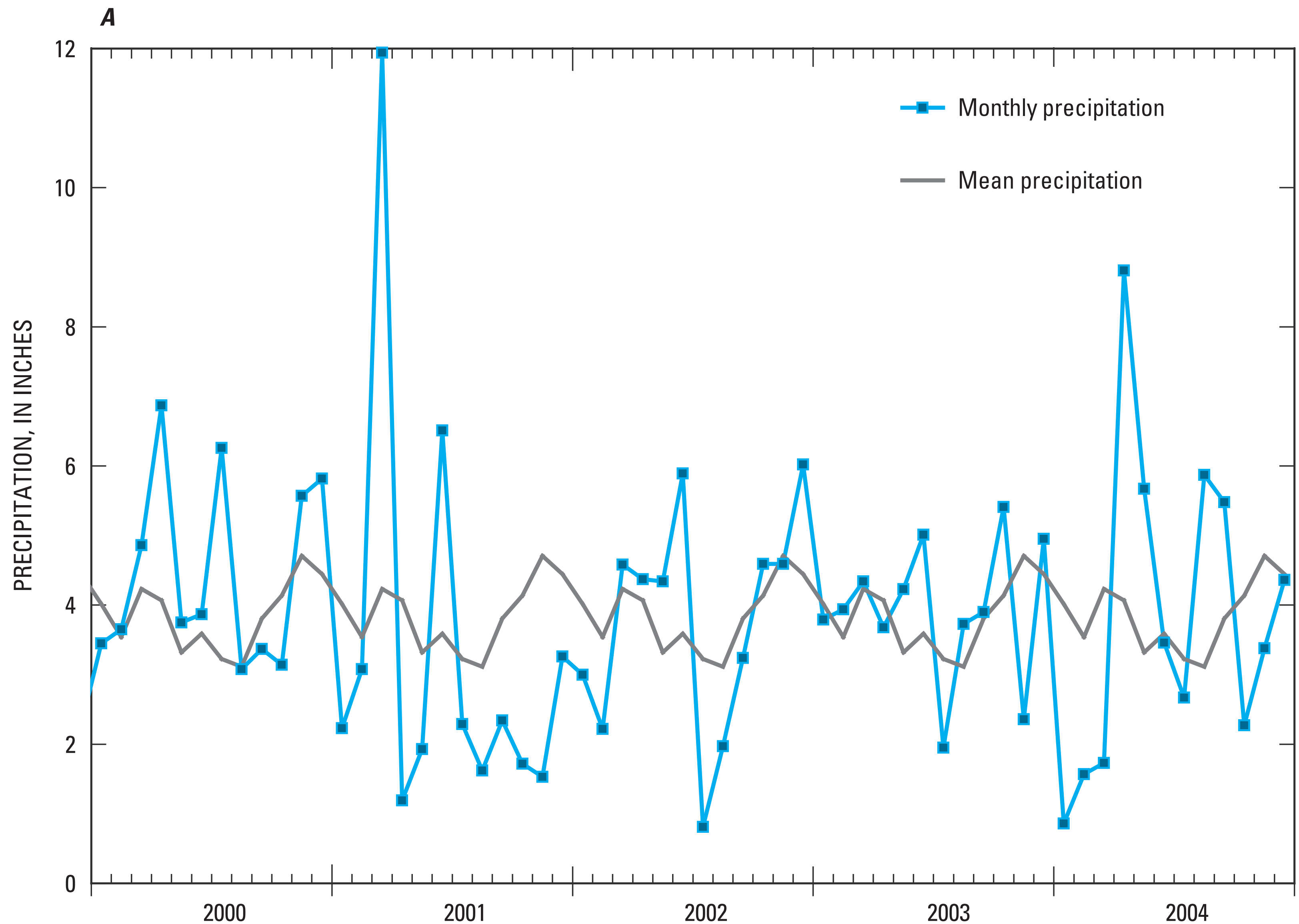
The study area is within the Seaboard Lowland physiographic province and the climate is humid and temperate. Long-term precipitation collected between 1896 and 2004 (David Brown, New Hampshire State Climatologist, written commun., 2005) at Durham, 5 mi west of the study area, averaged about 41 in/yr with a standard deviation of 7.4 in. During the 50-year period shown in figure 1–1, precipitation was low during intervals of a range of magnitudes and durations. The second lowest annual total precipitation during 1896–2004 was 24.6 in. measured in 2001. The lowest annual total precipitation occurred in 1941 (23.9 in.). The effects of low precipitation in 1910 (25.6 in.) were more severe because this year was preceded and followed by years of below-normal precipitation. The drought of 1965 (30.4 in.) also was severe because it was preceded by 2 years of below-normal precipitation. In recent years, total annual precipitation in most of the 1990s and the 2000s was above average. Precipitation totals at Durham in 2002, 2003, and 2004 were 98, 111, and 107 percent of the long-term average respectively. Precipitation data were collected in the model area at the Pease International Tradeport (former Pease Air Force Base) in Portsmouth from 1954 to 1973 and in Greenland, 3.7 mi to the south, from 1973 to the present (fig. 1–1). Annual total precipitation at the Portsmouth and Greenland stations for the period 1955 through 2004 average about 3 in. more (7 percent), with about the same standard deviation, than precipitation at Durham for the same period. Most of this difference is accounted for by slightly greater average monthly precipitation during the winter months (October through March) at Portsmouth and Greenland.

Monthly total precipitation is generally similar across the study area. Monthly totals during 2000–04 and station records (fig. 1–1) were comparable, particularly when precipitation totals were low, with the exception of the influence of coastal storms that increase total precipitation closer to the shore. For example, storms in March 2001 accounted for about 9 more inches of precipitation at Greenland than was observed in Durham. This anomalous month caused the total annual precipitation during the 2001 drought to be only slightly below average at Greenland (39.6 in.), whereas the total precipitation at Durham was the second lowest recorded (24.6 in.) (fig. 1–1). Precipitation across the study area was below average during several months of the summer of 2001 and the summer of 2002. During the period when temporary streamflow stations were operated in the study area, monthly total precipitation in the study area was generally near average with the exception of low monthly totals in July and August 2002 (0.81 and 1.97 in., respectively) and low monthly totals in January and February 2004 (0.86 and 1.57 in., respectively) (fig. 1–2A). The total annual precipitation in 2004 was near average at Portsmouth and Greenland, whereas October 2004 was below the monthly average (fig. 1–2B).



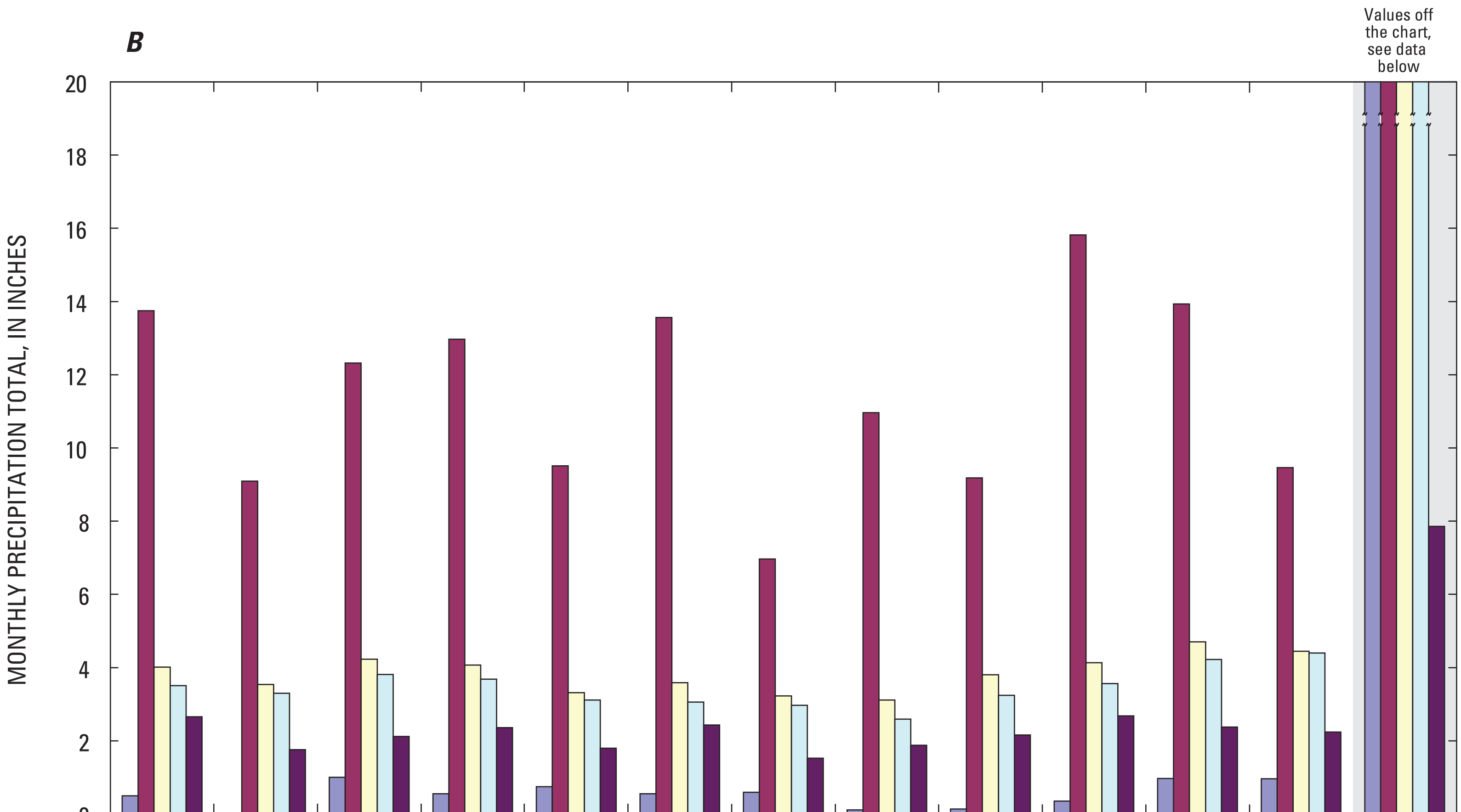
1. Source of data, for Durham is State Climatologist.
2. Source of data for Portsmouth and Greenland is the National Oceanic and Atmospheric Administration.

Figure 1–1. Long-term annual precipitation at Durham (inland) and Portsmouth and Greenland (on the coast), New Hampshire.



Sources of data: Durham, State Climatologist; and Portsmouth and Greenland, National Oceanic and Atmospheric Administration.

Figure 1–2. *(A)* Monthly and mean precipitation at Portsmouth and Greenland, New Hampshire, from January 2000 through December 2004.



	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	Annual
MINIMUM	0.5	0	1	0.55	0.75	0.55	0.59	0.11	0.14	0.35	0.97	0.96	29.19
MAXIMUM	13.75	9.09	12.32	12.97	9.51	13.56	6.97	10.96	9.18	15.82	13.93	9.46	71.26
MEAN	4.02	3.54	4.23	4.07	3.32	3.59	3.22	3.11	3.81	4.14	4.71	4.44	45.37
MEDIAN	3.51	3.3	3.815	3.68	3.11	3.06	2.97	2.59	3.24	3.56	4.22	4.4	44.84
STD. DEVIATION	2.66	1.75	2.12	2.36	1.80	2.43	1.53	1.88	2.16	2.68	2.38	2.24	7.86

Sources of data: Durham, State Climatologist; and Portsmouth and Greenland, National Oceanic and Atmospheric Administration.

Figure 1–2. *(B)* Monthly precipitation statistics at Portsmouth and Greenland, New Hampshire, from 1955 through 2005.—Continued

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Appendix 2. Bedrock-Well Yields

Figure

Tables

Appendix 2. Bedrock-Well Yields

Yields reported by drillers and discussed in this report generally were short-term (30-minute) air-lift yields and were considered approximate measures of sustained well yields. Examination of drillers' reported yields and aquifer-test yields for other wells in New Hampshire where more rigorous yield tests were required (Brandon Kernen, New Hampshire Department of Environmental Services, written commun., 2005) indicated that drillers' yields were similar to yields determined by aquifer tests. For example, about 40 percent of driller-reported and aquifer-test yields in the study area differed by less than 10 percent, and 67 percent of the yields differed by less than 20 gal/min. The statistical distribution of bedrock-well yields in the project area was skewed towards low yields (less than 10 gal/min), whereas well depths have a more normal statistical distribution than yields. Areas of moderate and high yields (10 and 40 gal/min) were fairly uniformly distributed throughout the study area. A variogram analysis of yields, however, indicated that yields were more similar in a northeast direction, the direction of the regional bedrock structure.

Statewide (Moore and others, 2002), the average bedrock well yield is approximately 6 gal/min, whereas the average yield of bedrock wells in the study area is 22 gal/min. Table 2–1 shows bedrock well-yield and depth statistics by bedrock formation for the study area. The means and standard deviations of yield by formation, as determined by Moore and others (2002) with an older, smaller data set, are listed in table 2–1 for comparison. Some formations—for example, the Breakfast Hill Granite, Rye, and Kittery Formations, and the Newburyport Complex—are entirely in the model area; and, therefore, the differences in the number of wells represent the addition of wells. The regional variations in well yields associated with each formation were similar to the variations in the data used by Moore and others (2002). For example, the Rye Complex previously had 29 wells with an approximate mean yield and standard deviation of 39 and 63 gal/min, respectively, and now has 239 wells with an approximate mean yield and standard deviation of 34 and 42 gal/min (table 2–2). Therefore, the yield probability relations and general trends found by Moore and others (2002) hold true for the current study. The high standard deviations, relative to the mean values reflect the fact that the yield distributions are skewed toward lower values.

Nonzero well yields less than or equal to 40 gal/min in central New Hampshire (Drew and others, 2001) and in a similar crystalline-bedrock setting in Virginia (Sutphin and others, 2000) have also been found to have directional yield characteristics related to the rock structure. Directional yield characteristics were assessed by using ArcView[1] variographic analysis (Environmental Science Research Institute). Low-yielding wells were more likely to be spatially correlated because the regional hydraulic characteristics of the bedrock aquifer were controlled, or limited, by the smaller fractures of the bulk rock. For example, a fracture zone may locally provide a zone of increased hydraulic conductivity; however, unless wells are tested within a limited distance of this same fracture zone, the hydraulic conductivity of the bulk rock will provide the hydraulic connection in the region and be the principal factor determining the well yields. The hydraulic connection of the bulk rock also may be termed the "connectivity." Variographic analysis of yields greater than zero and less than 60 gal/min indicate a north-to-northeast-trending spatial continuity (table 2–2). Because bedrock wells yields in the Seacoast study area were higher than those analyzed in similar variographic investigations (Drew and others, 2001; Sutphin and others, 2000) higher well yields were included in this analysis than in other investigations. The northeast trend is likely to be related to the regional bedrock structure and has also been observed in fractures oriented along bedding planes (Escamilla-Casas, 2003; Fargo and Bothner, 1995; Novotny, 1969), local borehole investigations (Mack and Degnan, 2003; Mack and others, 1998; and Johnson and others, 1999), fracture-correlated lineaments (Degnan and Clark, 2002), and in regional bedrock-yield probabilities (Moore and others, 2002).

[1] Use of commercial software name for informational purposes.

Table 2–1. Bedrock well yields and depth characteristics for geologic units in the Seacoast model area and in southeastern New Hampshire.

[Geologic unit and geologic code shown on figure 2–1: Lyons and others (1997); gal/min, gallons per minute; ft, feet; —, not applicable or not calculated]

Geologic unit	Dominant lithology	Geo-logic code	Model code	Seacoast model area[1]					Southeastern New Hampshire[2]		
				Number of wells	Yield (gal/min)		Depth (ft)		Yield (gal/min)		
					Mean/ median	Standard deviation	Mean/ median	Standard deviation	Number of wells	Mean	Standard deviation
Exeter Diorite	Diorite	DE9	Rx4	78	19/11	22	281/250	145	82	15	22
Breakfast Hill granite	Granitic gneiss or migmatite	OZrb	Rx1	88	26/20	28	295/240	186	23	18	28
Rye Complex	Schist and gneiss	OZrz	Rx1	239	34/20	42	263/240	134	29	39	63
Newburyport Complex[3]	Porphoritic granite	SN1x	Rx4	50	24/17	24	276/242	138	2	12	12
Newburyport Complex	Tonalite and granodiorite	SN2-3a	Rx4	—	—	—	—	—	3	49	61
Berwick Formation	Schist	SOb	Rx4	79	14/8	16	322/300	139	1,595	16	27
Eliot Formation	Phyllite	SOe	Rx3	875	20/12	22	265/225	137	292	16	20
Kittery Formation	Metasandstone	SOk	Rx2	824	22/15	24	266/240	126	169	27	56
All	—	—	—	2,237	22/15	26	269/240	136	—	—	—

[1] Based on extent of the geologic unit in the model area shown in figure 2–1 and wells in the New Hampshire Geological Survey database as of March 2006.

[2] Based on extent of the geologic unit in southeastern New Hampshire as used by Moore and others, 2002.

[3] Statistics in Seacoast model area shown for combined Newburyport Complexes.

Table 2–2. Bedrock well yield variography and geologic units within the Seacoast model area, southeastern New Hampshire.

[Formation and code from Lyons and others (1997); Variography (anisotropy) calculated for well yields less than 60 gallons per minute[1] by using ArcView (Environmental Systems Research Institute)[2]; gal/min, gallons per minute[1]; Deg.TN, degrees from true north; —, not available]

Geologic unit	Dominant lithology	Geologic code	Number of wells	Yield trend orientation and range of trend line, indicates anisotropy		Notes
				Direction Deg. TN	Approximate well-yield range (gal/min)	
All	Varies		1,571	—	10–20	Higher yields in middle of study area and increasing to east.
Newburyport Complex	Granite, tonalite, and granodiorite	SN1x, SN2–3a	34	—	—	Too few points to assess trends; however, may be higher at contacts.
Breakfast Hill granite	Granitic gneiss or migmatite	OZrb	74	34	10–30	Greater yields towards center of unit.
Rye Complex	Schist and gneiss	OZrz	204	20	10–30	Greater yields towards center of complex.
Kittery Formation, east	Metasandstone	SOk	623	60	15–20	Little trend.
Kittery Formation, west	Metasandstone	SOk	58	24	28–38	Greater yields towards contacts.
Eliot Formation	Phyllite	SOe	408	29	10–20	Little trend, slightly greater yields towards center of formation.
Berwick Formation	Schist	SOb, SOeb	73	58	15–30	Strongly convex, greater yields in center and increasing to southwest.
Exeter Diorite	Diorite	De9	55	67	18–28	

[1] Based on extent of geologic unit in the model area shown in figure 2–1 and wells in the New Hampshire Geological Survey database as of March 2006.

[2] Use of commercial software name for informational purposes.

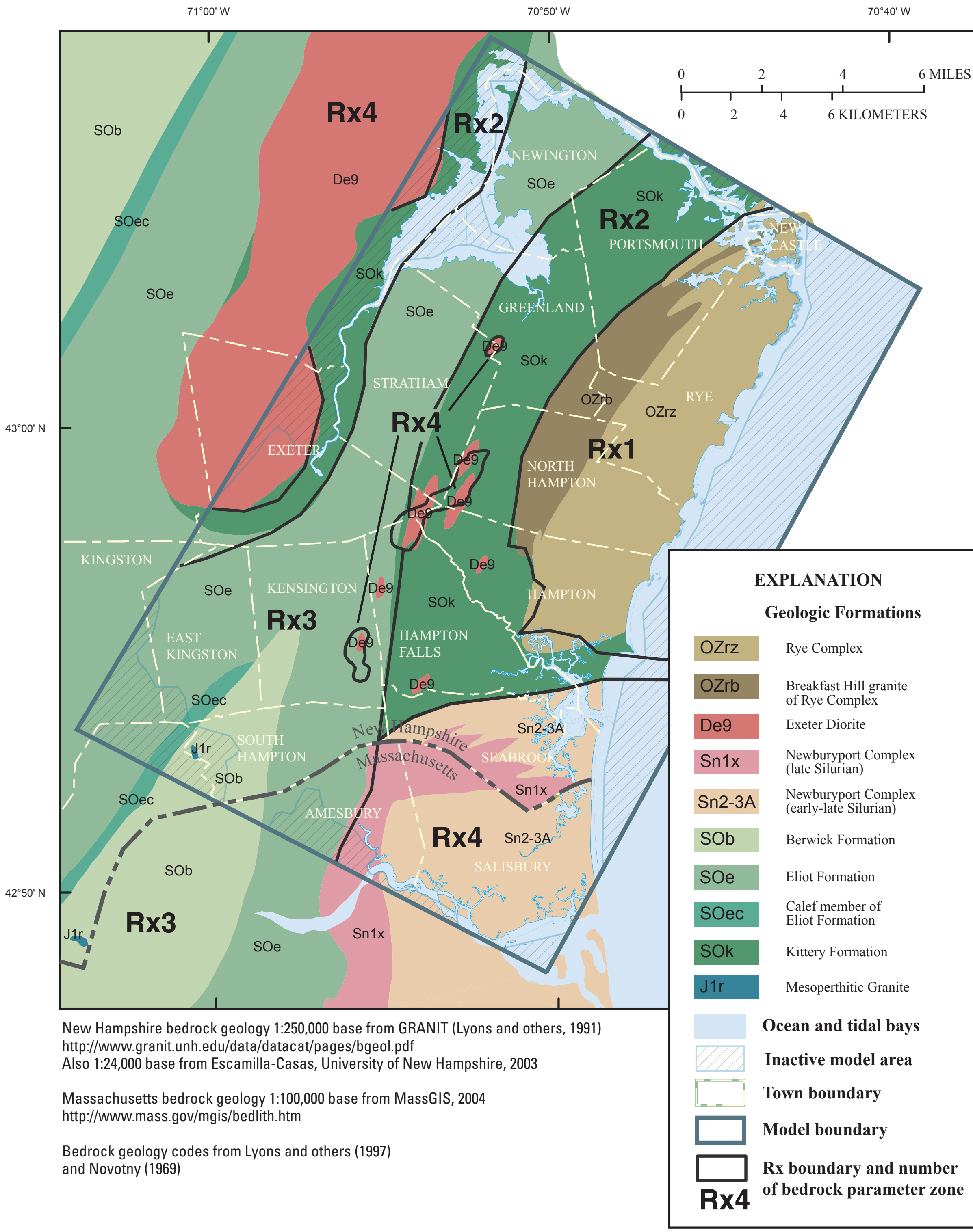

Figure 2–1. Dominant bedrock formations in the Seacoast area and bedrock parameter zones used in the Seacoast model, southeastern New Hampshire. (This figure is the same as figure 4 on page 7 in the report.)

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Appendix 3. Tidal Water-Level Responses in Wells

Figures

Appendix 3. Tidal Water-Level Responses in Wells

Water levels in the bedrock aquifer show a confined aquifer response to Earth tides and barometric pressure changes. Tidal responses in Seacoast bedrock wells were examined to assess their use in quantifying aquifer properties and to assess hydraulic connections between the freshwater aquifer and the ocean and estuaries. Figure 3–1 illustrates water-level fluctuations in three wells in the bedrock aquifer typical of an earth-tide response in the region. Measured fluctuations were about 0.2 to 0.4 ft and 0.1 to 0.2 ft, respectively, for wells GTW-141 and HEW-44 (figs. 3–1A and 3–2). A similar response has been observed at bedrock wells considerably inland where there is no connection to ocean tidal fluctuations (ground-water level hydrographs can be accessed at http://waterdata.usgs.gov). For example, hydrographs for PBW-148 (about 35 mi inland), and ME-ANW-1135 (about 20 mi inland) show typical earth-tide ranges of 0.05 to 0.1 ft and 0.2 to 0.4 ft, respectively. In areas where there is no hydraulic connection to tidal waters, the earth-tide effect on bedrock-aquifer ground-water levels is opposite of the tidal effect on the oceans. As gravitational forces from planets and the moon and sun pull at the surface of the earth, surface gravity is less, fractures in the rock are dilated, and ground water fills the fractures, causing the bedrock water level to drop. When the gravitational force is included, gravitational attraction is higher, and the fractures close forcing water out of the fractures and raising the water level. The magnitude of the earth-tide response differs with bedrock-aquifer transmissivity and storativity (or specific storage times thickness) and with tidal gravity (Merritt, 2004; Bredehoft, 1967; Hsieh and others, 1987, 1988). It is possible to estimate the hydraulic diffusivity of an aquifer (the hydraulic conductivity divided by the specific storage) from measurements of earth-tide water-level fluctuations and the magnitude and timing of gravitational forces, which can be calculated for any location (Hsieh and others, 1987, 1988; Merritt, 2004). The approximate yield of bedrock wells in the region is generally determined during drilling and is more accurate than could be estimated by gravitational methods. Specific storage and porosity, which generally require aquifer or borehole testing, however, can be estimated by an analysis of earth tides by the methods outlined by Merritt (2004) and Sheets and Darner (U.S. Geological Survey, written commun., 2006). Porosity is related to specific storage using barometric efficiency (from analysis of earth tides and the compressibility and density of water (Merritt, 2004). Porosity and specific storage were calculated for wells GTW-141, HEW-44, and PBW-148 (Sheets and Darner, U.S. Geological Survey, written commun., 2006). A porosity of 0.02 and specific storages of 1.5×10^{-7}, 2.4×10^{-7}, and 4.0×10^{-7}, respectively, were estimated for the aquifers in which the three wells are completed. Approximately 86 percent of the variance in well water levels, detrended for barometric influence, was explained by earth-tide effects.

The tidal water levels in wells were qualitatively assessed for hydraulic characteristics and to assess whether ocean-tides propagate into the Seacoast fractured bedrock aquifer. Earth-tide effects on bedrock water levels in the study area can be qualitatively assessed by comparison to water levels in bedrock well PBW-148, 35 mi west of the study area. Tidal responses occurred at the same time throughout the area. The gravitational forces caused by the moon and sun, because of their magnitudes and distances from Earth, can be considered to be equal and instantaneous (no lag) throughout southeastern New Hampshire and Maine. For example, comparison of water levels at PBW-148 and ME-ANW-1135 (hydrographs accessible at waterdata.usgs.gov) shows that the timing of the earth-tide peaks in water levels is identical.

Water-level records for bedrock monitoring well GTW-141 (fig. 3–1) were not found to have a measurable connection with ocean tides. This well is less than 50 ft from a section of the Winnicut River on the south side of Great Bay with a mean tidal range of about 7 ft. The tide at the Squamscott River railroad bridge, about 3.5 mi to the west in Great Bay and at a distance about equal to that of the well from the ocean, has a phase lag of 2 hours after the high and low ocean tides. Squamscott River has a mean tidal range of 7 ft, whereas the ocean has a mean range of about 8 ft. On September 29, 2004, the water level in the well peaked at 07:00 and 18:00 hours, at the same time as water-level peaks in other bedrock observation wells in the area, while the bay tide peaked at 01:18 and 13:40 (EST). The ocean tide peaks were at 23:13 (previous night) and 11:34, or about 7 hours offset from the peak water level in the bedrock. Water levels completed in bedrock wells with very low permeability showed no earth-tide response (Pease monitoring well W611, not shown in fig. 3–1; Montgomery, Watson, Harza, 2002). Bedrock aquifers with low hydraulic conductivity have few fractures to expand and contract and few connections for water to move between fractures. In contrast, water levels monitored at a high-yielding well, for example monitoring well RYW-49 (fig. 3–2), showed little tidal response (0.1–0.2 ft) because the bedrock aquifer at that location is essentially unconfined and responds differently to pressure loading.

Water-level records for two wells immediately adjacent to tidal water bodies in Hampton, N.H., were examined because the wells were believed to be mixed with or include ocean water. The wells were assumed to be hydraulically connected to tidal water bodies because the daily water-level fluctuation observed in the wells did not follow the earth-tide pattern described above. For example, figure 3–1B shows the resulting water-level fluctuation in a well (HEW-153) that is affected by both earth and ocean tides. The water-level responses in the wells were influenced by conflicting earth and ocean tides; the result for each well was a single daily water-level peak that was more closely aligned with the larger ocean tide. It is interesting to note that although well GTW-141 also is very close to a saltwater body (Great Bay, fig. 3–2), the well is not contaminated by chloride. The hydraulic head in this inactive well is above sea level because of the regional ground-water-flow system; if the well were in use, the head would be lower.

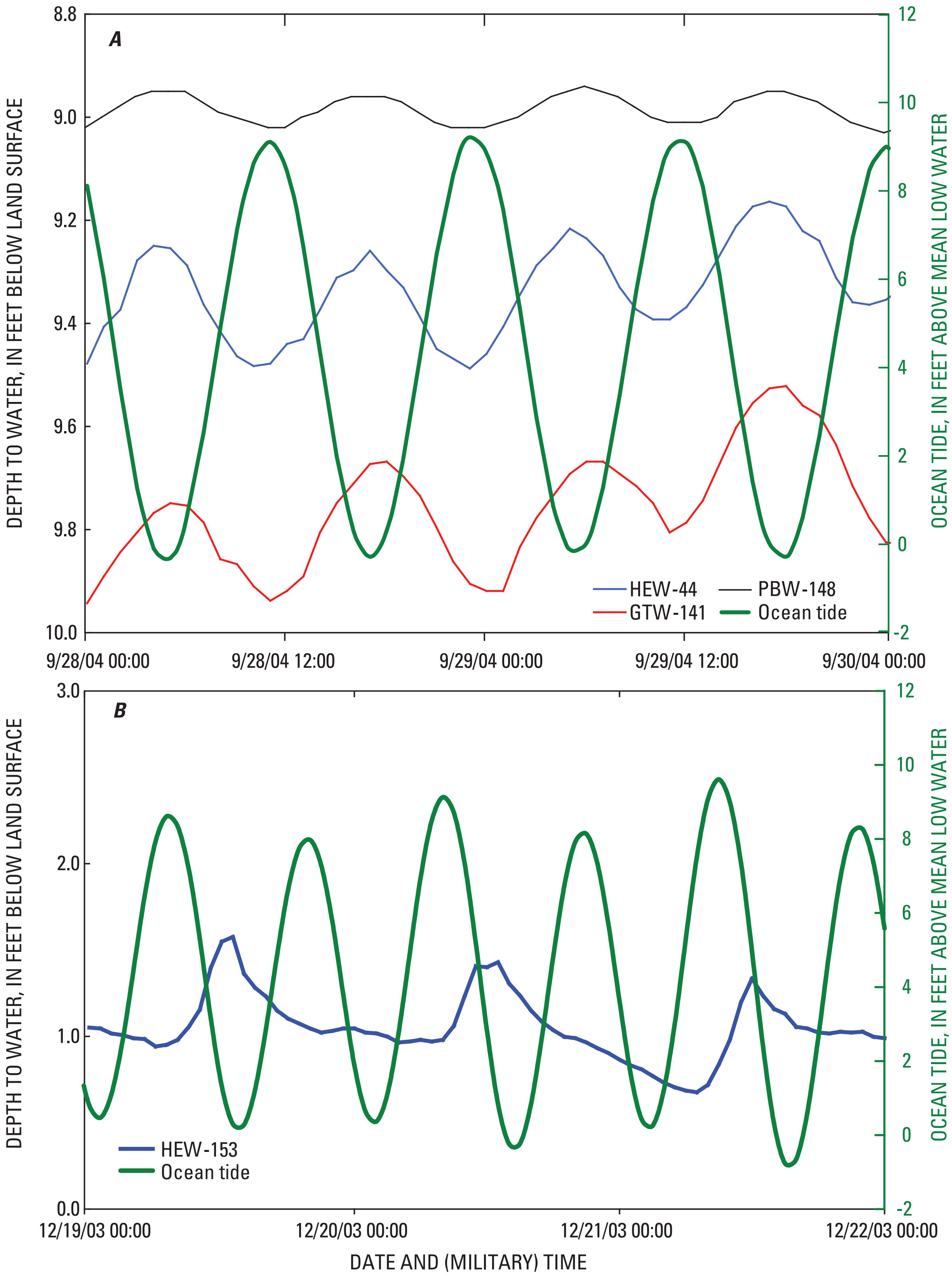

Figure 3–1. Earth-tide water-level responses and ocean tides at *(A)* observation wells GTW-141, HEW-44, PBW-148, unaffected by ocean tides, and at *(B)* observation well HEW-153, affected by ocean tides, southeastern New Hampshire. (Location of wells shown on figure 3–2. Well PBW-148 is outside the study area and not shown on any figure.)

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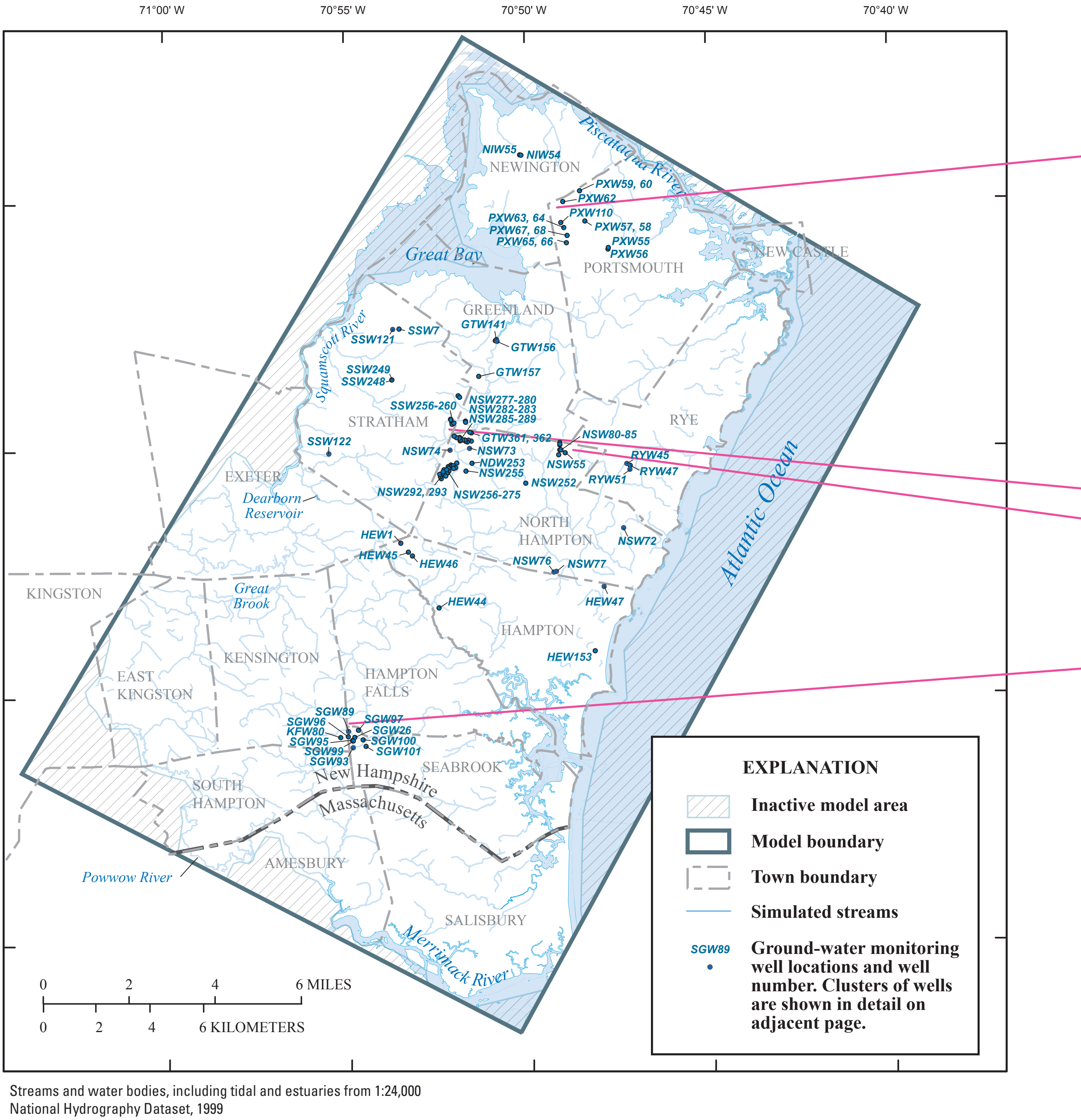
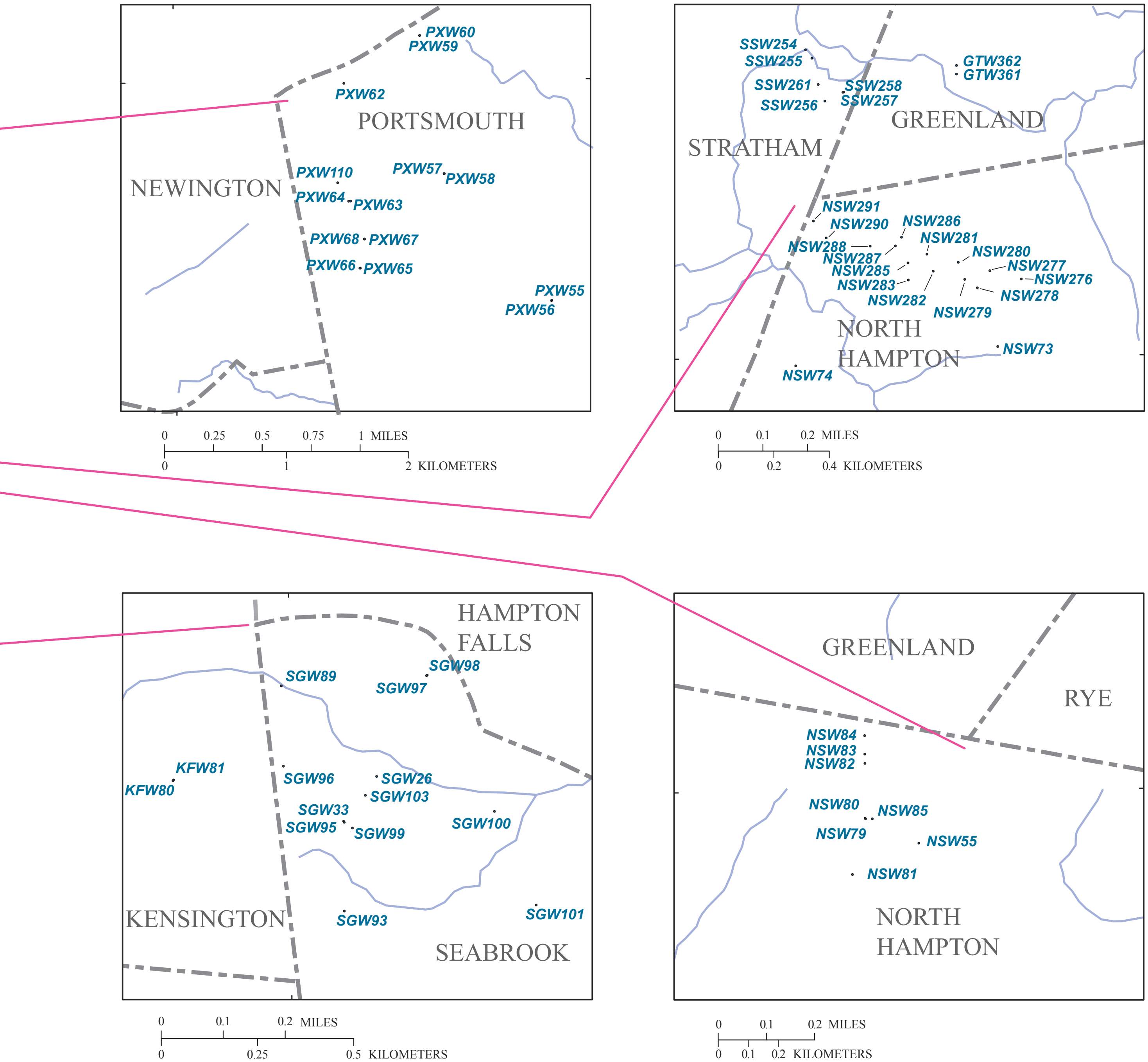


Figure 3–2. *(A)* Ground-water monitoring wells in the study area. (This figure is the same as figure 7 on page 16–17 in the report.)


PXW60
PXW59
PXW62
PORTSMOUTH
NEWINGTON
PXW110
PXW57
PXW58
PXW64
PXW63
PXW68
PXW67
PXW66
PXW65
PXW55
PXW56
0 0.25 0.5 0.75 1 MILES
0 1 2 KILOMETERS
SSW254
SSW255
SSW261
SSW256
SSW258
SSW257
GTW362
GTW361
GREENLAND
STRATHAM
NSW291
NSW290
NSW286
NSW281
NSW288
NSW287
NSW285
NSW283
NSW282
NSW280
NSW277
NSW276
NSW278
NSW279
NORTH HAMPTON
NSW73
NSW74
0 0.1 0.2 MILES
0 0.2 0.4 KILOMETERS
HAMPTON FALLS
SGW98
SGW89
SGW97
KFW81
KFW80
SGW96
SGW26
SGW103
SGW33
SGW95
SGW99
SGW100
KENSINGTON
SGW93
SGW101
SEABROOK
0 0.1 0.2 MILES
0 0.25 0.5 KILOMETERS
GREENLAND
RYE
NSW84
NSW83
NSW82
NSW80
NSW85
NSW79
NSW55
NSW81
NORTH HAMPTON
0 0.1 0.2 MILES
0 0.1 0.2 KILOMETERS

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Appendix 4. Description of Selected Unconsolidated and Bedrock Aquifers

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Appendix 4. Description of Selected Unconsolidated and Bedrock Aquifers

Limited and discontinuous stratified-drift aquifers were present in the study area and were described by Moore (1990) and Stekl and Flanagan (1992). Many of these aquifers are hydraulically connected to bedrock aquifers that are undergoing increased use and development.

Seabrook

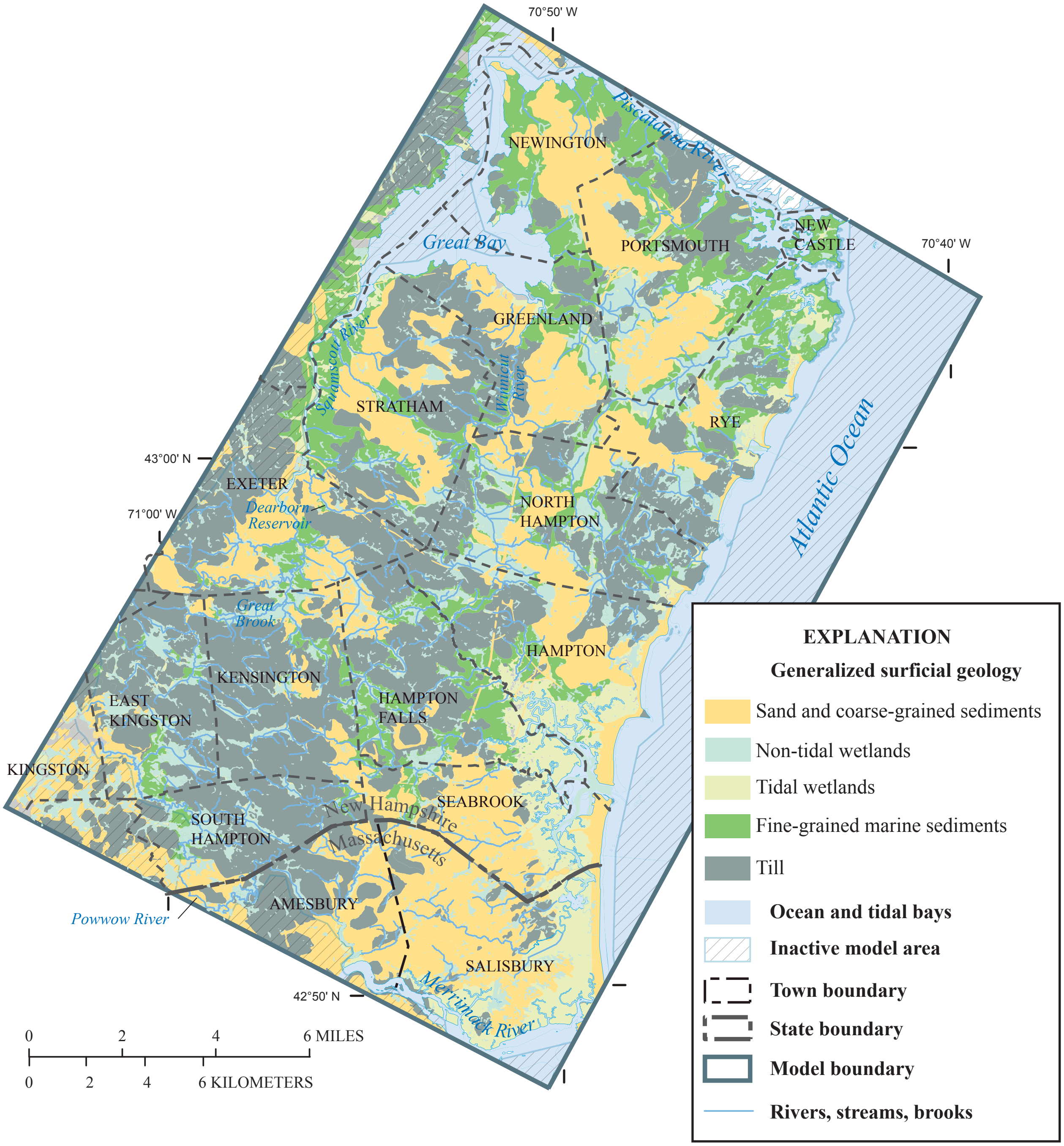
In the town of Seabrook several stratified-drift aquifers of limited extent and generally less than 40 ft thick were along the Salisbury, Mass., town line and at the boundary with South Hampton and Kensington (Stekl and Flanagan, 1992). These stratified-drift aquifers (fig. 4–1) were fully developed by the towns of Seabrook and Salisbury and unavailable for additional water supply. A well field in a stratified-drift aquifer that is a deltaic deposit (Koteff and Schafer, 1989) in the southwest part of town is a major source of water for Seabrook. This well field includes a few high-yield overburden and bedrock wells. In contrast, the towns of Hampton Falls, South Hampton, and Kensington have little stratified drift (fig. 4–1) and no large community ground-water systems. Three sand and gravel aquifers in the town of Seabrook were estimated from aquifer tests (Earth Tech, Inc., 1998) to have hydraulic conductivities of about 100 to nearly 400 ft/d and a storativity (defined as specific storage/thickness) of about 6×10^{-5}.

Seabrook operates five bedrock supply wells in the well field in the southwest part of town. Bedrock wells 1–4 were situated in an area of about 500 ft^2 and bedrock well 5 (SGW-93, fig. 4–2) is about 2,000 ft to the south of the other wells. The bedrock supply wells were all about 500 ft deep and near the contact between the Kittery and Eliot Formations. Wells 1–4 were operated together for a combined capacity of 1,300 gal/min, whereas well 5 has an operating capacity of about 560 gal/min. The specific capacity of bedrock well 5 was estimated at 5 gal/min/ft. The bedrock aquifer at the well field was estimated to have a hydraulic conductivity of about 3.3 ft/d, a storage coefficient of 4×10^{-4}, and a reported porosity of 0.02 (table 4–1) (Earth Tech, Inc., 1998). (Because the reported porosity is from a hydraulic test, it is likely a percent volume associated with gravity drainage and not an actual porosity). The bedrock aquifer responds as a leaky confined porous medium. The drillers of bedrock wells 1–4 reported caverns (Whitman and Howard, 1993) that may be the result of dissolution in calcareous or dolomitic metamorphic rock. In an investigation in the Eliot Formation about 10 mi south of Seabrook (Lyford and others, 2003; Walsh, 2001), calcareous lenses were associated with water-bearing fracture zones. Separate aquifer tests at the two well fields (Whitman and Howard, 1993) revealed only small drawdowns (less than 1 ft) resulting from pumping at the other site; this finding indicates that the well fields were not well connected hydraulically. Greater drawdowns caused by pumping at each site at test wells about 1,500 ft east of wells 1–4 indicate a greater hydraulic connection in that direction. During a prolonged aquifer test, the cone of depression for bedrock well 5 was found to be elliptical in a northeast direction (Earth Tech, Inc., 1998). Geophysical analyses indicate that a northeast-trending fracture zone at bedrock well 5 may be related to a N. 17 E. photolineament (Mack and others, 1998). Like the variographic analysis of bedrock well yields, these observations indicate a northeast anisotropy to the bedrock hydraulic properties.

Most of the town of Seabrook south and east of the well field and in areas of the ground-water-flow model in Massachusetts is underlain by dioritic rocks of the Newburyport Complex. Exploratory drilling programs in the towns of Salisbury, Mass., and Seabrook, which are seeking additional ground-water supplies, have found this complex to be generally poor-yielding.

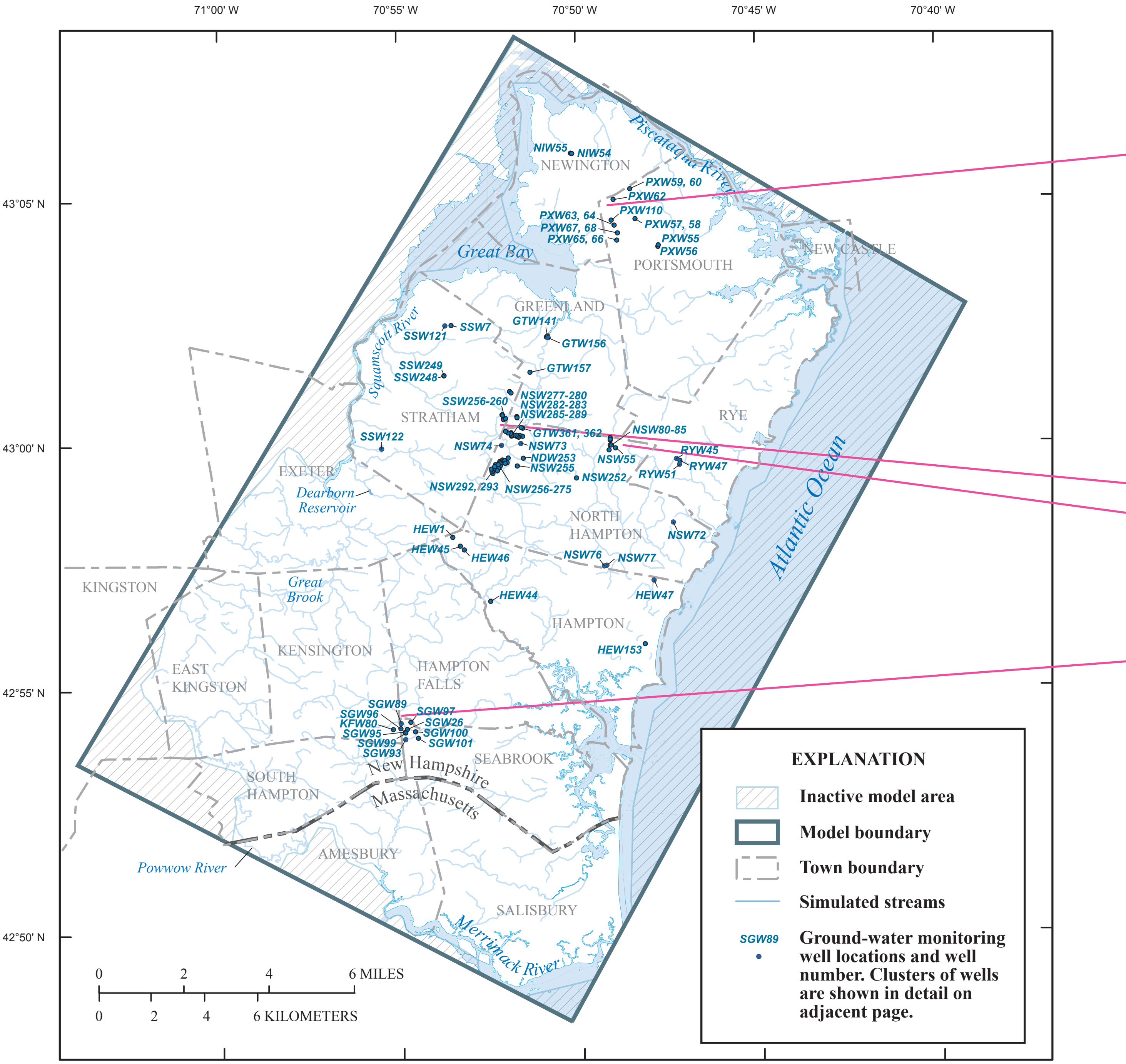
Hampton/North Hampton

The Mill Road well field along the Hampton and North Hampton town line consists of four surficial and two bedrock wells. The surficial wells produced a combined annual total withdrawal of about 1 Mgal/d in 2002 and 2003. Two high-yield bedrock wells were brought on line in 2004. The permitted total production rate for the two wells, bedrock wells 20 and 21 (NSW-76 and NSW-77), spaced 356 ft apart, was 0.5 Mgal/d. A stratified-drift aquifer with a saturated thickness of 0 to 40 ft, and an area of 2.4 mi^2, includes nearly 1 mi^2 of the area upgradient of the well field. An area of about 0.5 mi^2 of this upgradient stratified-drift aquifer in the Little River drainage area (fig. 4–1 and subwatershed 11, fig. 4–3), produces a high yield and has a transmissivity of 2,000 ft^2/d or greater (Stekl and Flanagan, 1992), equivalent to a hydraulic conductivity greater than about 200 ft/d. This aquifer is 2 mi from both the Atlantic Ocean to the east and a large saltwater marsh to the south. Bedrock in this area is mapped as the Rye Complex and the contact with the Kittery Formation, which is the Portsmouth Fault, is believed to be about 1 mi to the



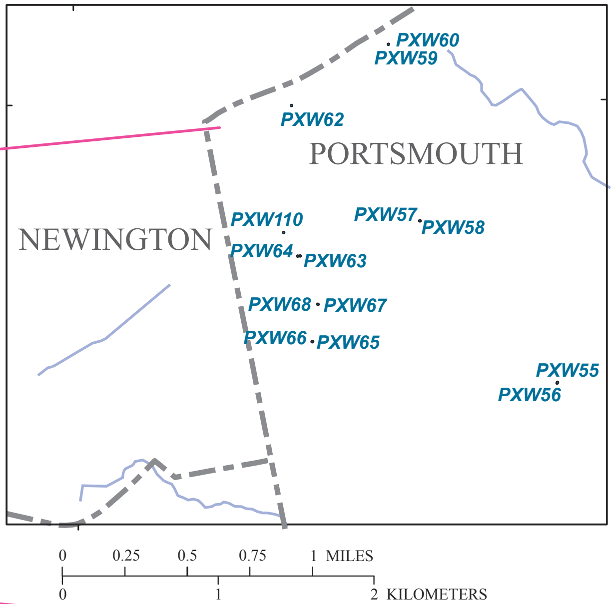
New Hampshire surficial geology base from 1:24,000 N.H. State Geologist, 2005
Massachusetts base from 1:250,000 MassGIS, 1999

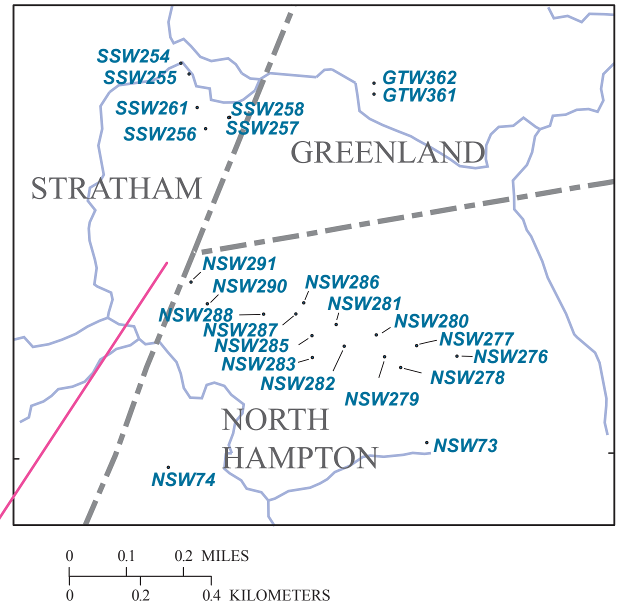
Figure 4–1. Distribution of surficial sediments, wetlands, and water bodies in the Seacoast model area, southeastern New Hampshire. (This figure is the same as figure 3 on page 6 in the report.)

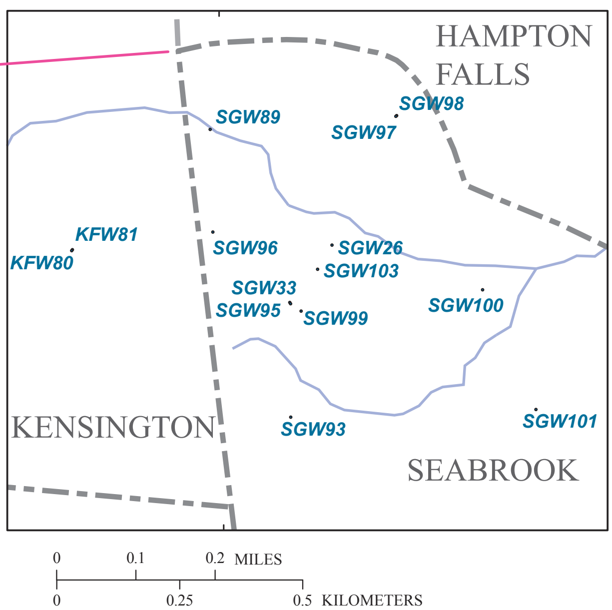


Streams and water bodies, including tidal and estuaries from 1:24,000
National Hydrography Dataset, 1999

Figure 4–2. *(A)* Ground-water monitoring wells in the study area. (This figure is the same as figure 7 on page 16–17 in the report.)


PXW60
PXW59
PXW62
PORTSMOUTH
NEWINGTON
PXW110
PXW57
PXW58
PXW64
PXW63
PXW68
PXW67
PXW66
PXW65
PXW55
PXW56
0 0.25 0.5 0.75 1 MILES
0 1 2 KILOMETERS


SSW254
SSW255
GTW362
GTW361
SSW261
SSW258
SSW256
SSW257
GREENLAND
STRATHAM
NSW291
NSW290
NSW286
NSW281
NSW288
NSW287
NSW280
NSW285
NSW277
NSW276
NSW283
NSW278
NSW282
NSW279
NORTH HAMPTON
NSW73
NSW74
0 0.1 0.2 MILES
0 0.2 0.4 KILOMETERS


HAMPTON FALLS
SGW98
SGW89
SGW97
KFW81
KFW80
SGW96
SGW26
SGW103
SGW33
SGW95
SGW99
SGW100
KENSINGTON
SGW93
SGW101
SEABROOK
0 0.1 0.2 MILES
0 0.25 0.5 KILOMETERS

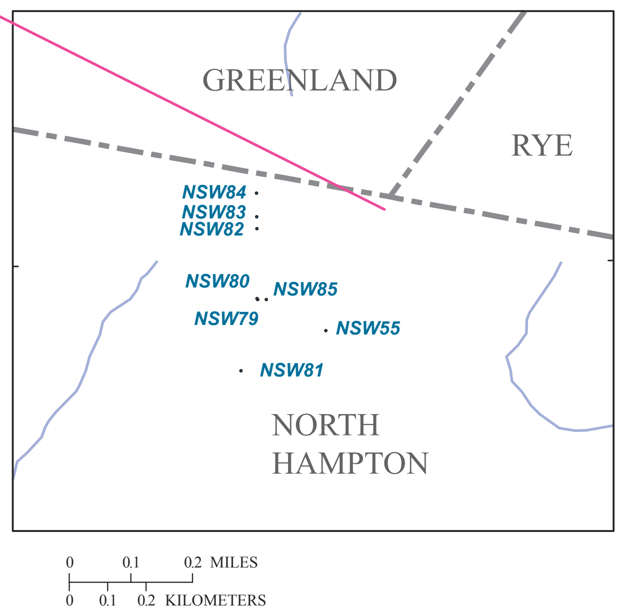

GREENLAND
RYE
NSW84
NSW83
NSW82
NSW80
NSW85
NSW79
NSW55
NSW81
NORTH HAMPTON
0 0.1 0.2 MILES
0 0.1 0.2 KILOMETERS

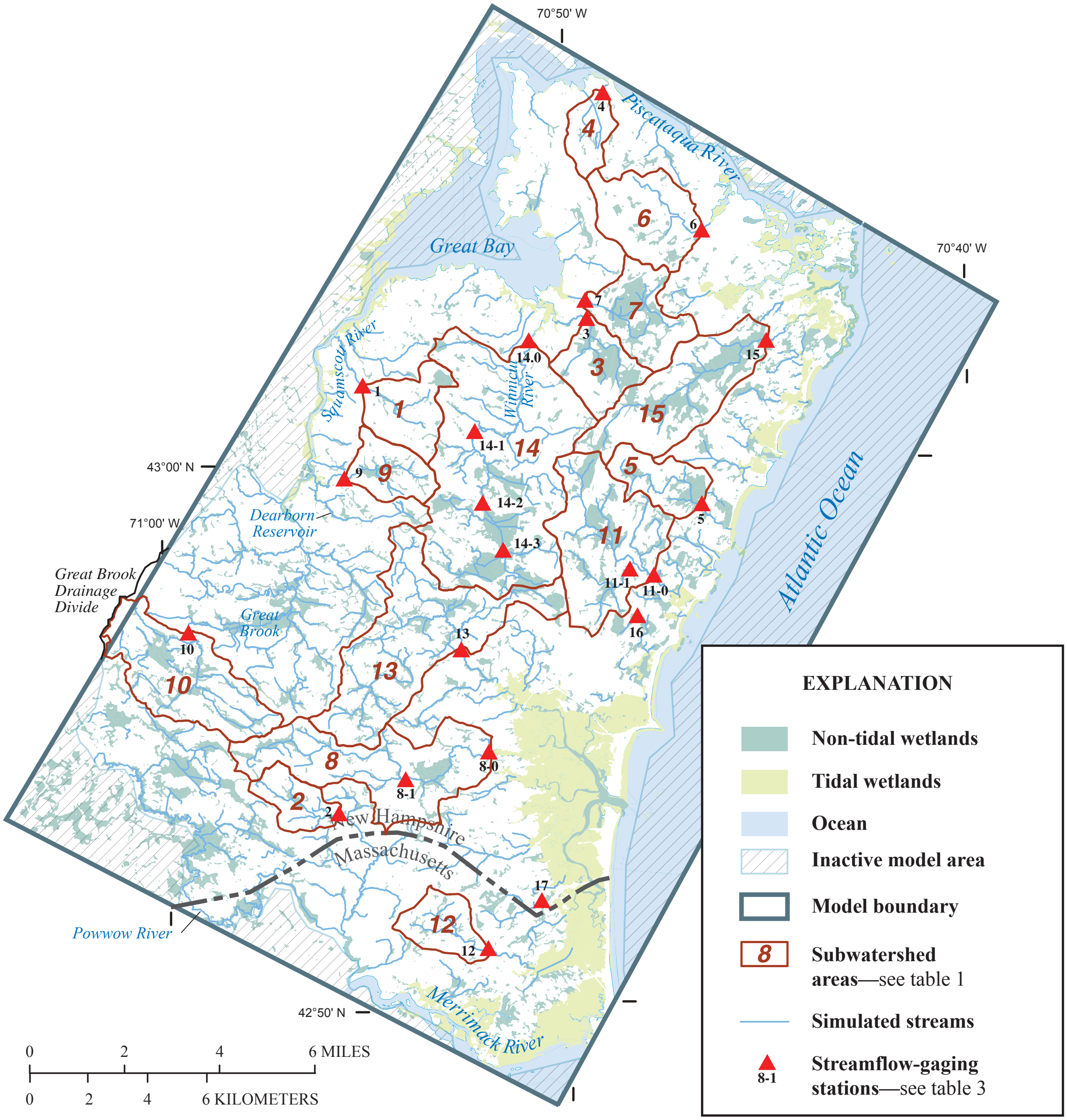
Table 4–1. Reported characteristics of selected bedrock wells, or well fields, in the Seacoast model area, southeastern New Hampshire.

[Wells shown on figure 4–2 unless otherwise indicated; gal/min, gallons per minute; ft/d, feet per day; gal/min/ft, gallons per minute per foot; *, not shown on figure 4–2; —, not available]

Town	Well site	Local well name	Average total yield or discharge (gal/min)	Depth (ft)	Draw-down (ft)	Storage coefficient	Hydraulic conductivity (ft/d)	Specific capacity (gal/min/ft)	Porosity or gravity drainage yield	Geologic unit	Reference
Seabrook	[2]SGW-89	Wells 1–4	1,300	500	—	4×10^{-4}	3.3	—	0.02	Kittery/Eliot	Earth Tech, Inc., 1998.
Seabrook	SGW-93	Well 5	560	492	—	4×10^{-4}	3.3	5	.02	Kittery/Eliot	Earth Tech, Inc., 1998.
North Hampton	NSW-76	Well 20	175	600	175	—	—	1.32	.02	Rye	Geosphere, Inc., 2003.
North Hampton	NSW-77	Well 21	200	600	440	—	—	.47	.02	Rye	Geosphere, Inc., 2003.
Rye	RYW-45	Bailey Brook	335	551	40	—	—	5.8	—	Rye	D.L. Maher, Inc., 1982.
Rye	RYW-51	Cedar Run	320	437	50	—	—	6	—	Rye	D.L. Maher, Inc., 1997b.
Stratham	*	Well 16	242	57	27	—	—	—	—	Kittery	D.L. Maher, Inc., 1997a.
North Hampton	NSW-78	Well 17	120	456	111 (80)[1]	—	—	[1]1.5	—	Kittery	D.L. Maher, Inc., 1996.
North Hampton	NSW-74	Well 18	150	600	109 (80)[1]	—	—	[1]1.9	—	Kittery	D.L. Maher, Inc., 1996.
North Hampton	NSW75	Well 19	220	435	133 (99)[1]	—	—	[1]2.2	—	Kittery	D.L. Maher, Inc., 1996.
Greenland	*	Assett 1	207	53	25	—	—	2.1	—	Kittery	Hydroterra Environmental, 2001.
Greenland	*	Assett 2	300	52	29	—	—	1.8	—	Kittery	Hydroterra Environmental, 2001.
Stratham	*	WM-1	42	400	69	—	—	.6	—	Kittery	Hydroterra Environmental, 2001.
Stratham	*	WM-2	43	400	54	—	—	.8	—	Kittery	Hydroterra Environmental, 2001.

[1] Estimated based on reported information.

[2] Wells 1, 3, and 4 are adjacent to SGW-89 (Well 2).



Streams and water bodies, including tidal and estuaries from 1:24,000 National Hydrography Dataset, 1999

Figure 4–3. Watershed drainage divides, tidal areas, and streamflow-gaging stations in the Seacoast model area, southeastern New Hampshire. (This figure is the same as figure 2 on page 5 in the report.)

west (Escamilla-Casas, 2003; Novotny, 1969). The pH of ground water withdrawn from the surficial aquifer is higher than water from other surficial aquifers (7 to 7.2) and indicates that some of the water in the surficial aquifer is likely to be supplied by the underlying bedrock aquifer (Raymond Talkington, Geosphere, Inc., oral commun., 2007) augmenting recharge directly on the aquifer. Thus, large ground-water withdrawals from the bedrock aquifer downgradient of the surficial aquifer probably are not supplied by recharge originating in the high-transmissivity surficial aquifer.

Lineaments were delineated in this area by Ferguson and others (1997a) and Geosphere, Inc. (2003). Most lineaments have a north-south orientation; however, several large lineaments, including a nearly 3-mi-long Landsat and 1-mi-long side-looking airborne radar (SLAR) lineament, were oriented in a northwest orientation along (or parallel to) a tributary to the Little River about 1,300 ft northeast of the well field. Several streams, including the Taylor River, Little River, and Bailey's Brook, have this same orientation (about N. 130 E.) and may represent a conjugate-fracture pattern orthogonal to the regional structure. Borehole and surface geophysical surveys conducted by Hager-Richter Geophysical, Inc. and reported by Geosphere, Inc., (2003) indicate that the predominant fracture orientation in the two wells is north-south and east-southeast, and that possible fracture zones also are oriented east-southeast. The east-west fractures at the site may intersect the large northwest-southeast trending lineaments (Geosphere, Inc., 2003). The specific capacities of wells 20 and 21 were calculated to be 1.32 and 0.47 gal/min/ft, with drawdowns of 175 and 440 ft, respectively, during an aquifer test of both wells (table 4–1) (Geosphere, Inc., 2003). A zero-drawdown distance was estimated to be 1,000 ft to the north, and 1,400 ft to the east. The porosity of the bedrock aquifer was assumed to be 2 percent. Withdrawals from this aquifer are distributed over the Aquarion Water Company system serving the towns of Hampton, North Hampton, and Rye.

Rye

High-yield bedrock aquifers have been identified in the town of Rye (Maher, 1982, 1997b). Lineament analysis indicated the presence of a possible fracture zone that may control the orientation of Berry's Brook (Maher, 1982). Lineaments along Berry's Brook (Ferguson and others, 1997b) and an unnamed tributary 3,000 ft south of the brook and south of Wallis Road both trend N. 50–70 E. in the direction of the regional structure. A 450-ft-deep bedrock well installed adjacent to Berry's Brook (RYW-52) with a reported yield of 150 gal/min was believed to be in a fault zone (Maher, 1982). Because the chloride concentration of the wells was 860 mg/L, it was suggested that the ground water may contain remnant saline water from the Pleistocene Epoch (Maher, 1982). The wells were not investigated further. A high-yield bedrock aquifer is also adjacent to Bailey Brook in Rye (Maher, 1997b). Bailey Brook well (RYW-45) and Cedar Run well (RYW-51, fig. 4–2), 920 ft southeast of the Bailey Brook well, both yield more than 300 gal/min with very little drawdown (about 50 ft) (table 4–1). This area is believed to be part of a broad northeast-trending fracture zone (Maher, 1997b). Borehole geophysical analysis (Johnson and others, 1999) identified northeast- and orthogonal northwest-trending fracture sets indicated in the lineament analyses of others. It is interesting to note that during drilling of the Bailey Brook well by high-pressure air-rotary methods, air bubbles were observed along the northwest-trending Bailey Brook (Gary Smith, Wright-Pierce, oral commun., 2004). The borehole analysis by Johnson and others (1999) also found the bedrock aquifer to be so highly fractured that the average radar-wave velocity approached values similar to those of an unconsolidated aquifer. Water-level monitoring at the Cedar Run well indicated very little interference—about 5 ft of drawdown—from withdrawals at the Bailey Brook well about 1,000 ft to the northwest. Withdrawals from this aquifer are distributed through the town of Rye's municipal water system.

Hampton/Stratham/Greenland

A high-yield bedrock aquifer is in an area surrounding the intersections of North Hampton, Stratham, and Greenland town lines in the Winnicut River watershed. This area, known as the Winnicut-Lovering Road (North Hampton) area, includes large withdrawal wells for the Aquarion Water Company. This area contains 3 overburden and 4 bedrock supply wells with combined yields of approximately 800 (overburden) and 700 (bedrock) gal/min, respectively. Ground-water levels in numerous residential wells in this area have been monitored since 1997 (Raymond Talkington, Geopshere, Inc., written commun., 2005). Well 16, the primary overburden well in this well field, is located in ice-contact glacial deposits of limited extent (fig. 4–1) that appear to follow a lineament identified by Ferguson and others (1997a) and Maher (1997a). Well 16 may be located in a trough in highly fractured Kittery Formation (Maher, 1997a). Three bedrock wells, 17, 18, and 19, were located 245 to 460 ft apart and had reported drillers yields of 175, 250, and 300 gal/min, respectively (Maher, 1997b). The total permitted pumping rate for this bedrock well field is 470 gal/min. Aquifer testing indicated that surficial and bedrock ground-water withdrawals at these wells most likely capture water discharging from the aquifer and do not induce infiltration from the Winnicut River (Maher, 1997a,b). Other nearby large ground-water withdrawals adjacent to the Winnicut River include ground water pumped seasonally for the Golf Club of New England (GCNE). Two sets of wells about 200 ft apart in Greenland (Assett 1 and 2), adjacent to the Winnicut River and in Stratham (MW-1 and MW-2), about 3,000 ft north of the Winnicut River were tested at a combined rate of 200 gal/min (Hydroterra Environmental Services, Inc., 2001). Aquifer tests at GCNE indicated that overburden aquifers (till and stratified drift, fig. 4–1) are well connected to the bedrock aquifer and that the Winnicut River may act as a hydraulic boundary limiting drawdowns in the bedrock aquifer (Hydroterra Environmental Services, Inc., 2001).

Greenland/Portsmouth/Newington

North of the Winnicut River watershed, the bedrock aquifer is not used for large ground-water withdrawals. Detailed characterizations of the bedrock hydraulic properties, however, have been conducted at the former Pease Air Force Base (PAFB) (Bechtel Environmental, Inc., 2000). Bedrock hydraulic conductivities vary from zero in unfractured rock to probably tens of feet per day in fractures. To determine bulk bedrock hydraulic properties, Bechtel Environmental Inc. (2000) conducted an aquifer test with three observation wells at least 450 ft from the pumped well, which is centrally located at PAFB near the contact between the Eliot and Kittery Formations. On the basis of this test, hydraulic conductivities of 2 to 15 ft/d and storage coefficients of 0.0002 and 0.0005 were calculated, and the bedrock aquifer was found to be hydraulically connected to a lower unconsolidated aquifer (Bechtel Environmental, Inc., 2000). At the northern area of the PAFB, hydraulic conductivity of 4 ft/d, storage of 2.6×10^{-4}, and a porosity[1] of 0.001 were estimated for the bedrock aquifer (Roy F. Weston, Inc., 1992).

[1] Because the reported porosity is from a hydraulic test, it is likely a percent volume associated with gravity drainage and not actual porosity.

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Appendix 5. Steady-State Model

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Appendix 5. Steady-State Model

The steady-state model was developed using a variety of observation data and was evaluated primarily with streamflow-discharge and ground-water head data collected in October 2004. The model represents ground-water flow during a seasonal low-flow period. The steady-state model parameters were developed with a combination of parameter estimation, literature values, and "transient model" results discussed later in the report (appendix 7).

Boundary Conditions

Boundary conditions include the movement of water (fluxes) into and out of the model cells. Fluxes were simulated by MODFLOW-2000 (Harbaugh and others, 2000) packages to represent: constant head surface, streams and streamflow routing, recharge, well withdrawals, and spatially distributed withdrawals and returns. Simulated withdrawals and returns are discussed in the steady-state model, "Water Use and Stresses" section.

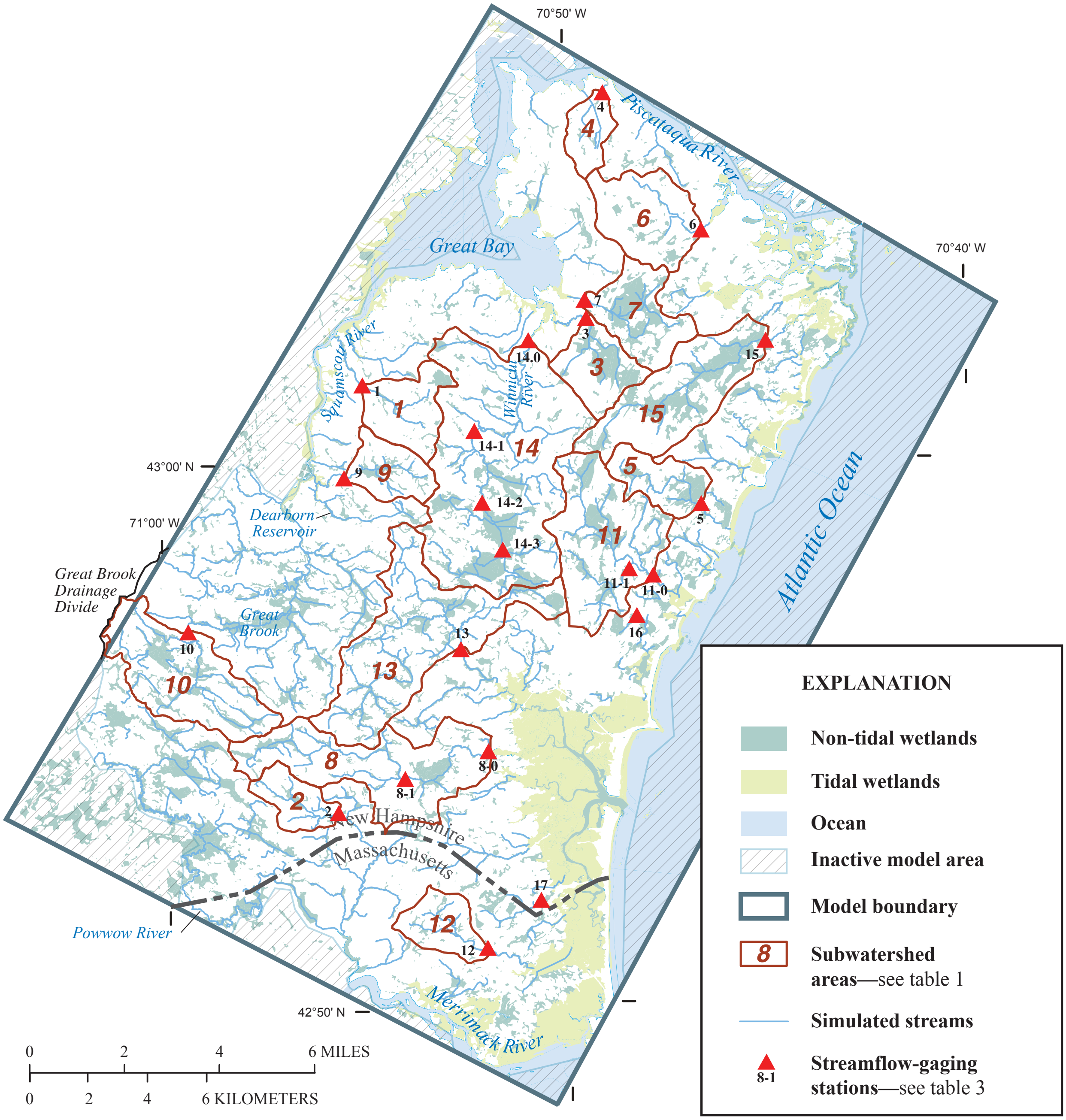
Lateral Extent

The lateral model extent was selected to coincide with major hydrologic features, or boundaries, which consisted primarily of surface water bodies and, in one location, part of a watershed divide (fig. 5–1). A 5-mi segment of the Great Brook drainage divide at the southwestern boundary of the model was defined as a no-flow boundary in model layer 1 (fig. 5–2). Below layer 1, all external lateral boundary cells were simulated as no-flow boundaries. All other lateral boundaries in model layer 1 were coincident with surface-water bodies and were simulated as constant-head boundaries. The lateral 6-mi long boundary south of the Great Brook watershed coincided with the Powwow River in New Hampshire and Massachusetts and was the only freshwater constant-head boundary in the model. More than three quarters of the model's lateral boundaries, a total length of about 50 mi, were defined by saltwater bodies including the Atlantic Ocean to the southeast, the Piscataqua River to the northeast, Great Bay and Squamscott River to the northwest, and the Merrimack River to the southwest.

Constant Head

The location of the fresh ground-water and saltwater interface in the bedrock aquifer of the Seacoast study area is not well known. The ground-water-flow model developed does not explicitly simulate the interface but it is assumed to be coincident with the shoreline on the basis of simulated heads and data from wells near the shoreline. In some low-lying areas immediately adjacent to Great Bay and the estuaries in Hampton Falls and Hampton, completion reports for domestic wells indicate seawater contamination (Frederick Chormann, New Hampshire Geological Survey, written commun., 2005). Seawater contamination can be readily apparent during drilling, and can be distinguished from road salt because it causes the circulated drilling water to foam during air-rotary drilling. In some cases such wells were grouted and another well was completed nearby that yields freshwater. Because such events have been reported only within the past decade, the sustainability of such withdrawals is not known. Locally, the occurrence and movement of water to an individual well depends greatly on the fracture network intersected by the well and the fracture network's connection to the regional fracture network. At the regional scale, the saltwater interface is believed to intersect the land surface at the shoreline (Mack, 2004). However, wells drilled farther inland may intersect the interface in low-lying areas with low hydraulic heads and withdrawal stresses as indicated by well-completion reports.

The saltwater bodies were simulated as constant-head boundaries with an equivalent freshwater head (EFH) (fig. 5–2) determined by the depth of the water body and the density of saltwater. Following this methodology (Langevin, 2003b), the EFH is equal to the depth at the midpoint of the saltwater body (or one-half the water depth) times a factor of 1.025 to account for the greater density of saltwater. Tidal water bodies in the study area generally are deep—in many places more than 50 ft deep—and, therefore, water bodies such as Great Bay form important hydrologic boundaries. Because saltwater depths are shallowest at the shoreline, the cells with the lowest EFH are in the saltwater body adjacent to the shoreline. The effect of the seaward extent of the EFH boundary area was assessed in preliminary model testing (Mack, 2004). It was found that increasing the areal extent of the EFH boundary in the seaward direction increased the flux of water from the sea toward the cells with lowest EFH simulated head; however, increasing the EFH boundary extent did not affect ground-water flow in the interior of the model representing the freshwater system. In a different hydrogeologic setting, with greater withdrawal stresses and hydraulic conductivity,



Streams and water bodies, including tidal and estuaries from 1:24,000 National Hydrography Dataset, 1999

Figure 5–1. Watershed drainage divides, tidal areas, and streamflow-gaging stations in the Seacoast model area, southeastern New Hampshire. (This figure is the same as figure 2 on page 5 in the report.)

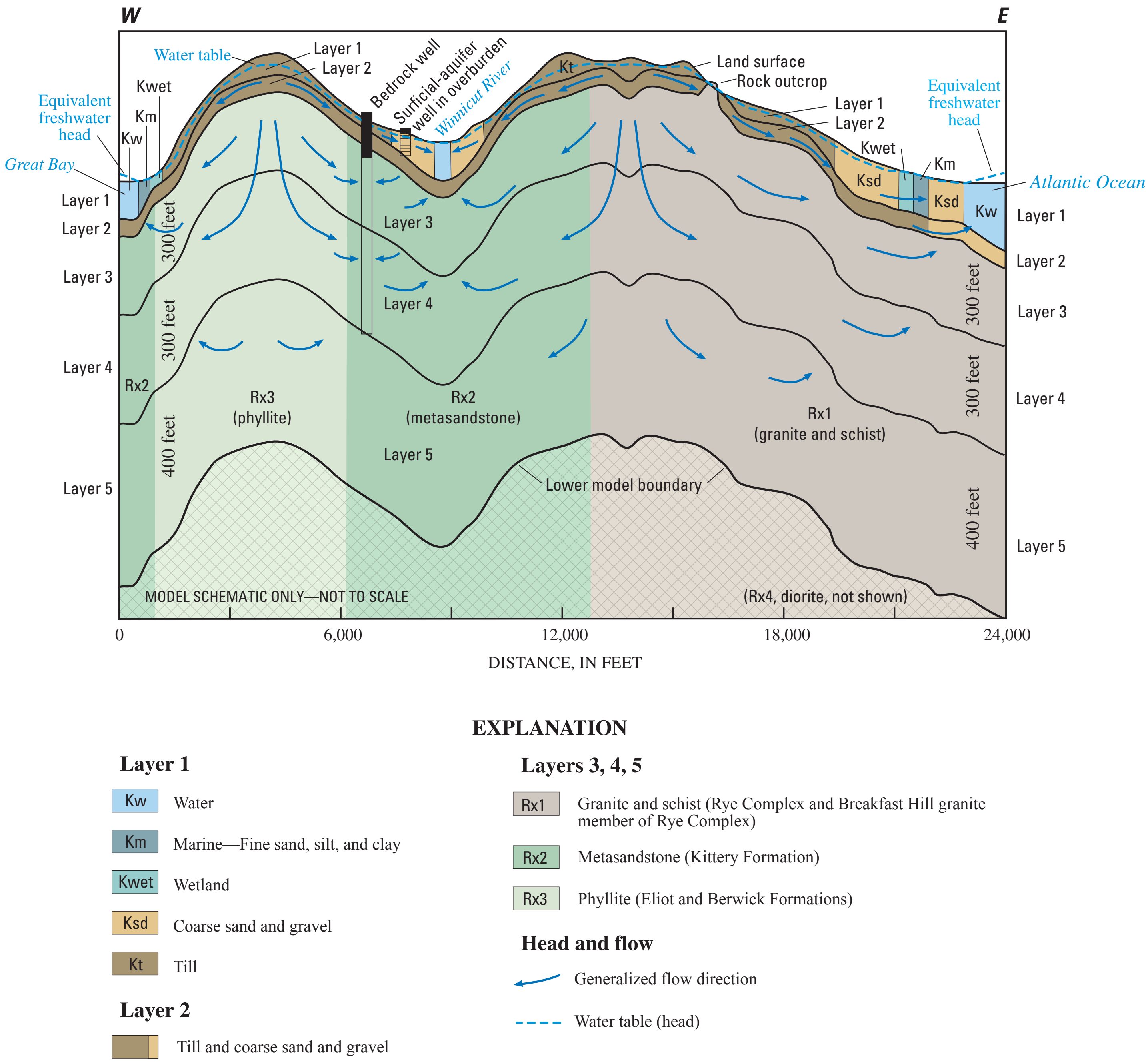


Figure 5–2. Schematic cross section of the ground-water-flow model for the Seacoast model area, southeastern New Hampshire. (This figure is the same as figure 13 on page 28 in the report.)

the lateral extent of the EFH boundary would likely be more important. In regional ground-water-flow simulations of the coastal-plain sediments of Georgia, Payne and others (2006) and Provost and others (2006) found that heads in the freshwater aquifer were not very sensitive to the offshore extent of the EFH boundary unless the offshore extent of that boundary was placed very close (immediately adjacent) to the shoreline. In the Seacoast model, ground-water flow in the freshwater aquifer was insensitive to the lateral extent of the EFH boundary because the withdrawal stresses were low, or not present, near the shoreline and the bedrock aquifer hydraulic conductivity was also low at the shoreline. Although the EFH boundary could have been placed at the point of the lowest EFH head (the shoreline) to represent the Seacoast hydrologic system (accurately), the boundary was placed a few hundred feet to a few thousand feet offshore to ensure that the lateral extent of this boundary was not a concern.

Streams

Stream boundaries were placed at intermittent and perennial streams and rivers in the study area (fig. 5–1), with the exception of tidal rivers. The Streamflow-Routing Package (STR1) (Prudic and others, 2004) for use with MODFLOW-2000 (Harbaugh and others, 2000; Hill and others, 2000) was used because it provides streamflow-routing capability in addition to the use of parameters for estimating streambed conductance, and observations of streamflow for the parameter estimation and observation processes. Stream characteristics required as model input include stream stage, streambed conductance, top and bottom elevation of the streambed, and width.

The flux (Q_L) from the stream to and from the aquifer in the model is controlled by the variables in equation 1:

$$Q_L = (K_{sb} wL/m)*(h_s - h_a), \tag{1}$$

where

(K_{sb})	is the streambed hydraulic conductivity,
w	is stream width,
(L)	is stream segment length,
m	is streambed thickness, and
h_s and h_a	are heads in the stream (stage) and aquifer, respectively.

The streambed hydraulic conductivity (K_{sb}) was assigned a parameter *(Ksb1)* and estimated by parameter-estimation techniques. The streambed hydraulic conductivity (K_{sb}) and bed thickness *(m)* however, were not known, as is commonly true in ground-water and simulations. Values of 1 to 5 ft/d have been calculated for streambed conductivity in New England (Mack and Harte, 1996; Lyford and others, 2003; DeSimone, 2004). It was not necessary to precisely determine the streambed hydraulic conductivity and thickness to simulate the effects of streams in this regional system; therefore, streambed conductance is effectively a lumped parameter.

Conceptually the aquifer system is well connected to the regional river system, which functions as the primary drain for the hydrologic system of the Seacoast. Parameter-estimation tests indicated that ideally the streambeds should not restrict discharge from the regional aquifer system to the streams. The optimal streambed conductivity was likely greater than 10 ft/d; however, lower values were required to prevent numerical oscillations caused by high fluxes at stream cells. Locally, such as at flow scales of tens or hundreds of feet, variations in streambed conductance limit or enhance the flux of water between the stream and the aquifer. Local effects, however, are not apparent at larger scales and were not apparent in the regional ground-water-flow system of the Seacoast area. For example, an aquifer test of Well 16 in Stratham adjacent to the Winnicut River indicated that discontinuous clays limited the drawdown in surficial sediments at the river in the vicinity of the well (Maher, 1997a). Over a larger area, however, withdrawals are supplied by the river-aquifer system. The flux of water into and out of the stream may depend more on the wider ranging hydraulic conductivity of the underlying aquifer sediments than on the local streambed hydraulic conductance. A spatially variable parameter for streambed conductance was assessed in preliminary models with the River Package (Harbaugh and others, 2000) but could not be applied in the current model using the Stream Package and MODFLOW-2000.

The stream-segment length *(L)* and elevations can be readily determined from DEM data. Stage was assigned the DEM elevation closest to the stream channel; the streambed top and bottom were assumed to be 1 and 2 ft, respectively, below the stage. Streams were generally small and were assigned a width of 5 ft. Actual stream widths may differ considerably at the cell scale (200 ft). In some wetland areas, due to the 40,000-ft^2 cell area, the cell elevation did not accurately reflect the true stream-surface elevation; as a result, the stages for a few cells did not decrease in downstream order. This problem arose for some wetlands with a poorly defined channel or high points in the wetland. Simulation of a stream channel in the wetland was not necessary because the wetland itself had a greater effect on the system than the stream. For the few areas where this occurred, preventing numerical convergence, streams in the selected cells were deleted, and streamflows were effectively routed through the wetland.

Recharge

Initial estimates of seasonal and average annual recharge in New Hampshire were from Flynn and Tasker (2004). Long-term average annual recharge in the Oyster River watershed, about 5 mi north of the Seacoast model area, was estimated to be approximately 19 in/yr. Recharge was applied to the numerical model by the MODFLOW-2000 Recharge package.

Recharge was represented with a parameter (Rech1), at an initial rate of 4.75×10^{-3} ft/d (19 in/yr), and applied to the topmost active model cell. The two exceptions were constant-head cells representing saltwater bodies for which it is not necessary to simulate a recharge, and exposed bedrock. About 0.2 percent of the model area consisted of exposed bedrock (table 5–1), which was generally represented by isolated cells or small clusters of cells. The application of an areal recharge rate, to a low-hydraulic-conductivity model cell representing bedrock would result in an anomalously high simulated head for that cell. In nature, recharge would not enter the bedrock outcrop at the areal rate, but would flow off the outcrop to an adjacent location; in this model, recharge was not applied to cells representing bedrock.

The areal recharge rate estimated for the model was reduced in two areas; wetlands and areas covered by marine sediments. Wetlands were considered to be hydraulically connected to streams, to have a high horizontal hydraulic conductivity, and therefore, to drain rapidly to surface-water bodies. In areas covered by low-hydraulic conductivity marine sediments, a full recharge rate results in water levels that are excessively high relative to the land surface. For these reasons recharge rates were arbitrarily reduced by half in wetland and marine areas. Similar approaches for recharge on wetlands and marine sediments were used by DeSimone (2004). Because marine sediments covered about 18 percent of the total model area (table 5–1) and do not completely cover any one watershed, their areal extent was too small to allow for the estimation of recharge rates by parameter estimation. Additionally, the effect of reducing recharge rates on wetland and marine areas was slight, a change of approximately a few percent, on the regional water balance.

Hydraulic Properties

The hydraulic properties of the surficial and bedrock aquifers differ with sediment and bedrock type. The surficial aquifers consist of glacial sediments that cover more than 80 percent of the model area (table 5–1), and the remainder consists of wetlands and water bodies (fig. 5–3). These aquifers are generally thin and their properties discontinuous. The bedrock aquifers exhibit regional variations in hydraulic properties that are reflected by well yields. Hydraulic properties of surficial and bedrock aquifers were simulated with MODFLOW-2000 using the Layer Flow Parameter (LFP) package. Required model inputs include aquifer thickness and hydraulic conductivity.

Regionally, high-conductivity stratified-drift aquifers act as a local short circuit in the regional ground-water-flow system (Harte and Winter, 1995); for this reason, vertical head differences within these aquifers are negligible. In addition, accurate calculation of vertical ground-water-flow gradients within the surficial aquifer was not critical in the regional model. Therefore, because the surficial aquifer is relatively thin regionally, and detailed vertical flow is not needed in the surficial unit, subdivision of the surficial aquifer beyond the 2 layers described above was not necessary.

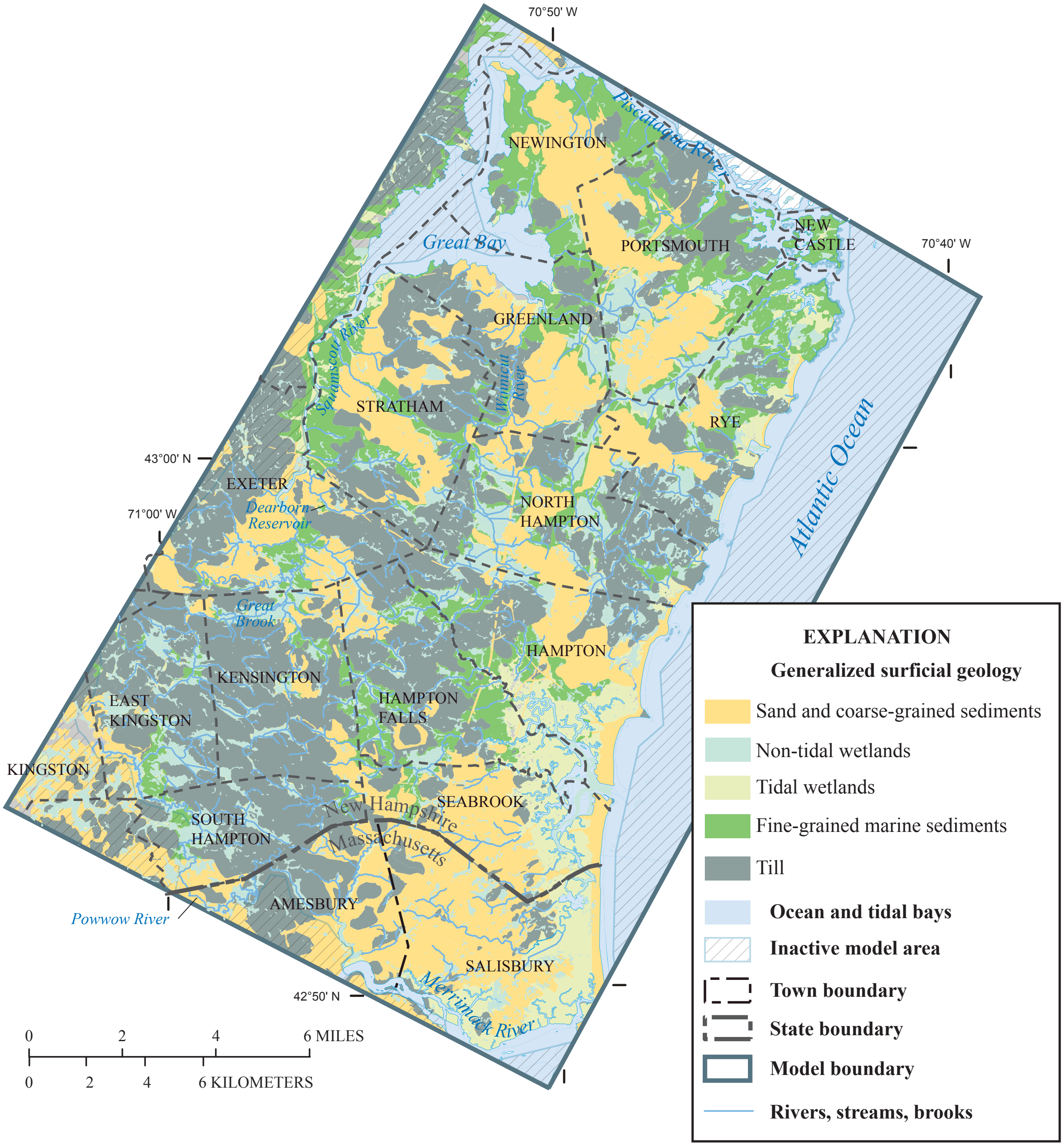
Surficial Aquifers

Most surficial aquifers, which cover approximately 80 percent of the simulated land area, consist of fine-grained till and marine silts and clays (fig. 5–3, table 5–1). Areas of coarse-grained stratified drift, primarily sands and gravels, are discontinuous and cover a smaller percentage of the study area (fig. 5–3, table 5–1). Surficial sediments generally are between 10 and 50 ft thick. The more extensive, high-transmissivity (on the order of thousands of ft^2/d), stratified-drift aquifers in the study area include the Pease aquifer and the stratified-drift aquifer at Great Brook in Kensington (fig. 5–3). Because the specific yields of the overburden aquifer deposits (till, fine and course grained stratified-drift) are similar—about 20 percent—the total amount of water stored in these deposits is controlled by thickness of the deposit.

Table 5–1. Subwatersheds and percentages of surficial geologic sediments, wetlands, surface-water bodies, and bedrock within each subwatershed, Seacoast model area, southeastern New Hampshire. (This table is the same as table 1 on page 10 in the report.)

[All streams are in New Hampshire unless otherwise noted. Subwatershed areas shown on figure 2; mi², square miles; —, not available]

Sub-watershed number (fig. 2)	River or stream name	Area (mi^2)	Stratified drift and other coarse-grained sediments	Marine sediments	Till	Wetland	Surface-water bodies	Bedrock
1	Mill Brook, Stratham	1.98	64.1	24.8	5.3	5.8	0.0	0.0
2	Back River, South Hampton	1.53	1.6	.0	94.1	4.0	.3	.0
3	Packer Brook, Greenland	2.31	49.2	27.0	7.3	14.8	1.7	.0
4	Pickering Brook, Newington	1.29	73.2	22.8	3.9	.0	.0	.0
5	Bailey Brook, Rye	1.95	39.5	10.1	43.0	7.1	.3	.0
6	Hodgson Brook, Portsmouth	3.52	49.4	26.4	23.0	.9	.3	.0
7	Pickering Brook, Greenland	2.97	43.5	11.8	15.8	28.1	.6	.1
8.0	Hampton Falls River, Route 1, Hampton Falls	6.66	22.3	21.7	52.0	3.2	.8	.0
8.1	Hampton Falls River, Mill Lane, Hampton Falls	3.61	10.4	.1	45.0	44.1	.4	.0
9	Parkman Brook, Stratham	1.89	23.8	33.8	42.1	.0	.3	.0
10	Great Brook, Kensington	5.45	1.1	6.8	81.3	10.6	.3	.0
11.0	Little River, North Hampton	6.12	22.9	23.2	46.1	7.4	.4	.0
12	Smallpox Brook, Salisbury, Mass.	1.83	95.0	5.0	—	—	—	—
13	Taylor River, Hampton	8.41	7.1	24.2	59.6	8.5	.6	.0
14.0	Winnicut River, Greenland	14.19	32.5	13.7	43.1	10.0	.6	.0
15	Berrys Brook, Rye	5.38	36.1	35.8	13.7	14.2	.1	.0
	Approximate total area and percentages of materials in the total area	230	24.3	17.6	39.1	7.7	11.1	.2



New Hampshire surficial geology base from 1:24,000 N.H. State Geologist, 2005
Massachusetts base from 1:250,000 MassGIS, 1999

Figure 5–3. Distribution of surficial sediments, wetlands, and water bodies in the Seacoast model area, southeastern New Hampshire. (This figure is the same as figure 3 on page 6 in the report.)

Hydraulic Conductivity

The hydraulic conductivity of surficial sediments was estimated for zones of materials with similar identifiable properties. Initial values of hydraulic properties were assumed on the basis of results from previous investigations described earlier in this report. The hydraulic-conductivity zones used were till (Kt): silt, clay, and undifferentiated marine sediments (Km); wetlands (Kwet); open water bodies (Ksw); and all other glacial sediments not designated as marine fine-grained, which primarily comprised stratified drift but included alluvium and fill (Ksd).

The horizontal hydraulic conductivity of stratified-drift aquifers was calculated as transmissivity divided by saturated thickness both of which were derived from contours determined in previous investigations (Moore, 1990; Stekl and Flanagan, 1992). The calculated horizontal hydraulic conductivity of coarse-grained sediments differed spatially from a few feet per day to more than 100 ft/d. Unlike the other parameter zones, the parameter zone Ksd was defined as a multiplier applied to the spatially differing hydraulic conductivity. The hydraulic conductivity within all other zones was kept constant.

Open water bodies (Ksw), including ponds and tidal water (ocean), were assigned horizontal and vertical hydraulic conductivities of 10,000 ft/d to effectively create flow-through cells and were not evaluated with parameter estimation. Wetland areas were simulated in a similar manner; the assignment of large horizontal hydraulic conductivities (100 ft/d) allowed water to be transmitted horizontally to streams or other features in or adjacent to the wetland, whereas the use of a low vertical hydraulic conductivity (1 ft/d) restricted vertical water movement.

The sensitivities of all parameters (except Ksw) were calculated, and based on the sensitivity analysis, selected values were estimated by using parameter estimation techniques (Hill and others, 2000). Parameter sensitivities and estimated values are discussed under the calibration section later in the report. Because of the regional nature of the Seacoast model, multiple layers of sediment were, in some areas, represented within a single layer (layer 1). Therefore, the effective hydraulic conductivities simulated by the regional parameter zone might have been higher or lower than the hydraulic conductivity that would have been simulated in a finely discretized, or site-specific, representation of a particular sediment. Therefore, the effective hydraulic conductivity calculated for a layered sediment as a whole is greater than that of a single low-hydraulic-conductivity layer within the unit.

Thickness

The thicknesses of layers 1 and 2 (fig. 5–2), which were primarily surficial deposits, were determined by subtracting each layer's thickness from the DEM elevation to produce elevations for layer 1 and layer 2. Layer 1 was meant to account for the varying thickness of stratified drift or other surficial deposits and was assigned a minimum thickness of 3.3 ft. Layer 2 was assigned a uniform thickness of 6.6 ft and was primarily meant to represent a till layer beneath other sediment types. Layer 2 was designed also to provide a thin saturated layer above the bedrock surface to accommodate some fluxes (recharge and water-use-return flows).

Saturated thickness, mapped by stratified-drift aquifer investigations (Stekl and Flanagan, 1992; Moore, 1990), was used as the primary thickness data for layer 1. The depth to bedrock, or secondarily the well-casing length minus 10 ft (the length of casing typically set into bedrock) for wells completed in bedrock, was used where available for the bottom of layer 1. For a group of boreholes within a few hundred feet of each other, such as in the study area for a site-specific investigation, the average depth to bedrock for the borings was used.

For areas where stratified-drift thickness contours or well data were not available, surficial geology (Bennett and others, 2004) was used to approximate the thickness of layer 1 for an area coded as bedrock, 0 ft; for an area designated as "thin," 15 ft; for areas designated as till (not including thin till), 25 ft; and for all other areas (primarily coarse-grained sediments, wetlands, and open-water bodies), 30 ft (a typical thickness). The thicknesses of surficial sediments in Massachusetts (Salisbury and Amesbury) were approximated by using geographic information system (GIS) coverages from MassGIS (http://www.mass.gov/mgis): for areas coded as till or bedrock, 20 ft; areas coded as unclassified sand, 20 ft; areas coded as sand 0–50 ft thick, 30 ft; for areas coded as sand 50–100 ft thick, 50 ft. Although MassGIS information indicated thick surficial sediments in Salisbury, few areas were expected to have thick surficial deposits. For areas with little or no thickness information, generally till areas, layer 1 was assumed to be 15 ft. In the model, till was assumed to be present in all non-stratified drift areas inland of the Atlantic Ocean. Till often is discontinuous beneath stratified-drift aquifers; therefore, for purposes of the regional-scale model, it was not assumed to be present in areas of stratified drift. Layer 1 also includes ocean and tidal-water bodies for which bathymetry data were used to estimate the thickness.

In areas of mapped bedrock outcrops, the thickness of all sediments is zero. Such areas generally were small and discontinuous, usually less than the area of a few model cells or even a single model cell. The incorporation of isolated inactive cells reduced the stability of the numerical model without increasing its capability. For this reason, a minimum thickness of 15 ft for a sediment layer (till) was applied in areas of bedrock outcrop, as described above, and bedrock parameters (discussed below) were assigned to the cell.

Bedrock Aquifers

Bedrock in the study area consists of crystalline metasedimentary and igneous rocks (Novotny, 1969). Heterogeneity in the bedrock aquifer was indicated by an analysis of statewide bedrock well-yield probabilities (Moore and others, 2002) that revealed distinct differences from formation to formation in the model area. Some of the highest well-yield probabilities in the State were associated with the Seacoast's Kittery Formation and Rye Complex. Other bedrock units in the study area, such as the Exeter Diorite and Newburyport Formations, were found to have low well-yield probabilities (Moore and others, 2002). Bedrock well-yield probabilities in the Seacoast area (Moore and others, 2002) differed regionally with geologic units (Lyons and others, 1997) and indicated regional variations in bedrock-aquifer hydraulic conductivity. The higher yield probabilities corresponded to areas of coarser grained bedrock such as the well bedded schist and gneiss components of the Rye Complex. Data from high-yielding bedrock wells in the Kittery Formation (Frederick Chormann, New Hampshire Geological Survey, written commun., 2006) that were not available at the time of the investigation by Moore and others (2002) show higher well yields than previously found (appendix 2, table 2–1).

The model grid was oriented parallel to the northeast-southwest regional structural pattern (fig. 5–4). Hydraulic conductivities of the bedrock aquifers in the Seacoast model were examined by zones (fig. 5–4) in the MODFLOW-2000 parameter-estimation process.

The actual hydraulic conductivity of bedrock aquifers in the study area, as in many investigated areas, is not known. The hydraulic conductivity of crystalline bedrock may span several orders of magnitude, as shown by Hsieh and others (1993), and also depends on the scale of investigation. An individual fracture or fracture zone can have a high hydraulic conductivity of hundreds of feet per day. At the regional scale, however, the hydraulic conductivity of the crystalline-bedrock aquifer is determined by the smaller fractures of the pervasive fracture network that forms the connection between high-conductivity zones (Tiedeman and others, 1997, 1998). The regional hydraulic conductivities estimated at the USGS's fractured-rock research site at Mirror Lake, N.H., ranged from about 0.01 to 0.1 ft/d (Tiedeman and others, 1997), whereas the hydraulic conductivities of fractures measured in boreholes at Mirror Lake ranged seven orders of magnitude (Hsieh and others, 1993).

In explorations for bedrock water-well locations, consultants generally assess lineaments as a first step in searching for fracture zones. For example, an assessment of a fractured-bedrock aquifer in coastal Maine found fracture-correlated lineaments, including a buffer zone of about 100 ft, to be positively correlated with greater bedrock well yields (Mabee and others, 1994). A spatial analysis of New Hampshire bedrock well yields (Moore and others, 2002) found lineaments within a 100-ft buffer zone to be positively related to yields. In a similar use of lineament data in finite-difference EPM model of a carbonate-aquifer system, which he terms a "fracture-zone continuum model," Langevin (2003a) simulated fracture traces (lineaments) with a hydraulic conductivity 100 times the matrix conductivity. Langevin (2003a) stochastically assessed bulk (regional) and matrix-block transmissivities and the effects of the matrix-block conductivity of fracture zones on ground-water-flow paths and traveltimes to large ground-water withdrawals. In the Seacoast model, ground-water head and discharge data were not sufficiently detailed to calculate fracture-zone block conductivity or estimate the sensitivities. Bedrock aquifer heterogeneity was incorporated into the model, however, by simulating the hydraulic conductivity of bedrock at cells containing lineaments (Degnan and Clark, 2002; Ferguson and others, 1997a,b) at 10 times the bulk hydraulic conductivity. Within a model-cell area of 200 by 200 ft, this increased value of hydraulic conductivity represents a buffer zone of slightly more than 100 ft around the lineament. A fracture zone may be less than the width of the model cell (200 ft), and the conductivity of fractures in such a zone is likely very high. A preliminary simulation of fracture zones with a hydraulic conductivity two orders of magnitude higher than the bulk conductivity, indicated that fracture zones, although locally very important, do not have a large effect on the regional flow system. The regional aquifer system is more sensitive to the degree of fracturing in the bulk rock matrix (Tiedeman and others, 1997, 1998).

In this investigation the bedrock aquifer was divided into three layers (fig. 5–2). The upper two layers (layers 3 and 4), each 300 ft thick, represented the layers in which most bedrock wells were completed. The lowest bedrock layer (layer 5) was 400 ft thick and represented the depth of a few deep bedrock wells in the study area. Layer 5 likely represents the greatest depths of

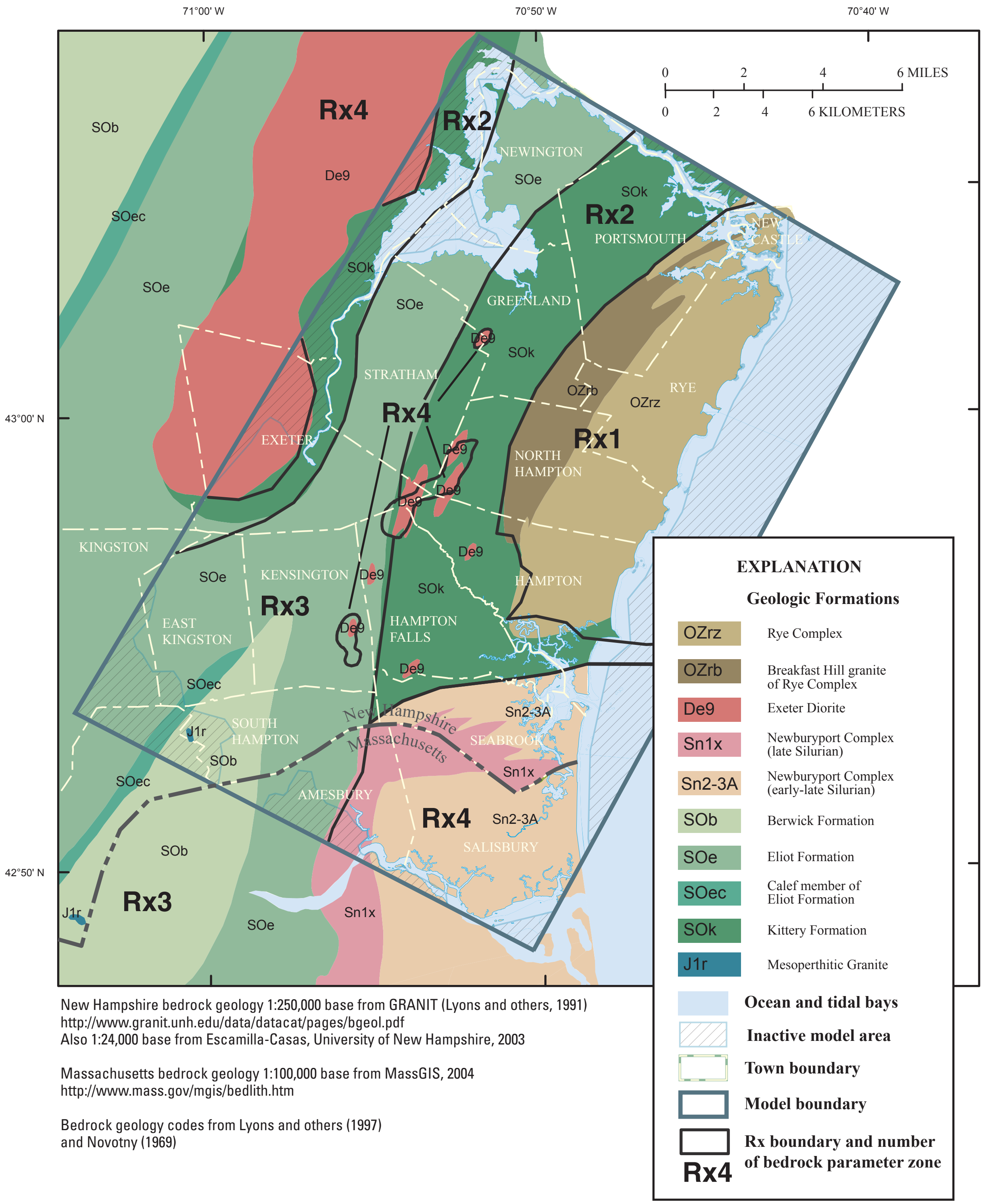


Figure 5–4. Dominant bedrock formations in the Seacoast area and bedrock parameter zones used in the Seacoast model, southeastern New Hampshire. (This figure is the same as figure 4 on page 7 in the report.)

the principal bedrock-aquifer flow system. Although fracture density most likely decreases with increasing depth, fracture density was assumed to be uniform for the depths investigated (less than 1,000 ft below land surface) and was held constant throughout all of the bedrock model layers (3–5). Johnson and Dunstan (1998) found no uniform pattern of fracturing with depth in a detailed investigation of bedrock boreholes at Mirror Lake, N.H. Hydraulic properties of the bedrock aquifers were simulated by the MODFLOW-2000 Layer-Property Flow (LFP) package (Harbaugh and others, 2000). Initial bedrock hydraulic conductivities of about 0.2 ft/d were modified by using the parameter-estimation process.

The bedrock aquifer was subdivided into zones representing the major geologic formations. Preliminary assessments evaluated nine bedrock parameter zones based on bedrock-formation subdivisions: Rye Complex, Breakfast Hill Granite, Eliot Formation, Kittery Formation east and west of Great Bay, Newburyport Complex, Exeter Diorite and inclusions of Exeter Diorite in other formations, and the Berwick Formation (Escamilla-Casas, 2003; Lyons and others, 1997). Individual zonation of the nine mapped bedrock formations, however, was not supported by the available data used in the regional ground-water-flow simulation. In consultation with Dr. Wallace Bothner (University of New Hampshire, oral commun., 2006) the bedrock units were grouped into four zones of similar hydraulic conductivity on the basis of bedrock-well yields. The formation groupings and the four associated abbreviations for hydraulic conductivity were (fig. 5–4) Rye Complex, and related Breakfast Hill Granite (Rx1); Kittery Formation (Rx2); Berwick and Eliot Formations (Rx3); and the Exeter Diorite Formation and Newburyport Complex (Rx4).

The anisotropy of the bedrock aquifer may have little influence on the quantity of water in the bedrock aquifer. Anisotropy is of interest in this investigation, however, because it is a variable affecting recharge source areas and residence time of ground-water flow to bedrock water-supply wells. Additionally, anisotropy is particularly important with respect to water-supply protection in the model area. In an investigation of coastal bedrock aquifers in Maine, few bedrock wells along Maine's coastline were found to be affected by saltwater intrusion (Caswell, 1979a, b). Caswell suggests that the absence of extensive intrusion is probably the result of the water-bearing fractures of the crystalline rock being parallel to the coastline. In another investigation (Richard, 1976), saltwater was to found to have contaminated wells in a coastal area of Maine where the water-bearing fractures were perpendicular to the regional structure (the coastline). The model area in this study was also characterized by bedrock with a prominent southwest-to-northeast structure. Studies of fracture orientations in the Seacoast area (Escamilla-Casas, 2003; Novotny, 1969) indicated that fractures were predominantly oriented along the regional structure parallel to the coastline. An investigation of bedrock-fracture orientations (Mack and Degnan, 2003) in boreholes in the Kittery Formation also found the dominant fracture orientation to be aligned with the regional structure.

Anisotropy was assessed in two parameter zones; one anisotropy zone (Hani1) included the bedrock zones Rx1, Rx2, and Rx3 because the general fabric of these three bedrock zones follows the northeast-trending bedrock structure. The second anisotropy zone (Hani2) is the fourth bedrock zone (Rx4), which consists primarily of intrusive bedrock with less fabric-controlled anisotropy (fig. 5–4).

Water Use and Stresses

The distribution of water uses simulated in the Seacoast model is illustrated in figure 5–5. Registered withdrawal wells, withdrawals greater than 40,000 gal/d and community-supply wells were simulated in layer 1 (overburden) and layers 3 and 4 (bedrock) by the Well (WEL) package (Harbaugh and others, 2000). All other withdrawals for distributed commercial, industrial, and domestic water use were simulated in layers 3 and 4 by the Flow and Head Boundary (FHB) package (Leake and Lilly, 1997). Returns associated with the distributed withdrawals were simulated in layer 2 with the FHB package.

Water uses in the Seacoast area at the time of this study, include surface- and ground-water withdrawals and returns for supply, domestic, commercial, and industrial uses. Water use in the Piscataqua River and coastal watersheds has been described by Horn and others (2007). Water-use data used as model input were based on water-use and return coefficients (Horn and others, 2007) and compiled for the ground-water-flow model (Marilee A. Horn and Laura Hayes, U.S. Geological Survey, written commun., 2006). Commercial, industrial, and domestic uses were estimated from use coefficients determined from metered data, business, and census data. Large withdrawals greater than 20,000 gal/d reported to NHDES were incorporated into the model as wells in layer 1 and layer 3 (fig. 5–5A). Minor water users included community water systems (CWS) and industrial, commercial, and domestic users. Water use at CWSs was calculated on the basis of the number of homes connected to a system and water-use coefficients (Horn and others, 2007). Industrial and commercial water-use rates were calculated on the basis of water-use coefficients and business employee and process information. Large withdrawals and CWSs registered with NHDES were simulated as wells and totaled about 7.8 Mgal/d in the model area.

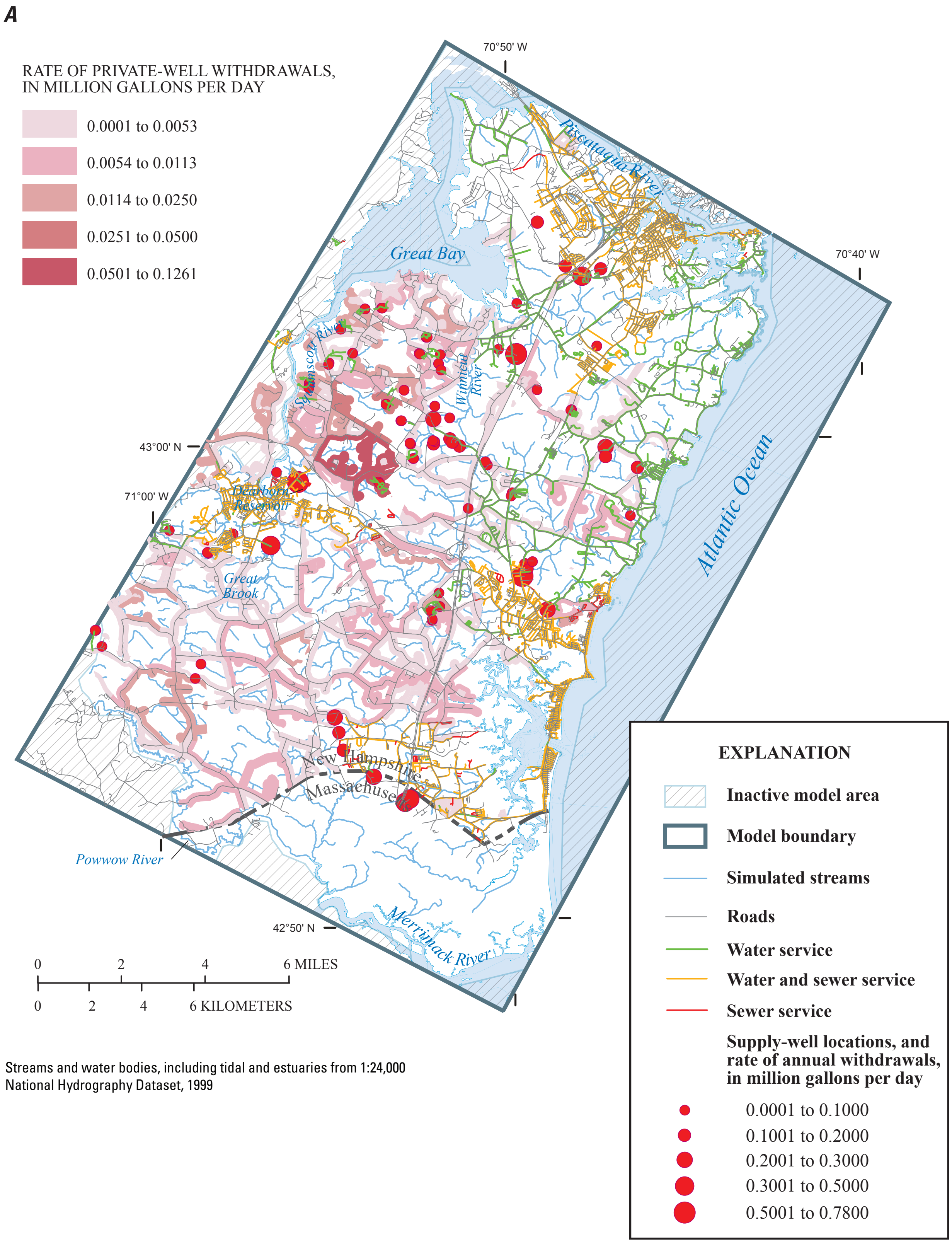


Figure 5–5. *(A)* Private-well and community-supply withdrawal rates, water-distribution, and sewer-service systems in the Seacoast model area in 2003, southeastern New Hampshire.

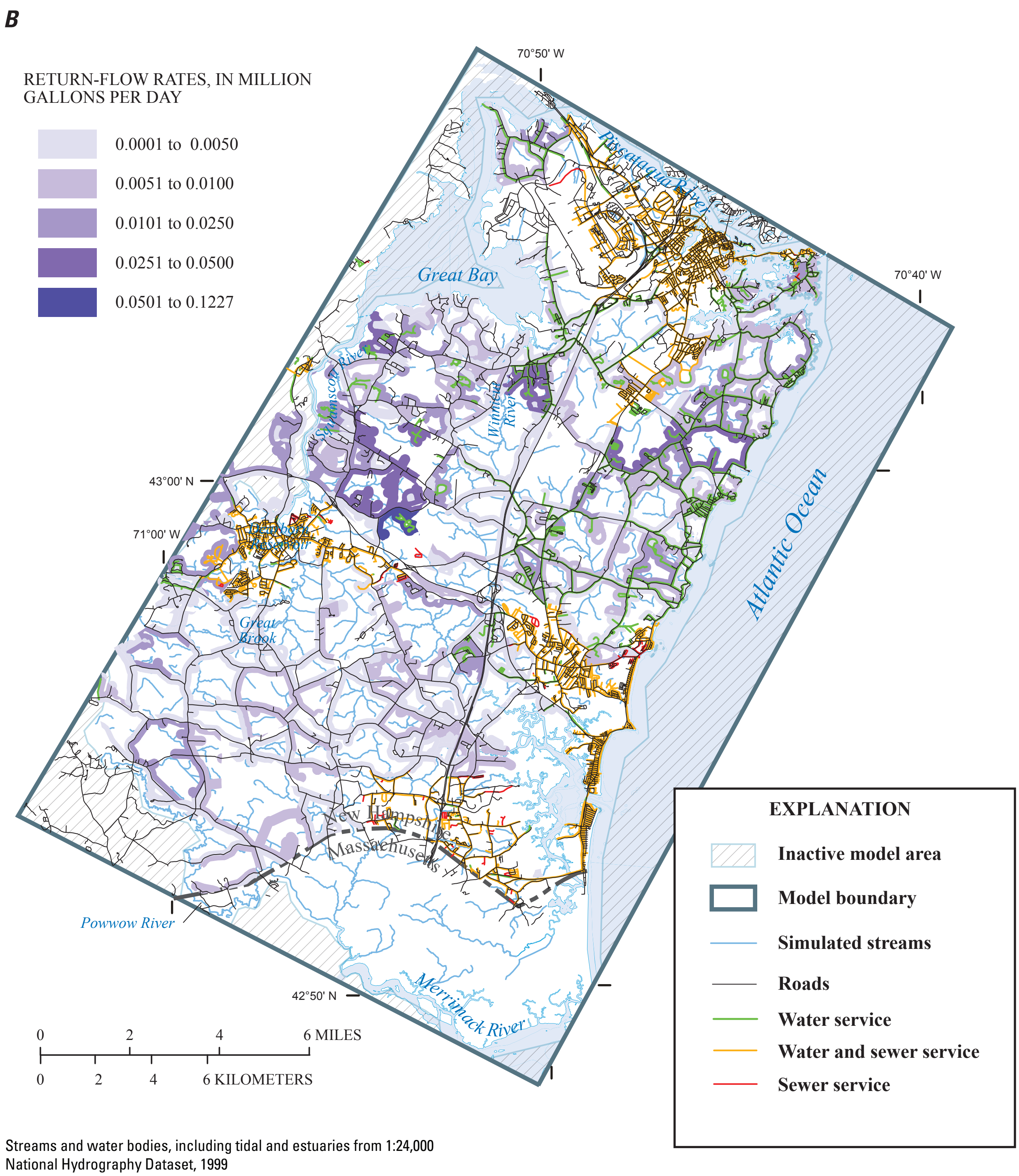


Figure 5–5. *(B)* Water-return rates, and water-distribution and sewer-service systems in the Seacoast model area in 2003, southeastern New Hampshire.—Continued

Smaller withdrawals (not large withdrawals or CWS systems) were almost entirely from bedrock wells and were simulated as distributed uses by the FHB package in model layers 3 and 4. The distributed withdrawals amounted to about 2.7 Mgal/d in the model area. Water returns from the distributed withdrawals were simulated in model layer 2 to approximate infiltration of water from a leach field to the surficial aquifer in all areas that were not sewered (fig. 5–5B). These distributed water uses were estimated by census block for the model area (Horn and others, 2007). The census blocks differed in area from a city block to nearly one-half a square mile, depending on local demographics, and therefore, each block was represented by a few to hundreds of model cells (fig. 5–5B). For most census blocks, the water is actually used near the perimeter of the census block by the homes and businesses predominantly along the streets that form the block boundary. In this case, the water use for the block was applied to model cells on the inside perimeter of the block. At a census-block boundary formed by a stream, the boundary was assumed not to be associated with water use, and the use was distributed to model cells on the inside perimeter of the other three boundaries. The distributed returns amounted to about 2.2 Mgal/d in the model area.

For census blocks with no sewer systems, water returns were simulated by the same method as the distributed withdrawals. For blocks with withdrawals and sewers, withdrawals but no water returns were simulated for that block (fig. 5–5). For blocks with a water-supply system (supplied water) but no sewers, only returns were simulated for that block (fig. 5–5). For blocks with water-distribution systems or sewers, both withdrawals and returns were simulated for that block (fig. 5–5). Consumptive use was estimated by comparison of summer and winter water-use rates (Horn and others, 2007). Returns differed with water-use category and season but were about 85 percent on an annual basis. In some areas with supplied water and sewering, major water uses include the watering of lawns and landscaped areas. It was assumed that most such water use is evaporated or transpired from the surface and does not leach to the underlying aquifers—in other words, that this water is consumed. Such uses were accounted for in the model as a loss.

Surface-water withdrawals, such as agricultural or golf-course withdrawals, were often from small ponds and were simulated as a withdrawal (by the WEL or FHB package) in model layer 1. Surface-water withdrawals from the Dearborn Reservoir in Exeter (fig. 5–1), the only surface-water supply in the model area, was simulated as a withdrawal (well) in a cell of the cluster of cells that represent the reservoir in the model.

Calibration and Observation Data

The steady-state model was calibrated to observations of ground- and surface-water levels and stream base flows from September and October 2004 with additional ground and surface-water-level observations from other periods. Nine broad geohydrologic zones used were used in the model to form consistent geologic or hydrologic areas. The zones consisted of four zones unconsolidated sediment (stratified drift, till, wetlands, and marine sediments), four bedrock zones, and one zone representing open water bodies. Parameter zones were used to represent the hydraulic properties of the units (horizontal and vertical hydraulic conductivity and horizontal anisotropy) and other features such as recharge or streambed conductivity. During calibration, model characteristics were adjusted by parameter zone; for example, the hydraulic conductivity of each zone was consistent within that zone and changes were made to the zone as a whole. Although a better model fit could have been obtained by adjusting the characteristics for individual model cells within parameter zones, such modifications made without a conceptual basis do not improve the quality of information about hydrologic processes in the area and may not result in a realistic model. Instead, the goal of the calibration process was to provide information about regional hydrogeologic processes as opposed to matching discrete observations.

Model calibration depends on observations of the ground-water-flow system. Observations were used to find the best-fit model parameters, and the known or estimated errors of the observations were used to calculate the sensitivity of the ground-water-flow model to the model parameters. Observations included measured or estimated ground-water heads, ground-water discharges (base flows), and the ages of ground-water samples. The accuracies of sets of observations were determined, following the methods of Hill (1998), by weighting observations according to their measurement error. By this process, data sets with greater accuracy were given greater weight in the parameter-estimation process; this permits data sets with different levels of accuracy to be used simultaneously in the parameter-estimation process. Although observational error is rarely known in practice, it can be estimated, and parameter values generally were not sensitive to moderate changes in the weights (Hill, 1998).

The steady-state parameter-estimation process was done for all model layers simulated as nonconvertible (saturated) to linearize the numerical calculations. Although some areas in the natural system were likely to become unsaturated, simulating all layers in the numerical model as saturated greatly simplifies the numerical calculations for a highly heterogeneous model. As was true in this investigation, simulation of low hydraulic-conductivity aquifers can be subject to convergence difficulties and thus unstable; the same problems apply to nonlinear parameter estimation. The simplification (linearization) approach is presented as a guideline for effective model-calibration method described by Hill (1998). Hill (1998) also describes recent publications that indicate that linear confidence intervals were accurate enough for many ground-water flow problems. To ensure that the parameter estimates produced by linear processes were acceptable, the ground-water-flow model was simulated with the same linear parameter estimates while layers 1 and 2 (surficial aquifer) were allowed to convert to unsaturated (nonlinear) conditions. The unconfined (nonlinear) ground-water-flow simulation was found to be less stable, as a result of cells drying; however, the simulation converged with less than 1 percent discrepancy in the volumetric budget.

Base Flows

During periods with little recharge, the streamflow in a watershed is primarily the result of ground-water discharge and is called base flow. Continuous streamflow data can be used to calculate ground-water discharge from a watershed (Rutledge, 2000; Risser and others, 2005). Streamflows were measured throughout the study area on October 7 and 8, 2004, during a period of streamflow recession (table 3). The flow duration at the Oyster River streamflow-gaging station during this period was about 70 percent. Estimated annual average base flows were used as observations of long-term steady-state conditions, and October 2004 base flows were used as observations of a low base flows.

Streamflow measurements in the model area were expressed with an accuracy that represents the estimated percentage of values within 95 percent of their true value (Keirstead and others, 2005). The accuracies of streamflow records were described as excellent, good, fair, or poor indicating that 95 percent of the daily discharges were within 5, 10, 15, or less than 15 percent, respectively, of their true values (Keirstead and others, 2005). Continuous streamflow records in the model area were rated on the basis of site conditions and station operation during the study as: Mill Brook, fair; Winnicut River, fair; Berry's Brook, fair; Little River, good; and Hampton Falls River, good (Keirstead and others, 2005). Spillway operation at the Winnicut River Dam and beaver activity at Berry's Brook prevented the collection of better records at those sites. For comparison, the streamflow record for the Oyster River station was rated good for the same period of record. Individual (miscellaneous) measurements, collected at several streamflow stations in the model area, generally were considered to be good (within 10 percent of their true values). A standard deviation for the measurements within a 95-percent confidence interval can be calculated as (observation × accuracy)/1.96 (Hill, 1998). In the parameter-estimation package for MODFLOW-2000, the coefficient of variation can be specified directly with each observation. In the model area, base flows derived from streamflow measurements were observations of the net gain in streamflow over the streamflow in a subwatershed upstream of the measurement point.

Observed and simulated base flows were listed in table 5–2 and shown in figure 5–6. In general simulated base flows agree well with observed base flows. Base flows in most of the larger streams in the model area were simulated well, including Winnicut River, Little River, and Hampton Falls River, as indicated by a weighted residual (dimensionless) within one standard error of regression. The standard error of regression, or standard model error, is defined as the square root of the calculated error variance. If the fit of the model is consistent with the data accuracy, as reflected in the weighting, the expected value of the standard model error is 1.0 (Hill and Tiedeman, 2007). In practice, the standard model error is commonly greater than 1 and reflects model and measurement errors (Hill and Tiedeman, 2007). The standard error of regression was 5.6 for this simulation.

Fourteen streams were simulated within 2 standard model errors (table 5–2, fig. 5–6), and 9 were simulated within one standard model error. Streams that were simulated poorly included some of the small watersheds with the exception of Great Brook, a midsized watershed (5.50 mi^2). The simulated base flow in Great Brook was about twice the measured base flow. A similar anomalous condition was found by Flynn and Tasker (2004) for a station on Dudley Brook in Exeter, about 1 mi west of the model area in a similar surficial and bedrock setting. The measured base flow at Dudley Brook was found to be much lower than the value estimated by hydrograph separation. It is possible that the hydraulic conductivity and storage in the principal bedrock unit underlying the Great Brook drainage were lower than estimated by the model or that more connected wetlands than were simulated drained the Great Brook watershed. The results for Great Brook indicate that this watershed system is not well understood or that it may not be more complex than the modeled watershed. Streamflow measurements were collected only once at Great Brook, and those measurements may not be representative of base-flow conditions.

Nilus Brook is in a small (1.5 mi^2) watershed where the model calculated essentially no base flow. Streamflow measured in Nilus Brook (table 3) in October 2004, however, was drainage from a pond and likely does not include ground-water discharge. For this reason, the Nilus Brook streamflow measurement was removed from the observation data set.

Table 5–2. Observed and simulated base flows for October 2004 in the Seacoast model area, southeastern New Hampshire.

[Site number shown on figure 2; mi^2, square miles; ft^3/s, cubic feet per second; —, not applicable]

Site number	Stream	Area (mi^2)	Observed (ft^3/s)	Simulated (ft^3/s)	Weighted residual (dimensionless)
14-0	Winnicut River, Greenland	14.2	-7.3	-7.6	0.4
13	Taylor River, Hampton Falls	8.41	-4.8	-6.9	4.4
15	Berrys Brook, Rye	5.38	-3.1	-3.9	2.5
11-0	Little River, North Hampton	6.12	-2.5	-2.8	1.1
10	Great Brook, Kensington	5.5	-1.8	-3.7	10.3
8-1	Hampton Falls River, Hampton Falls	3.62	-1.7	-1.4	-1.9
6	Hodgson Brook, Portsmouth	3.52	-1.2	-0.3	-7.1
5	Bailey Brook, Rye	1.73	-1.1	-.5	-5.0
1	Mill Brook, Stratham	2.48	-1.0	-.9	-1.1
12	Smallpox Brook, Salisbury	1.83	-1.0	-1.6	6.4
16	Nilus Brook, Hampton	1.5	-0.61	—	—
7	Pickering Brook, Greenland	2.97	-.6	1.0	5.9
9	Parkman Brook, Stratham	1.91	-.6	-.6	.0
3	Packer Brook, Greenland	2.25	-.6	-.6	1.5
2	Back River, South Hampton	1.53	-.5	-1.1	10.8

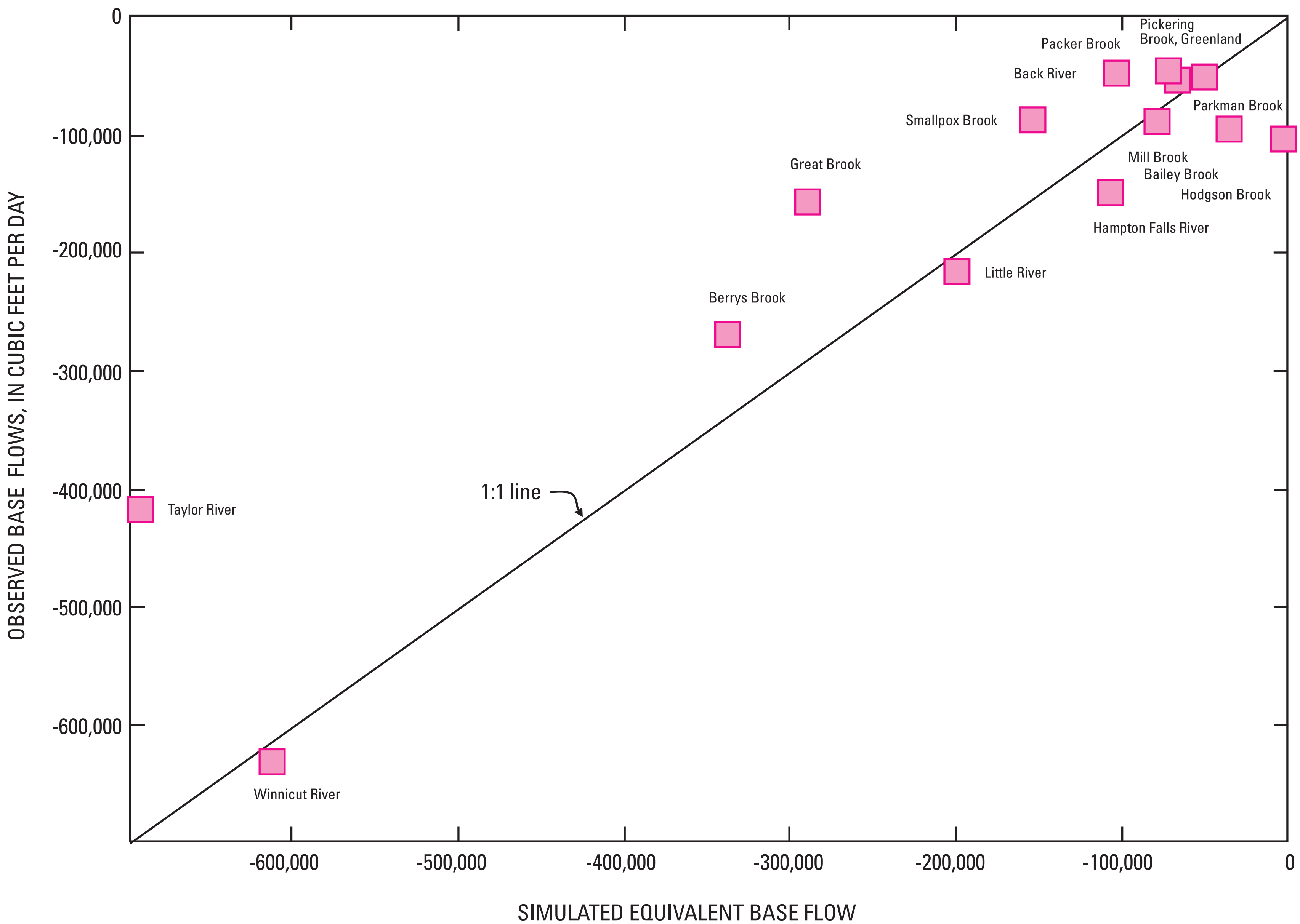


Figure 5–6. Observed and simulated base flows for October 2004 in the Seacoast model area, southeastern New Hampshire. The base flows are negative because they represent flow out of the aquifer system.

Ground-Water Levels

Preliminary analyses indicated that in the regional simulation, a greater distribution of less accurate observations is more important than fewer highly accurate observations (Mack, 2003). For this reason, ground-water levels (heads) used in model calibration were obtained from six sources to provide areally distributed calibration points. The sources included well completion reports, waste-site reports, previous investigations, hydrographic coverages of water suppliers water-level networks, and heads measured in this study. Overburden-well data, or other surficial-head data, were used for model layer 1, and bedrock-well data were used for model layers 3 and 4. Head data generally were expressed as a depth or elevation with an estimated error (length). Ground-water-head observations were weighted according to measurement accuracy according to the guidelines of Hill (1998) and Hill and others (2000).

As of March 2006, the New Hampshire database of well-completion reports (Frederick Chormann and Derek Bennett, New Hampshire Geological Survey, written commun., 2006) included nearly 2,800 georeferenced wells in the model area. Of the ground-water-level measurements in this data set, termed “Historical” heads in the calibration analysis, about 75 were in the overburden aquifer and 820 in the bedrock aquifer. Most of the measurements were in drillers’ completion reports for wells constructed during the past 20 years. Ninety-eight percent of those wells were bedrock wells drilled for domestic use. The water-level observations represent measurements recorded by drillers in all seasons with a slight seasonal bias. Seventy-three percent of the bedrock wells for which water levels were recorded were drilled in the 7 months from April through October, while 27 percent of wells were drilled in the remaining 5 months. Most of the water-level measurements were equally distributed in time between April and October, the months during which the range in water levels is generally the greatest. The seasonal variation in overburden or bedrock ground-water levels, which was not accounted for in the model, is about 2 to 4 ft. The drillers’ measurements of depth to water may be accurate to less than a foot; however, the ground-water altitudes used contain other sources of error. Of greater magnitude than seasonal bias is resulting from estimation of the measurement-point elevation. Ground-water altitudes derived from this data set were calculated by subtracting depth to water from the measurement point, which in this case was the model-cell surface elevation interpreted from the DEM. The DEM can be considered to be accurate to within one half the contour interval, or 10 ft. If half of one contour interval (10 ft) is assumed to be the 95-percent confidence interval, the standard deviation of the DEM value would be about 5 ft. Because the measurement-point elevations were the primary sources of error in this water-level data set, the water-level data completion in the report were weighted on the basis of the DEM accuracy. Given the uncertainties involved in well location and measurement, a standard deviation of 10 ft was used for water-level observations from this data set.

Overburden and bedrock heads also were obtained from the NHGS GEOLOGS database for waste sites (Gregory Barker, New Hampshire Geological Survey, written commun., 2005). The water levels generally were measured quarterly or biannually at a specific site. Sites with a total of 78 overburden and 10 bedrock-aquifer monitoring wells with multiple water-level measurements were selected, and the measurements for each well were averaged to provide a mean level. Although the data generally were surveyed and collected with an accuracy of 0.01 ft, water-level data were averaged and a standard deviation of 7.5 ft was assumed.

Heads also were collected primarily in September and October 2004 from ground-water-level networks at 133 wells. The head data collected during this period were termed “Synoptic” heads. Ground-water levels also included 122 bedrock heads measured adjacent to Great Bay during June 2000 (Roseen, 2002) and heads measured at the former PAFB in Newington. These data generally were reported to be within 0.01 ft, and for the purposes of the regional ground-water-flow model, the standard deviation was 5 ft. These data and the GEOLOGS data were termed “Accurate” heads in the calibration analysis.

The well data used in calibration provided a widely distributed set of calibration points; however, areas of low relief were not represented by the wells because development was not in low-lying (stream and wetland) areas. Surface-water altitudes of stream and wetland surfaces are commonly used to approximate the water-table surface. The presence of streams and wetlands containing streams in the study area indicate that the water table in those areas is at the land surface. The hydrographic coverage in the National Hydrography Dataset (http://nhd.usgs.gov) was used to identify model cells representing persistent streams. Water-surface altitudes obtained from the DEM were used as head observations (water table) in model layer 1. Stream surfaces, particularly for the gaining streams which represent points of discharge, have less annual range in altitude than ground-water levels. Observations based on stream locations were considered to have the same accuracy as the DEM, one-half the contour interval, and therefore, the same standard deviation of 5 ft. The altitude of the water table is considered to be equal to the altitude of the cell in model layer 1, which represents the stream or water body. For the large areas with little relief at lower altitudes, surface-water heads were selected at 2-ft intervals at altitudes less than 60 ft, and at 5-ft intervals at altitudes over 60 ft.

Preliminary simulations were tested with thousands of surface-water points and with and without surface-water head data. The number of points used in the analysis was reduced to approximately 550 to avoid the potential of too much influence from one data source in the analysis. Because a low weight was assigned to these observations, this dataset did not excessively influence the results of the calibration. These data were termed “Stream” heads in the calibration analysis.

The average weighted-head residual for all head categories combined, including all simulated minus observed head data, was 0.3 ft (table 5–3). The average residual of unweighted simulated minus observed heads was -2.2 ft. In general, the model fit to ground-water levels and surface-water point elevations is good. On average, simulated heads were slightly less than observations. This is understandable because many of the observations were collected during periods of the year with higher flow conditions. Only the synoptic head data were specifically collected during low-flow conditions. Because head observations had varying degrees of accuracy, heads were compared by weight, or accuracy; group and weighted equivalent residuals and actual head residuals are shown in table 5–3. Weighted simulated and observed values were used in parameter estimation and sensitivity calculations. The unweighted, or actual, simulated minus observed values indicate that for the historical head values, although the standard deviation of simulated minus observed heads is nearly 22 ft, over an entire regional aquifer an unweighted average head difference of less than 2 ft is good.

The overall fit of simulated observed heads is shown by a plot of weighted head observations against weighted simulated equivalent heads coded by head category (figs. 5–7A, B). The scatter of observations about the 1:1 line (fig. 5–7A) indicated that the model calculates heads fairly well at a regional scale, and residuals (simulated minus observed weighted heads) were equally distributed above and below the zero residual (fig. 5–7B). The head observations, however, were clustered by location; therefore, the residuals also are clustered. An analysis of residuals indicates that the residuals are not independent and normally distributed likely because of the clustered nature of the data. Figures 5–7B illustrate that the historic data and the water surface, which are much less clustered than data for the other head categories, were simulated very well but have less weight in the calibration.

Most of the weighted residuals, or 91 percent (table 5–3), were within one standard model error of regression (5.6). The data set with the largest residuals was the synoptic data set, for which only 35 percent of the observations were within one standard error (table 5–3). Most of the synoptic head residuals were within 2 standard errors (fig. 5–7B). This analysis, however, indicated that the calibrated ground-water-flow model, although satisfactory for regional analysis, is not sufficiently accurate for detailed assessment of local heads. Table 5–3 indicated that the widely distributed but less accurate data were sufficient for regional-model calibration as suggested in the preliminary model analysis (Mack, 2003). Some large errors that were caused by a poorly determined measurement-point altitude by the model-grid discretization can result in differences between the cell altitude and

Table 5–3. Residuals between steady-state observed and model-calculated water levels by data group in the Seacoast model area, southeastern New Hampshire.

[ft, feet]

Head category[2]	Weight	Number of observations	Percentage within one standard error of regression (5.6)	Weighted simulated minus observed head[1]		Actual simulated minus observed head		Figure symbol (fig. 5–7)
				Average difference (ft)	Standard deviation	Average difference (ft)	Standard deviation	
Historical	0.1	711	98	0.2	2.2	-1.9	21.8	Red circle.
Accurate	.2	204	90	1.6	3.1	-8.3	16.4	Yellow square.
Synoptic	1	134	55	-.5	17.9	.5	17.9	Green square.
Stream	.16	546	99	.2	1.2	-.9	7.4	Blue triangle.
Combined	Mixed	1,595	91	.3	5.6	-2.2	17.2	

[1] Plot of weighted simulated equivalent and observed heads shown in figure 5–7B.

[2] Head categories discussed in text.

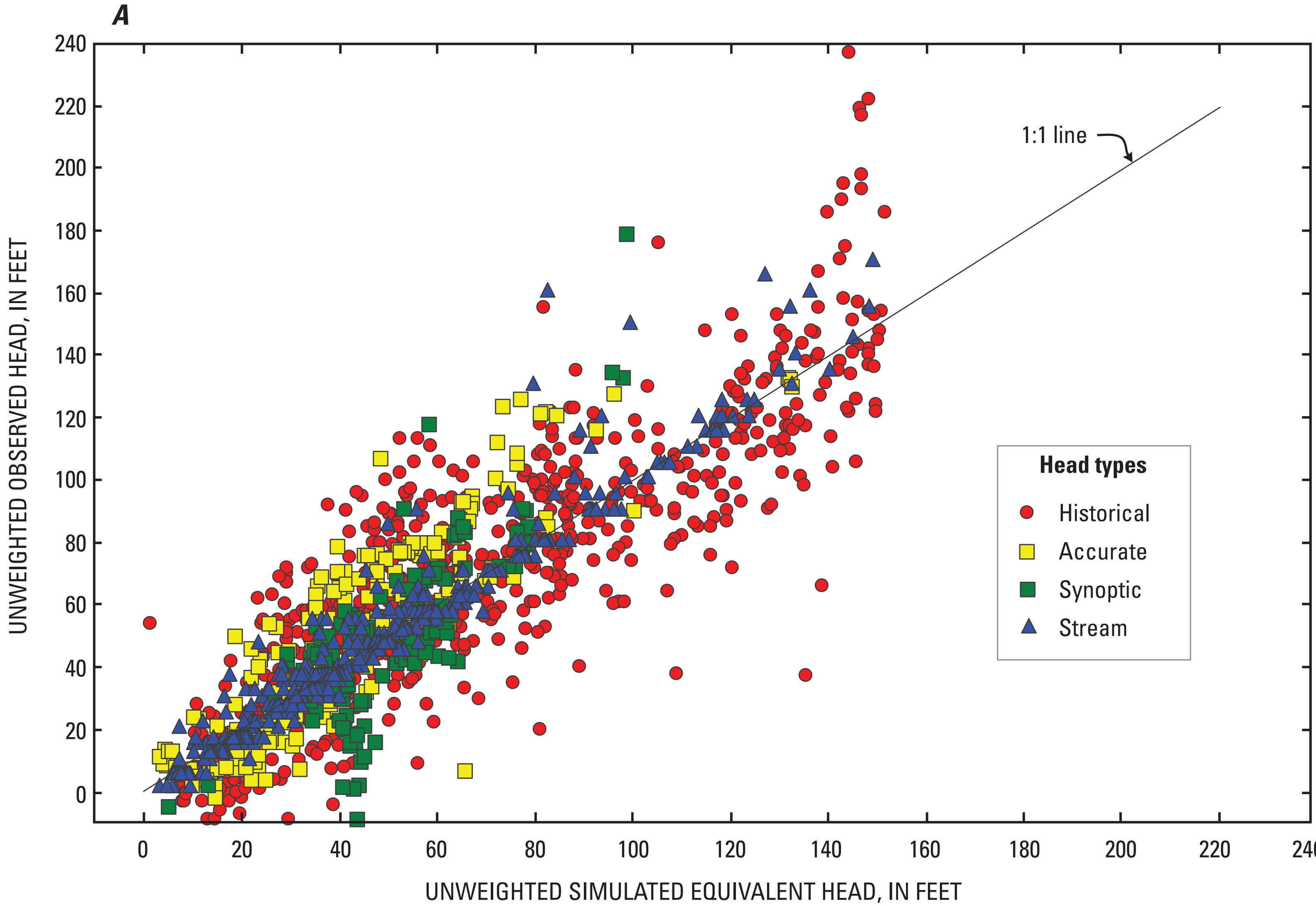


Figure 5–7. Simulated and observed ground-water heads for all categories, except for stream-observation data: *(A)* unweighted simulated and observed heads compared to a 1:1 line.

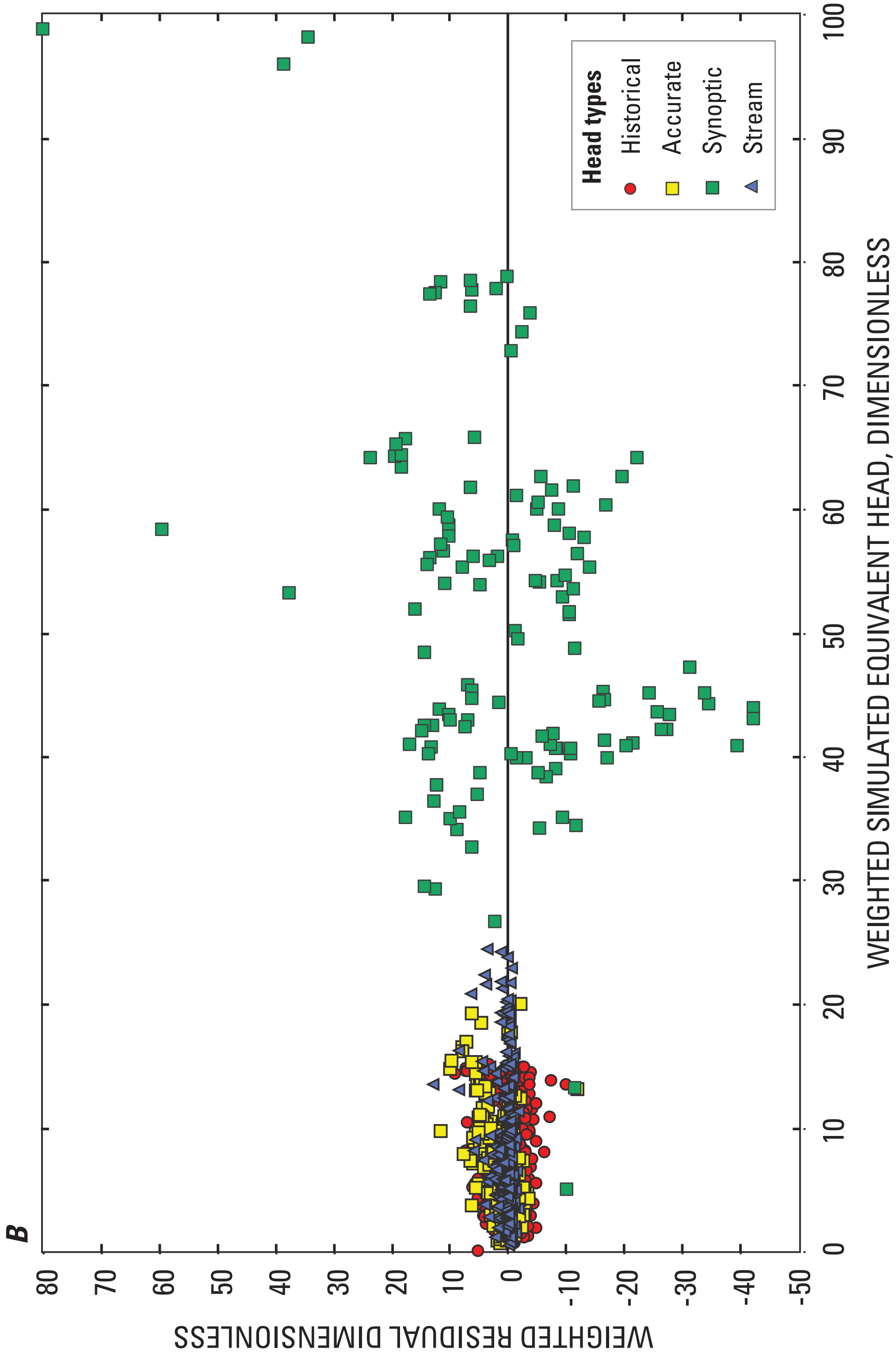


Figure 5–7. Simulated and observed ground-water heads for all categories, except for stream-observation data: *(B)* weighted residuals (simulated minus observed heads) for weighted simulated heads.—Continued

actual altitude. Some of the larger negative residuals could have been caused by local, or transient, pumping effects not explicitly accounted for in the simulation. Larger residuals also were present in geographically clustered data. Areas with large residuals generally correspond to areas with great relief. For example, the calculated head at SSW-7 is more than 50 ft lower than the measured head. This well is located at the base of a till drumlin, however, where the simulated head surface in the surficial aquifer has much less topographic relief than the actual head surface. The model standard error may be improved if local or transient observation errors were identified and some clustered data were excluded. However, it is important to note that ground-water levels can be measured with a far greater degree of accuracy, as indicated by table 5–3, than can be simulated with, or is necessary for, the regional ground-water-flow model.

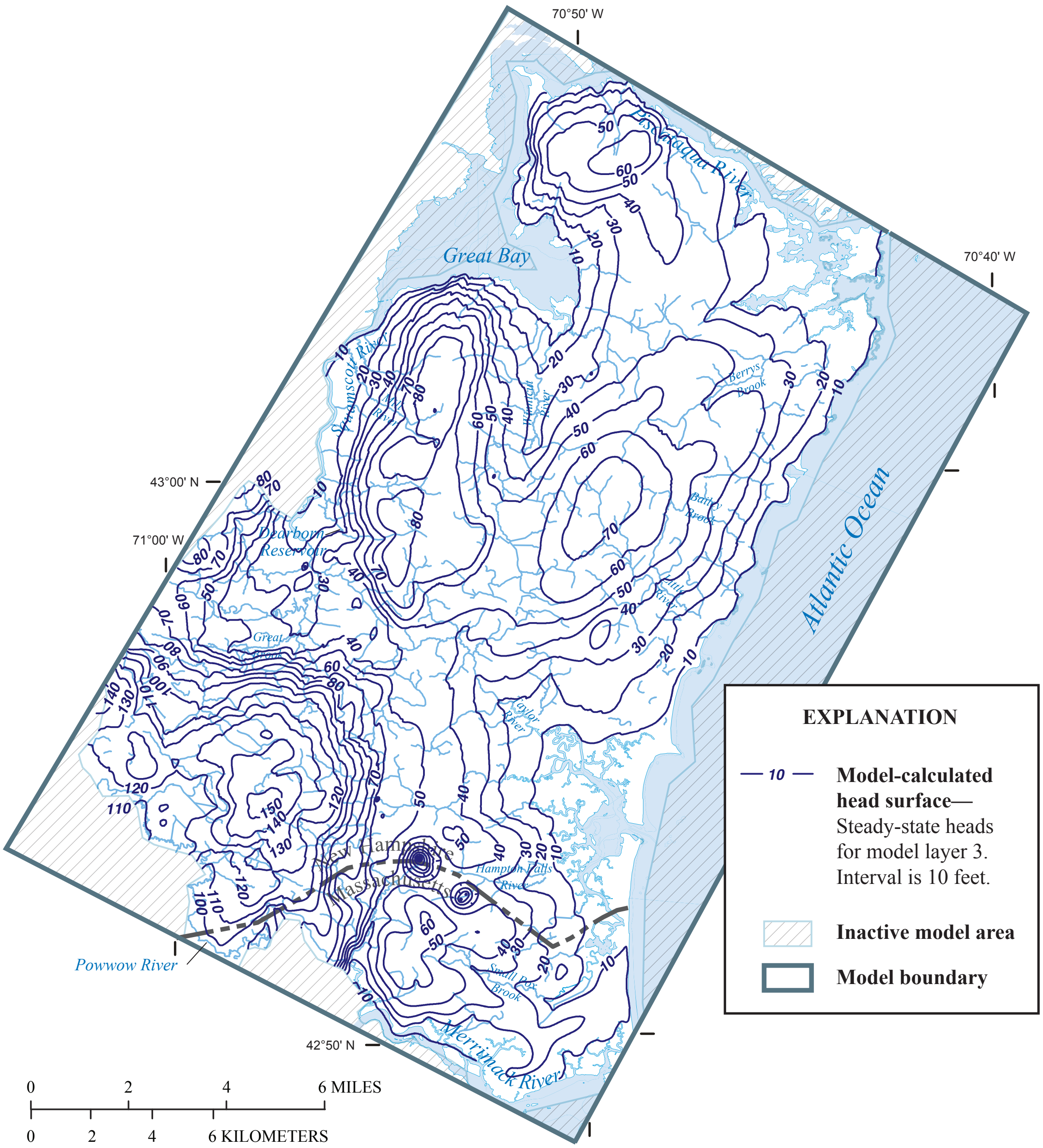
The simulated head surface is shown in figure 5–8. The simulation of heads with a fully linear model, necessary for parameter estimation, shows that in some areas the calculated head surface is above the land surface. In such areas, simulated ground-water flow in the surficial layers may be greater than is realistic. Areas with large positive residuals (heads more than 20 ft greater than DEM values) include parts of Newington, Stratham, and Kensington. Using estimated parameters with the top layer (1) convertible between saturated and unsaturated, allows areas of the model, particularly upland areas and areas with narrow ridges, to dewater. The overall model fit and simulated flows were similar for the fully linear (layer 1 confined) and nonlinear (unconfined) models. Although dewatering resulted in local differences between the linear and nonlinear models, the calculated heads and components of flow generally differed by less than 5 percent between the models. Residuals were analyzed on the basis of parameters estimated with the linear model and heads calculated with the nonlinear model; this approach is suggested by Hill (1998) for use with complex ground-water-flow models.

Estimated Model Parameters

Model parameters were estimated and their sensitivity evaluated using MODFLOW-2000 by the methods described by Hill (1998) and Hill and others (2000). Parameters were used in defining most components of the ground-water-flow equation as described above. In developing a ground-water-flow model, however, it is necessary to make simplifications and assumptions. The model, therefore, is not an exact representation of the ground-water-flow system. Likewise, the statistical analysis of the ground-water-flow system also incorporates simplifications and assumptions. For these reasons, the initial observation weights were adjusted to increase or decrease the relative importance of head and discharge information. Specifically, the calculation of observation weights described above resulted in greater weight placed on head observations as a group than stream observations as a group. This is true even if the surface-water head observations are removed from the analysis. Although the relative differences in head observations are appropriately accounted for, statistical weighting by measurement error does not adequately reflect the importance of the watershed-scale nature of the streamflow observations. Because the focus of this investigation was the regional water balance, observations of base flows on a watershed scale were of greater importance than head observations. For this reason, weights for surface-water observations were increased by a factor of about 5 so that their group weight was comparable to the group weight of the head observations. This method of weighting is currently favored by some researchers over a weighting scheme based entirely on statistical error (Randall Hunt, U.S. Geological Survey, written commun., 2007).

Table 5–4 lists 21 parameters that were assessed for sensitivity along with the final value and lower and upper 95-percent confidence intervals. A correlation matrix for the steady-state model parameters is provided in appendix 6. The final parameter values (table 5–4) are a result of estimation through inverse modeling, literature values, and results of a transient analysis discussed later in the report (appendix 7). A number of parameters were not sensitive enough, or were based on too few observation data, to estimate by inverse techniques. Less sensitive parameters (table 5–4) were removed from the estimation process and were assigned values estimated in other investigations, values published for similar materials, or through trial and error. Therefore, some manual steps were involved in the calibration process where parameters were removed from the parameter estimation process, and the parameter estimation procedures were repeated.

The relative sensitivity of the parameters and the calculated range of the confidence interval provides information about the ground-water-flow system and the relative importance of the components of flow. For example, areal recharge (Rech1) is the most important parameter in this ground-water-flow model. The aerial recharge, calibrated to low-flow conditions, was approximately 11 in/yr. Horizontal anisotropy for bedrock groups Rx1, Rx2, and Rx3 (Hani1) also was relatively significant and indicated that the hydraulic conductivity of the bedrock was greater in the direction of the dominant bedrock structure than transverse to the structure. Using horizontal anisotropy of about 2.5:1 (column to row) for Hani1 improved the model fit. Preliminary variographic analysis of bedrock well yields in the model area indicated similarities in yield in the northeast-southwest (column direction).



Base from USGS and GRANIT, New Hampshire State Plane Coordinate System, North American Datum 1983
Model-calculated head surface from steady-state model layer 3

Figure 5–8. Surface representing calculated steady-state heads for model layer 3, October 2004, Seacoast model area, southeastern New Hampshire. (This figure is the same as figure 14 on page 30 in the report.)

Table 5–4. Steady-state sensitivity analysis, parameter values, and confidence intervals for the Seacoast ground-water-flow model, southeastern New Hampshire.

[Most parameter groups shown on figures 5–2 and 5–4; C.I., confidence interval; ft/d, feet per day]

Sensitivity rank	Parameter name	Sensitivity (dimensionless)	Lower 95-percent C.I.	Final value	Upper 95-percent C.I.	Units	Parameter description, recharge zone or hydrogeologic material group
1	Rech1	6.02	2.0E-03	2.5E-03	3.0E-03	ft/d	Areal recharge.
2	Hani1	2.15	1.4E+00	2.5E+00	4.6E+00	ft/ft	Horizontal anisotropy, bedrock units Rx1, Rx2, Rx3.
3	Rxk2	2.12	6.0E-01	1.0E+00	1.7E+00	ft/d	Horizontal hydraulic conductivity, bedrock unit Rx2.
4	Rxk3	1.92	5.0E-02	1.0E-01	2.0E-01	ft/d	Horizontal hydraulic conductivity, bedrock unit Rx3.
5	Ksb1	1.07	1.8E+00	2.5E+00	3.5E+00	ft/d	Streambed hydraulic conductivity.
6	Rxk1	0.86	2.3E-01	5.0E-01	1.1E+00	ft/d	Horizontal hydraulic conductivity, bedrock unit Rx1.
7	Ksd	.64	3.7E+00	1.0E+01	2.7E+01	ft/d	Multiplier of horizontal hydraulic conductivity, coarse-grained sediment group.
8	Rxk2v	.37	5.4E-03	1.0E+00	1.9E+02	ft/d	Vertical hydraulic conductivity, bedrock unit Rx2.
9	Rxk3v	.35	1.5E-02	1.0E-01	6.9E-01	ft/d	Vertical hydraulic conductivity, bedrock unit Rx3.
10	Ktill	.31	4.2E-02	1.0E+00	2.4E+01	ft/d	Horizontal hydraulic conductivity, till group.
11	Kwet	.17	1.8E-01	1.0E+01	5.6E+02	ft/d	Horizontal hydraulic conductivity wetlands.
12	Rxk4	.17	1.2E-02	2.0E-01	3.4E+00	ft/d	Horizontal hydraulic conductivity, bedrock unit Rx4.
13	Kmv	.13	3.1E-04	1.0E-02	3.2E-01	ft/d	Vertical hydraulic conductivity, fine-grained sediments.
14	Kwetv	.13	2.1E-04	1.0E+01	4.9E+01	ft/d	Vertical hydraulic conductivity, wetlands.
15	Rxk1v	.11	1.4E-03	5.0E-01	1.8E+02	ft/d	Vertical hydraulic conductivity, bedrock unit Rx1.
17	Km	.08	1.9E-06	1.0E-01	5.4E+03	ft/d	Horizontal hydraulic conductivity, fine-grained sediment group.
16	Hani2	.07	3.1E-03	1.0E+00	3.3E+02	ft/ft	Horizontal anisotropy, bedrock unit Rx4.
18	Ksdv	.06	6.8E-12	1.0E+00	1.5E+11	ft/d	Multiplier of vertical hydraulic conductivity, coarse-grained sediment group.
19	Rxk4v	.03	2.2E-06	2.0E-01	1.8E+04	ft/d	Vertical hydraulic conductivity, bedrock unit Rx4.
20	Ktillv	.02	9.3E-15	1.0E+00	1.1E+14	ft/d	Vertical hydraulic conductivity, till.
21	Rech2	.02	-3.8E-03	1.3E-04	4.0E-03	ft/d	Areal recharge in wetland areas.

The simulations were found to be insensitive to horizontal anisotropy in the anisotropy zone for bedrock parameter zone Rx4 (Hani2), and therefore, Hani2 was kept at 1:1. The hydraulic conductivity estimated for Rxk2 was larger (1.0 ft/d) than for other bedrock groups; the hydraulic conductivity of Rx2 may be more strongly anisotropic than that of the other bedrock groups. There was not enough observation data, however, to assess the anisotropies of each bedrock group (Rx1, Rx2, and Rx3) independently in the inverse process. The ground-water-flow system also was very sensitive to streambed conductivity (Ksb1). This parameter is a controlling factor in limiting ground-water discharge to streams; ground-water discharge is the primary component of discharge from the aquifer system. The multiplier of hydraulic conductivity of coarse-grained sediments (Ksd), and the horizontal conductivities of till (Ktill), and of bedrock groups Rx3 and Rx1 (Rxk3 and Rxk1) were equally important in the ground-water-flow process, and their values were estimated with narrow (less than an order of magnitude) confidence intervals. The parameter Ksd is a multiplier of the hydraulic conductivity determined from mapped transmissivity and saturated thickness (Moore, 1990; Stekl and Flanagan, 1992). The multiplier (Ksd) initially estimated in the steady-state inverse process was near 1, indicating that the mapped values used provided a reasonable approximation of the hydraulic conductivity of coarse-grained sediments in the stratified-drift aquifer systems of the regional model during low flow conditions. However, a final value of 10 was used (table 5–4) based on results of the transient model analysis discussed later.

The regional ground-water-flow system was not sensitive to vertical hydraulic conductivities, recharge on wetland areas (Rech2), and anisotropy in bedrock group Rx4 (Hani2). These parameters have orders-of-magnitude ranges between their lower and upper confidence intervals. This indicated that these parameters were not important in the regional ground-water-flow system and that the use of published values would be sufficient. Sensitivities were low also because there was not enough hydrologic information (observations) to characterize the parameters. Some parameters may have a low sensitivity because of the nature of the regional aquifer system. For example, the sensitivity of parameter Rech2, recharge on wetlands, is low because recharge on wetlands in the model as in the natural system is generally removed from the system by hydraulically connected stream networks. The low level of sensitivity of Rech2 indicated that recharge on wetlands can be assigned a range of values with little effect on the flow system.

Bedrock hydraulic conductivities at high-yield bedrock wells are obviously much higher than the regionally estimated values. Calculated heads for areas within a few model cells of large withdrawals will, therefore, not be realistic. The calculated heads for areas more than a few model cells away from the large ground-water withdrawals in the bedrock aquifer should be regionally realistic because flow in the regional bedrock aquifer is determined by regional bedrock aquifer properties and not individual fracture zones. Similarly, drawdowns measured at large ground-water withdrawals in the model area generally were localized and did not extend great distances from the wells because the hydraulic conductivity of the bulk-rock matrix is lower than that at a high-yield bedrock well. Although the flow to a high-yield bedrock well may originate from a few high-yielding fractures or fracture zones such as those observed in a high-yield well in Seabrook (Mack and others, 1998), the extents of individual fractures in crystalline rock, even around high-yield well fields (Johnson and others, 1999; Mack and others, 1998), generally are local (up to hundreds of feet). Fracture zones that extend thousands of feet generally consist of a collection of fractures, and the fractures may even be oriented en echelon or off the axis of the lineament. The flow to a fracture zone depends on connections to other fractures or fracture zones and the regional or bulk-rock hydraulic conductivity (Shapiro, 2004).

The parameter values estimated in the inverse process were fairly robust in that similar final values were estimated with different starting values. Although a high degree of confidence is associated with most of the parameter values, the estimated values and the confidence intervals depends on the conceptualization of the ground-water-flow system and the observation data used in the inverse modeling. The conceptualization should provide a realistic representation of the regional ground-water-flow system. With any model, however, different conceptualizations are possible which can result in different confidence intervals or estimated values. Most parameters were not highly correlated to other parameters (appendix 8) with the exception of Hani1 and Rxk2 (-0.77) and Ksdv and Rxk2v (-0.95).

Calculated Water Balance and Flows

The simulated water balance, a steady-state representation of fall 2004 flow conditions, is provided in table 5–5. With model layer 1 unconfined, some areas of the model dewater; these areas include topographic high areas, particularly those in till, or areas near withdrawal wells. Such dewatering occurs in the natural system particularly during seasonal low flows. Unconfined conditions were difficult to simulate because model cells representing withdrawals or returns may dewater, and a flux in a dewatered cell would incorrectly be eliminated from the simulated water balance. Although flow in the natural system includes unconfined conditions, particularly in the overburden represented in model layer 1, the calculations were done with all model

Table 5–5. Model-calculated October 2004 steady-state water balance and components of flow, in the Seacoast model, southeastern New Hampshire.

[Mgal/d, million gallons per day; flux, flow into or out of a model layer or component of the aquifer system; —, not available or not calculated; positive values are fluxes into a model layer, negative values are fluxes out of a model layer]

Model layer	Total flux into layer (Mgal/d)	Flux into layer (land area) (Mgal/d)	Recharge (Mgal/d)	Stream leakage into layer (Mgal/d)	Stream leakage out of layer (Mgal/d)	Net stream-flow (Mgal/d)	Constant head into layer (Mgal/d)	Constant head out of layer (Mgal/d)	Net tidal discharge (Mgal/d)	Wells (Mgal/d)	Distribu-ted water uses (Mgal/d)	Flux into layer compared to total (percent)	Flux into layer com-pared to recharge (percent)
Total	167.0	—	—	—	—	—	72.0	98.7	-26.7	-7.8	—	—	—
Layer 1	—	92.4	82.9	9.9	-58.8	-49.0	—	—	-12.1	-6.2	—	100	—
Layer 2	115.7	74.4	—	—	—	—	—	—	-13.4	—	2.2	69	90
Layers 3 and 4	73.6	—	—	—	—	—	—	—	[1]-12.3	-1.5	-2.7	44	89
Layer 5	14.5	—	—	—	—	—	—	—	—	—	—	9	17

[1] Net discharge from layer 3 (horizontal and vertical flow) to layer 2 at ocean bottom.

layers confined. However, the confined model was believed to represent natural conditions because flows calculated with model layer 1 unconfined differed from those calculated with all layers confined by only about one percent or less.

The net recharge applied to the steady-state ground-water-flow model was 77.7 Mgal/d, or equivalent to an areal rate of about 1.4 in/mo. The ground-water-flow system is rarely likely to be completely in a steady-state condition, but during seasonal low-flow conditions, the flow system may be relatively stable and in a quasi-steady state. The estimated recharge for the quasi-steady state includes some release of water from storage and, therefore, may be slightly higher than a transient recharge for the same period.

In the natural system, there were both streamflow gains and losses along streams in the study area; and the fluxes calculated in the model include flow into, out of, and between cells simulating constant-head and stream boundaries. Simulated flow at the stream boundaries is the sum of all streamflow gains and losses at multiple locations along the stream. For example, the total streamflow into the model was 9.7 Mgal/d while 53.2 Mgal/d flowed out at stream boundaries for a net streamflow of -43.5 Mgal/d (table 5–5). For this reason, the calculated total flux at a boundary, or in a layer, may not portray the regional ground-water-flow pattern very well. Net boundary flows are presented in table 5–4 and were evaluated when discussing the simulated water balance.

Simulated tidal water bodies were represented by a constant-head boundary. In the model, this boundary, where the thickness of saltwater was represented by an EFW head, is greater than zero. The thickness of saltwater in some areas of the model was large, more than 50 ft in some areas of the Piscataqua River and Great Bay; this thickness created fluxes that are not part of the ground-water-flow system within the constant-head cells in layer 1, representing ocean water. The lowest elevation constant-head cells are immediately adjacent to the shoreline in the ocean. This area forms the ultimate point of discharge in the simulation for both freshwater fluxes from the land area and open-water fluxes within the constant-head boundary. A net constant-head flux of 26.1 Mgal/d represented the regional freshwater discharge to tidal water bodies (table 5–5).

Table 5–5 presents the calculated flux into model layers which is balanced by flow out of the layer and fluxes at specified boundaries (recharge, constant heads, streams, wells, and specified fluxes). In general, the total flux into a layer indicates the amount of water moving through that layer. A large part of the total flux in model layer 1, however, is attributed to flow at the constant-head boundary. Of the 83 Mgal/d water recharging the aquifer system, about 90 percent of the recharge (74 Mgal/d) flows into the bedrock aquifer (layers 3 and 4) and 17 percent (14 Mgal/d) of the recharge flows into the lowest model layer (layer 5) representing deep bedrock areas. Surficial-aquifer wells withdraw about 7 percent (6.2 Mgal/d) of the total flow in the system, and bedrock wells remove about 5 percent (4.2 Mgal/d) of the total flow in the system. Simulated return flows, representing supplied-water returns (leach fields), were about 2.2 Mgal/d.

Because the Seacoast hydrologic system is one in which the surficial aquifers generally are thin and the underlying bedrock aquifer is highly fractured, most recharge at the surface would be expected to continue into the bedrock aquifer. In the model, only a small percentage of the recharge (17 percent), however, flows into the lower bedrock aquifer. The amount and rate of recharge to the bedrock aquifer depends on the recharge available at the surface, the degree of bedrock fracturing and its connectivity, and stresses (withdrawals) in the bedrock which would cause water to flow into the lower bedrock aquifer. Under natural conditions, one with no deep stresses, the rate of ground-water flow into the lower part of the aquifer system will be low compared to shallower parts of the aquifer (table 5–5). Flow into the bedrock aquifer under current conditions is likely to be greater than it had been in the past with fewer withdrawals.

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Appendix 6. Matrix of Steady-State Model Parameter Correlation Coefficients

Table

Table 6–1. Matrix of correlation coefficients for steady-state model parameters for the Seacoast region ground-water-flow model, New Hampshire.

[Dimensionless correlation coefficients]

Parameter name	Rech1 Rxk1v Hani2	Rech2 Rxk2v	Ktill Rxk3v	Ktillv Rxk4v	Ksd Ksb1	Ksdv Km	Rxk1 Kmv	Rxk2 Kwet	Rxk3 Kwetv	Rxk4 Hani1
Rech1	1.00 .03 -.02	-0.37 .00	0.33 -.02	-0.16 .10	0.11 -.24	0.06 .20	0.10 -.02	0.20 -.26	0.09 .29	0.05 .17
Rech2	-.37 .17 -.26	1.00 -.30	-.36 -.11	.21 -.14	-.15 -.33	.31 -.11	-.19 .01	.36 .49	.34 .01	.30 -.43
Ktill	.33 .09 .16	-.36 .03	1.00 -.20	-.27 -.02	.42 .13	-.02 .21	-.18 -.12	-.22 -.45	-.67 .11	-.33 .31
Ktillv	-.16 -.18 .00	.21 -.49	-.27 -.08	1.00 -.16	-.14 .12	.39 -.04	.12 .02	.25 .23	.13 -.46	.03 -.09
Ksd	.11 .15 -.12	-.15 .14	.42 -.04	-.14 -.04	1.00 -.03	-.11 -.15	-.28 -.04	-.27 -.27	-.53 .08	-.14 .23
Ksdv	.06 -.33 -.04	.31 -.95	-.02 -.27	.39 -.11	-.11 -.07	1.00 -.03	.07 .22	.40 .04	.14 .15	.07 -.06
Rxk1	.10 -.61 -.12	-.19 -.03	-.18 .20	.12 .01	-.28 .05	.07 -.11	1.00 .14	.37 -.12	.36 -.01	.23 -.36
Rxk2	.20 -.11 -.26	.36 -.44	-.22 .03	.25 -.11	-.27 -.07	.40 .00	.37 .04	1.00 .03	.62 .27	.41 -.77
Rxk3	.09 -.01 -.24	.34 -.10	-.67 -.07	.13 .02	-.53 -.23	.14 -.07	.36 .03	.62 .12	1.00 .18	.48 -.60
Rxk4	.05 .13 -.64	.30 .01	-.33 .20	.03 -.26	-.14 -.12	.07 -.14	.23 .06	.41 .16	.48 -.02	1.00 -.54
Rxk1v	.03 1.00 -.16	.17 .37	.09 .02	-.18 .03	.15 -.02	-.33 .09	-.61 -.22	-.11 -.04	-.01 -.16	.13 -.06

Table 6–1. Matrix of correlation coefficients for steady-state model parameters for the Seacoast region ground-water-flow model, New Hampshire.—Continued

[Dimensionless correlation coefficients]

Parameter name	Parameter name									
	Rech1 Rxk1v Hani2	Rech2 Rxk2v	Ktill Rxk3v	Ktillv Rxk4v	Ksd Ksb1	Ksdv Km	Rxk1 Kmv	Rxk2 Kwet	Rxk3 Kwetv	Rxk4 Hani1
Rxk2v	0.00 .37 -.06	-0.30 1.00	0.03 .29	-0.49 .14	0.14 .02	-0.95 -.01	-0.03 -.19	-0.44 -.05	-0.10 -.18	0.01 .04
Rxk3v	-.02 .02 -.13	-.11 .29	-.20 1.00	-.08 .02	-.04 .03	-.27 -.48	.20 .30	.03 .03	-.07 .02	.20 -.13
Rxk4v	.10 .03 -.03	-.14 .14	-.02 .02	-.16 1.00	-.04 -.00	-.11 .02	.01 .01	-.11 -.05	.02 .02	-.26 .12
Ksb1	-.24 -.02 .12	-.33 .02	.13 .03	.12 -.00	-.03 1.00	-.07 .05	.05 -.02	-.07 -.07	-.23 -.20	-.12 -.01
Km	.20 .09 .13	-.11 -.01	.21 -.48	-.04 .02	-.15 .05	-.03 1.00	-.11 -.66	.00 -.02	-.07 -.18	-.14 -.03
Kmv	-.02 -.22 -.04	.01 -.19	-.12 .30	.02 .01	-.04 -.02	.22 -.66	.14 1.00	.04 -.03	.03 .18	.06 .11
Kwet	-.26 -.04 -.19	.49 -.05	-.45 .03	.23 -.05	-.27 -.07	.04 -.02	-.12 -.03	.03 1.00	.12 -.42	.16 -.12
Kwetv	.29 -.16 .14	.01 -.18	.11 .02	-.46 .02	.08 -.20	.15 -.18	-.01 .18	.27 -.42	.18 1.00	-.02 -.06
Hani1	.17 -.06 .43	-.43 .04	.31 -.13	-.09 .12	.23 -.01	-.06 -.03	-.36 .11	-.77 -.12	-.60 -.06	-.54 1.00
Hani2	-.02 -.16 1.00	-.26 -.06	.16 -.13	.00 -.03	-.12 .12	-.04 .13	-.12 -.04	-.26 -.19	-.24 .14	-.64 .43

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Appendix 7. Transient Model

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Appendix 7. Transient Model

The transient numerical model was developed to estimate storage characteristics in the aquifer system and evaluate transient ground-water-flow processes. Transient processes include seasonal storage depletion and recovery and assessment of ground-water movement from recharge to discharge. The transient model evaluated the seasonal effects of water use, recharge, and ET on ground water stored in the aquifer system; ET was assessed with the transient model only. This model also provided an analysis of mean monthly and 2003–04 specific monthly recharge and ET conditions. The use of different stress conditions, mean and specific monthly, provided confidence in the estimated model parameters. Parameter descriptions and abbreviations are given in table 7–1.

The transient model was similar to the steady-state model in that the grid and most boundary conditions, such as for streams and tidal water bodies (constant heads), were the same. The parameter zones were the same as in the previous model. Boundary conditions which differed from those used in the steady-state model were recharge, ET, and rates of specified fluxes (withdrawals and returns). Storage terms, including specific yield and specific storage, were assigned to the transient model in the same overburden and bedrock-parameter zones developed for the steady-state model. Transient parameter estimation was used to evaluate bedrock aquifer storage (Ss). Specific yield and specific storage in the surficial aquifers were not estimated, however, because these properties are relatively well known in comparison to those for the bedrock aquifer. Specific yield in the bedrock aquifer also was not estimated because of the probable limited extent and influence of this parameter in the bedrock aquifer.

The transient model consisted of a 4-year simulation developed to assess mean monthly conditions in the first 2 years of the simulation, and specific monthly conditions in the second 2 years of the simulation. Assessing mean monthly conditions is useful in assessing parameters for general or long-term simulations, whereas assessing specific monthly conditions provides more information on the potential range and variability of monthly model parameters. The first 2-year period was calibrated to mean monthly base flows and water levels calculated for the period from 2001 through 2004. The second 2-year simulation represents a calibration to actual monthly conditions observed in 2003 and 2004. The 2003–04 period was selected for detailed simulation because streamflow-gaging stations were operated during this period and detailed water-use data were available or estimated for this period.

Conditions used to initiate the model, particularly starting heads, affect subsequent simulated conditions; care in the selection of initial conditions will prevent the creation of artifacts later in the simulation. The simulation was initiated by using average monthly recharge estimates (fig. 7–1) and an initial head surface equal to the land surface. Model parameters, including monthly recharge, were estimated for the first 2-year simulation period on the basis of the mean of observations for 2001–04. The heads from the end of the first 2-year period were then used to reinitiate the simulation. This process—reinitiation of the model on the basis of the previous results of the 2-year simulation—was repeated several times until the effects of the initial conditions were not apparent and the simulation stabilized over the 2-year period. This stable simulation was then used to initiate the simulation for the second 2-year period; this simulation was calibrated to actual monthly observations for 2003 and 2004. The initial months of the second simulation, the first few months of 2003, were not well simulated because of the transition from mean monthly recharge parameters to actual monthly recharge parameters. Without observation data for a period longer than the 2 years of monthly observations, difficulties with this transition were unavoidable but were minimized by following this two-part simulation process.

This simulation could have also been conducted, but less efficiently, with two separate models which estimated parameters for the recharge conditions described above. Many of the model parameters, such as hydraulic conductivities, however, would have been the same in both simulations. For this reason, the mean monthly and the 2003–04 monthly periods were used in one simulation for more efficient parameter estimation. The time discretization was based on a monthly stress period with mean monthly stresses and observations. Major changes in boundary conditions, such as recharge, ET, and water use, generally occur by season, and monthly stress periods allow for gradations within seasons. The model consisted of 48 monthly stress periods each with two time steps of approximately 15 days in length. Shorter (more) time steps were investigated to provide smoother changes in boundary conditions; however, model improvement was slight with the expense of prohibitively long computation times during parameter-estimation simulations.

Table 7–1. Descriptions of transient parameters for the Seacoast model, southeastern New Hampshire.

[ft/d, feet per day; d.f., dimensionless factor or value]

Parameter name	Unit	Parameter description
Ktill	ft/d	Horizontal hydraulic conductivity, till group.
Ktillv	ft/d	Vertical hydraulic conductivity, till group.
Ksd	d.f.	Multiplier of horizontal hydraulic conductivity, coarse-grained sediment group.
Ksdv	d.f.	Multiplier of vertical hydraulic conductivity, coarse-grained sediment group.
Rxk1	ft/d	Horizontal hydraulic conductivity, bedrock group Rx1.
Rxk2	ft/d	Horizontal hydraulic conductivity, bedrock group Rx2.
Rxk3	ft/d	Horizontal hydraulic conductivity, bedrock group Rx3.
Rxk4	ft/d	Horizontal hydraulic conductivity, bedrock group Rx4.
Rxk1v	ft/d	Vertical hydraulic conductivity, bedrock group Rx1.
Rxk2v	ft/d	Vertical hydraulic conductivity, bedrock group Rx2.
Rxk3v	ft/d	Vertical hydraulic conductivity, bedrock group Rx3.
Rxk4v	ft/d	Vertical hydraulic conductivity, bedrock group Rx4.
Ksw	ft/d	Horizontal hydraulic conductivity, open water.
Kswv	ft/d	Vertical hydraulic conductivity, open water.
Ksb1	ft/d	Streambed hydraulic conductivity.
Km	ft/d	Horizontal hydraulic conductivity, fine-grained sediment group.
Kmv	ft/d	Vertical hydraulic conductivity, fine-grained sediment group.
Kwet	ft/d	Horizontal hydraulic conductivity, wetlands.
Kwetv	ft/d	Vertical hydraulic conductivity, wetlands.
Hani1	ft/d	Horizontal anisotropy, bedrock units Rx1, Rx2, Rx3.
Hani2	ft/d	Horizontal anisotropy, bedrock unit Rx4.
SSR1	d.f.	Specific storage, bedrock unit Rx1.
SSR2	d.f.	Specific storage, bedrock unit Rx2.
SSR3	d.f.	Specific storage, bedrock unit Rx3.
SSR4	d.f.	Specific storage, bedrock unit Rx4.
SSsd	d.f.	Specific storage, surficial sediment groups coarse: grained, till, marine.
SSwet	d.f.	Specific storage, wetlands.
R1	ft/d	Areal recharge, average January.
R2	ft/d	Areal recharge, average February.
R3	ft/d	Areal recharge, average March.
R4	ft/d	Areal recharge, average April.
R5	ft/d	Areal recharge, average May.

Table 7–1. Descriptions of transient parameters for the Seacoast model, southeastern New Hampshire.—Continued

[ft/d, feet per day; d.f., dimensionless factor or value]

Parameter name	Unit	Parameter description
R6	ft/d	Areal recharge, average June.
R7	ft/d	Areal recharge, average July.
R8	ft/d	Areal recharge, average August.
R9	ft/d	Areal recharge, average September.
R10	ft/d	Areal recharge, average October.
R11	ft/d	Areal recharge, average November.
R12	ft/d	Areal recharge, average December.
RCH25	ft/d	Areal recharge, January 2003.
RCH26	ft/d	Areal recharge, February 2003.
RCH27	ft/d	Areal recharge, March 2003.
RCH28	ft/d	Areal recharge, April 2003.
RCH29	ft/d	Areal recharge, May 2003.
RCH30	ft/d	Areal recharge, June 2003.
RCH31	ft/d	Areal recharge, July 2003.
RCH32	ft/d	Areal recharge, August 2003.
RCH33	ft/d	Areal recharge, September 2003.
RCH34	ft/d	Areal recharge, October 2003.
RCH35	ft/d	Areal recharge, November 2003.
RCH36	ft/d	Areal recharge, December 2003.
RCH37	ft/d	Areal recharge, January 2004.
RCH38	ft/d	Areal recharge, February 2004.
RCH39	ft/d	Areal recharge, March 2004.
RCH40	ft/d	Areal recharge, April 2004.
RCH41	ft/d	Areal recharge, May 2004.
RCH42	ft/d	Areal recharge, June 2004.
RCH43	ft/d	Areal recharge, July 2004.
RCH44	ft/d	Areal recharge, August 2004.
RCH45	ft/d	Areal recharge, September 2004.
RCH46	ft/d	Areal recharge, October 2004.
RCH47	ft/d	Areal recharge, November 2004.
RCH48	ft/d	Areal recharge, December 2004.

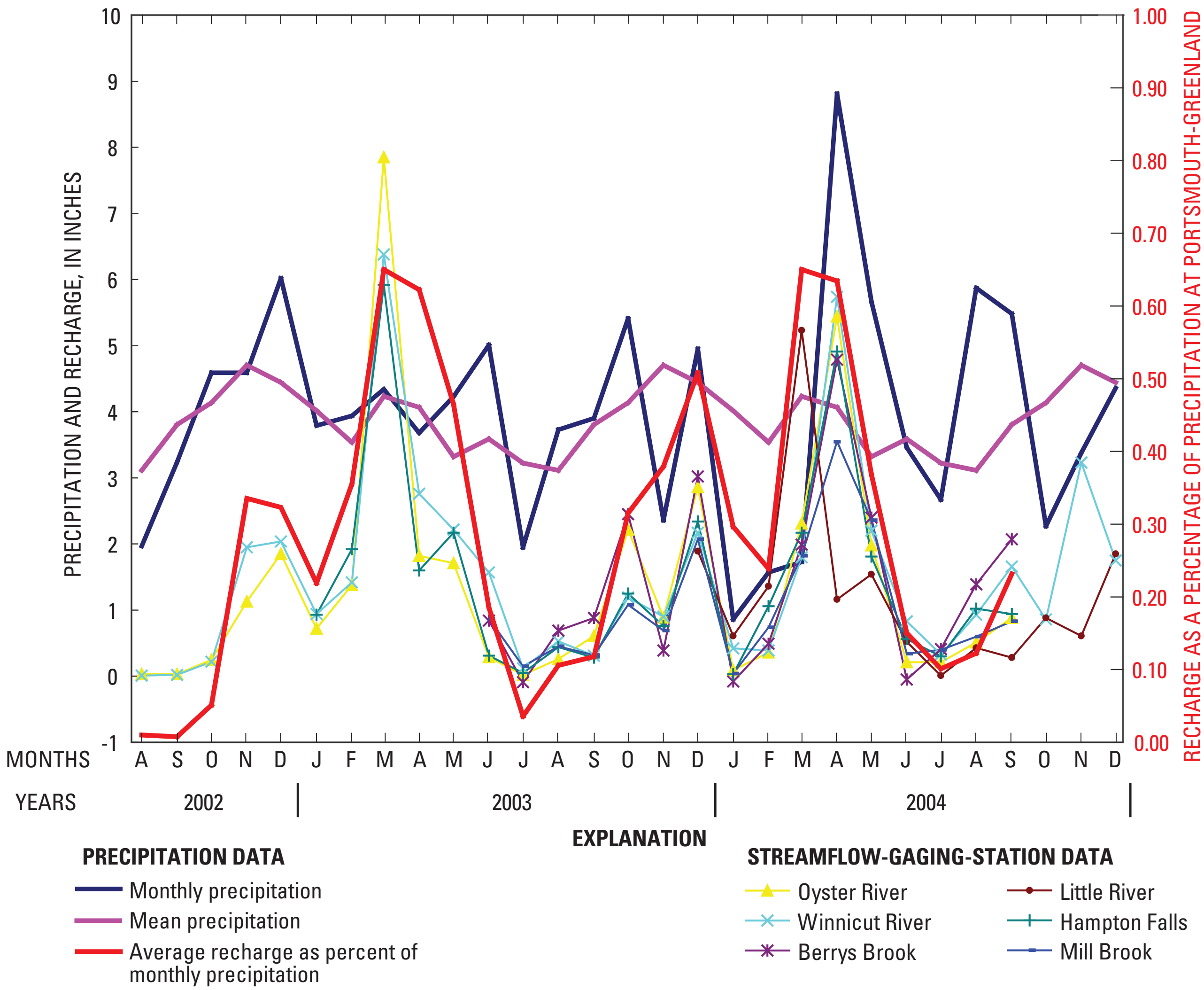


Figure 7–1. August 2002 to December 2004 monthly recharge estimated for Seacoast and Oyster River streamflow-gaging stations and precipitation in New Hampshire. (This figure is the same as figure 6 on page 15 in the report.)

Boundary Conditions

Withdrawals for the first 2 years of the 4-year simulation period were simulated on the basis of average monthly pumpages for 2003–04 registered withdrawals. For the calibration period 2003–04, actual monthly pumpages were used. As in the steady-state model, registered withdrawals were simulated as wells in the layer corresponding to the simulated withdrawal by the WELL package (Harbaugh and others, 2000). For nonregistered water uses, including domestic, community, industrial, and commercial, the rate of estimated water use or return was estimated by census block (Horn and others, 2007). Seasonally estimated returns and withdrawals were applied in the appropriate census block. These uses were distributed in the model as specified fluxes, by the Flow and Head Boundary (FHB) package (Leake and Lilly, 1997) and applied to cells within a 600-ft zone within the perimeter of each census block. Nearly all nonregistered withdrawals were from the bedrock aquifer and were simulated in model layers 3 and 4. Returns were simulated in model layer 2 to prevent returns from being inadvertently eliminated in areas where cells in model layer 1 were seasonally dry. Estimated withdrawal and return rates during winter were applied in December through January, while summer rates were applied in June through August. Average rates were applied in all other months.

Monthly average recharge (fig. 7–1) was used as an initial recharge in the model. Recharge was then refined for the two calibration periods by use of parameter estimation and observations of head and base flows. An observation data set was created for each calibration period, one of mean monthly observations and one of specific monthly observations. For the first calibration period, 12 recharge parameters (RCH1 through RCH12) representing a mean recharge for each month of the year were estimated on the basis of an observation data set consisting of the monthly means of estimated or observed head and base-flow observations for a recent 5-year period (2000–04). For the second calibration period, 24 recharge parameters (RCH25 through RCH48) were estimated to represent recharge in each individual month for the 2003–04 period. Actual monthly head and base-flow observations were used for the second calibration period. Estimation of physical parameters, such as hydraulic conductivities, is affected by all observations over the period represented by the simulation, whereas the parameter for a specific monthly recharge depends on antecedent conditions and observations for that month. In the parameter-estimation process, greater emphasis was given to calibration of the actual monthly recharge parameters than the mean monthly recharge parameters. The two sets of head and base-flow observations used in estimating recharge and other model parameters are described in the observation data section below.

ET from April through October in wetland areas was assessed by the EVT package (Harbaugh and others, 2000). In the steady-state model, ET is effectively accounted for in that the simulated annual recharge is a net recharge to the aquifer, that is, the infiltration of precipitation minus ET. ET was initially simulated in the model only in the wetland areas where it is likely to be larger than ET in other model areas, and the head is more likely to be simulated close to the land surface. Because some areas of the model represented considerable land-surface relief and simulated heads were less accurate in these areas, heads were not simulated well enough with respect to the land surface for the required ET extinction depth (generally about 6 ft) to be accurately represented. The sensitivity analyses, however, showed that ET rates could not be estimated by applying estimation to the available data because there was no unique information (observation data) to distinguish ET from net recharge. The base-flow observation data reflects the net recharge, or effective recharge accounting for ET. Therefore, ET was incorporated in the monthly net-recharge terms in the model. For this reason some estimated net recharge rates for summer months were negative; this result indicated that ET was greater than the infiltration of precipitation during those months. In an investigation about 50 mi south of the study area, DeSimone (2004) calculated a wetland ET rate of 29.4 in/yr (-6.7×10^{-3} ft/d) and simulated wetlands connected to streams as areas of no recharge. In the transient simulation reported here, net recharge on wetlands was simulated as zero which, on an annual basis over the entire model area, reduced the total simulated recharge flux by about 5 percent.

The use of 36 recharge parameters, although physically reasonable, resulted in the individual recharge parameters having a low sensitivity in the parameter-estimation process. Parameter insensitivity resulting from a highly parameterized model has been noted by Randall Hunt (U.S. Geological Survey, written commun., 2007). The recharge parameterization was retained, however, to allow for greater model utility. It also is important to note that for some months with similar ET conditions and total precipitation, the calculated base flows differed. For example, August and September 2003 were months with similar monthly precipitation totals (3.7 and 3.9 in.; fig. 7–1); however, hydrograph separations and calibration results indicate that monthly net recharge was much greater in August than September. Although the total precipitation for the two months was similar, daily precipitation data show that September had fewer and more concentrated periods of precipitation. The largest total daily precipitation for September 2003 was 1.7 in. compared to 1.04 in. for August 2003. Concentrated precipitation events results in less infiltration and less base flow.

Base Flows

Monthly base flows were needed for initial estimation of recharge, and observations of base flows and heads were needed for the transient parameter-estimation process. Monthly base flows were estimated from analysis of a 5-year synthetic streamflow record and 2003–04 streamflows. Continuous streamflows were measured at stations in the model area beginning at different times in 2002 and 2003 (table 7–2). Synthetic streamflow records for the model area continuous stations were extended back to January 1, 2000, by the Maintenance of Variance Extension Type 1 (MOVE.1) method (Hirsch, 1982) by developing correlations with records from the Oyster River streamflow-gaging station. The synthetic discharge records created for the period from January 2000 through December 2004 were used to estimate average monthly base flows for this period with the base-flow portioning program PART (Rutledge, 1993, 1998). The program RORA (discussed previously in the Recharge section) was applied to the extended record for the Winnicut River to estimate an initial average monthly recharge for the study area for the 2001–04 period.

Continuous streamflows were measured at five streamflow-gaging stations in the model area beginning in July 2002 at the Winnicut River station and in 2002 and 2003 at other stations until September 30, 2004 (table 7–2). Record extension was used to generate mean daily streamflows for the five streams from 2000 through 2004. The MOVE.1 method (Hirsch, 1982) was used if the logarithm of streamflows at a short-term streamflow-gaging station is linearly correlated to streamflows at a long-term station. Ries (1994) indicated that MOVE.1 can be used for record extension if the linear correlation coefficient between the two sets of concurrent streamflows is at least 0.80. The correlation coefficients between the logarithms of concurrent streamflows in the study area and of the Oyster River flows were Winnicut River, 0.93; Little River, 0.89; Mill Brook, 0.88; Berry's Brook, 0.83; and Hampton Falls, 0.92. These coefficients for the log-linear relations indicated that record extension was suitable for use in the study area. The MOVE.1 relations reflect current water uses, however, and are only suitable for use with streamflow records collected under similar water-use conditions. Changing water-use conditions affect streamflows, and record extension may not be suitable for other periods. The favorable comparison of streamflows generated by MOVE.1 relations to the measured streamflows for the Winnicut River are likely a result of similar water-use conditions throughout the period 2002–04 (fig. 7–2).

Average monthly base flow for the period 2000–04 were calculated by partition of streamflow records at the five stations. Calculated base flows converted to a linear rate per watershed area (in/mo) were compared to monthly average (2000–04) and monthly (2003–04) total precipitation for Portsmouth-Greenland (fig. 7–3). Base flows calculated by this technique for the months of March and April in 2003 and for the 5-year average for March and April were equivalent to or slightly greater than the corresponding precipitation rates. In other months, base flows were not more than 65 percent of the corresponding monthly precipitation. The base-flow partition technique was obviously not reasonable for these periods. Cautions on the use of streamflow-partition techniques for a monthly time scale were given by Rutledge (1993, 2000). A comparison of techniques for a similar setting in Pennsylvania, however, indicated that monthly base-flow estimates by streamflow partition were reasonable (Risser and others, 2005). For the monthly periods in this study when the calculated base-flow rate was more than 65 percent of the monthly precipitation, the base-flow rate was reduced to 65 percent of the precipitation rate. This condition occurred during one other month in the 5-year calculated base-flow record (April 2001), but in this case, the high base flow was influenced by high flows during the preceding month (effects of monthly discretization). Individual monthly results for this period were not used in the observation data for the model; averages were used for this period. Monthly annual base flows for 2000–04 are provided in table 7–3 to provide additional insight on apparent hydrologic conditions in the five watersheds during the investigation.

The calculated annual total base flows portray individual watershed characteristics and regional climatic conditions in the study area or climatic conditions as reflected by streamflows at the Oyster River watershed. The drought of 2002 is apparent in the calculated base flows for 2002, which were about 75 percent of the 5-year average for 2000–04 conditions (table 7–3). Base flows in 2003 (table 7–3) were about 10 percent greater than average, and 2004 base flows were average. Base flows in the study area generally were a little more than 13 in/yr; however, base flows in Little River were lower than in other watersheds. The lower flows probably reflect a greater water use per unit area than in the other watersheds. Flows in the Berry's Brook and Winnicut River watersheds were slightly higher than in other watersheds. In general, the calculated base flows were about 30 percent of precipitation with the exception of 2002 when base flow was about 22 percent of precipitation. More precipitation (46 in.) fell in 2002 than in the preceding year 2001 (40 in.), yet the base flows for 2002 were less than 2001. This observation indicates that, during periods of intense precipitation, a considerable volume of water may bypass the Seacoast aquifer system without becoming recharge. For example, removing the anomalous peaks from the March and April 2003 base-flow calculations resulted in a 15-percent reduction in total annual recharge for that year. This effect would be more pronounced for short periods of high precipitation (storms).

Table 7–2. Streamflow characteristics for streams in the Seacoast model area and for Oyster River, southeastern New Hampshire. (This table is the same as table 3 on page 25 in the report.)

[Site numbers shown on figure 2 unless otherwise indicated; C, continuous-record streamflow-gaging station; P, partial-record streamflow-gaging station; mi^2, square miles; ft^3/s, cubic feet per second; —, not available]

Site number	Station number	Stream	Location	Area (mi^2)	Station code	Mean flow 2004 (ft^3/s)	Calculated annual base flow 2004 (ft^3/s)	Streamflow measured October 7–8, 2004 (ft^3/s)	Streamflow measured January 4, 2004 (ft^3/s)	Base flow estimated January 4, 2004 (ft^3/s)	Base flow estimated January 27, 2004 (ft^3/s)
	01073000	Oyster River	Durham (not in model area)	12.1	C	19.4	16	4.1	24	10.6	3.5
9		Parkman Brook	Portsmouth	1.91	P	—	—	[1] 1	—	—	—
1	01073750	Mill Brook	Route 108, Stratham	2.48	C	—	2.5	1.00	4.9	2.3	.37
4		Pickering Brook	Shattuck Way, Newington	—	P	—	—	.095	—	—	—
6		Hodgson Brook	Cate Street, Portsmouth	3.52	P	—	—	1.18	—	—	—
3		Packer Brook	Ports Avenue, Greenland	2.25	P	—	—	.56	—	—	—
7		Pickering Brook	Ports Avenue, Greenland	2.97	P	—	—	.61	—	—	—
14-1	01073785	Winnicut River	Route 33, Greenland	14.19	C	22.3	19.3	7.3	27	10.3	2.4
14-2		Winnicut River	Winnicut Road, Stratham	—	P	—	—	4.94	—	—	—
14-3		Winnicut River	Walnut Road, North Hampton	—	P	—	—	3.47	—	—	—
14-4		Winnicut River	Route 111, North Hampton	—	P	—	—	1.71	—	—	—
15	01073810	Berrys Brook	Sagamore Road, Rye	5.38	C	9.8	7.6	3.1	8.1	6	.75
5		Bailey Brook	Love Lane, Rye	1.73	P	—	—	1.09	—	—	—
11-0	01073822	Little River	Woodbury Road, North Hampton	6.12	C	8.5	5.9	2.5	8.5	4.4	.4
11-1		Little River	Unnamed tribuary, North Hampton	—	P	—	—	.30	—	—	—
16		Nilus Brook	North Shore Road, Hampton	1.5	P	—	—	.61	—	—	—
13		Taylor River	Old Stage Road, Hampton	8.41	P	—	—	4.83	—	—	—
10		Great Brook	Giles Road, Brentwood	5.5	P	—	—	1.82	—	—	—
8-0		Hampton Falls	Route 1, Hampton Falls	6.66	P	—	—	3.68	—	—	—
8-1	01073848	Hampton Falls	Mill Lane, Hampton Falls	3.61	C	6	4.6	1.72	8	3.3	.72
2		Back River	Amesbury Road, South Hampton	1.53	P	—	—	.535	—	—	—
17		Cains Brook	Route 1, Seabrook	—	P	—	—	[1] 1	—	—	—
12		Smallpox Brook	True Road, Salisbury, Mass.	1.83	P	—	—	1.00	—	—	—

[1] Flow estimated on the basis of previous measurements or qualitative information.

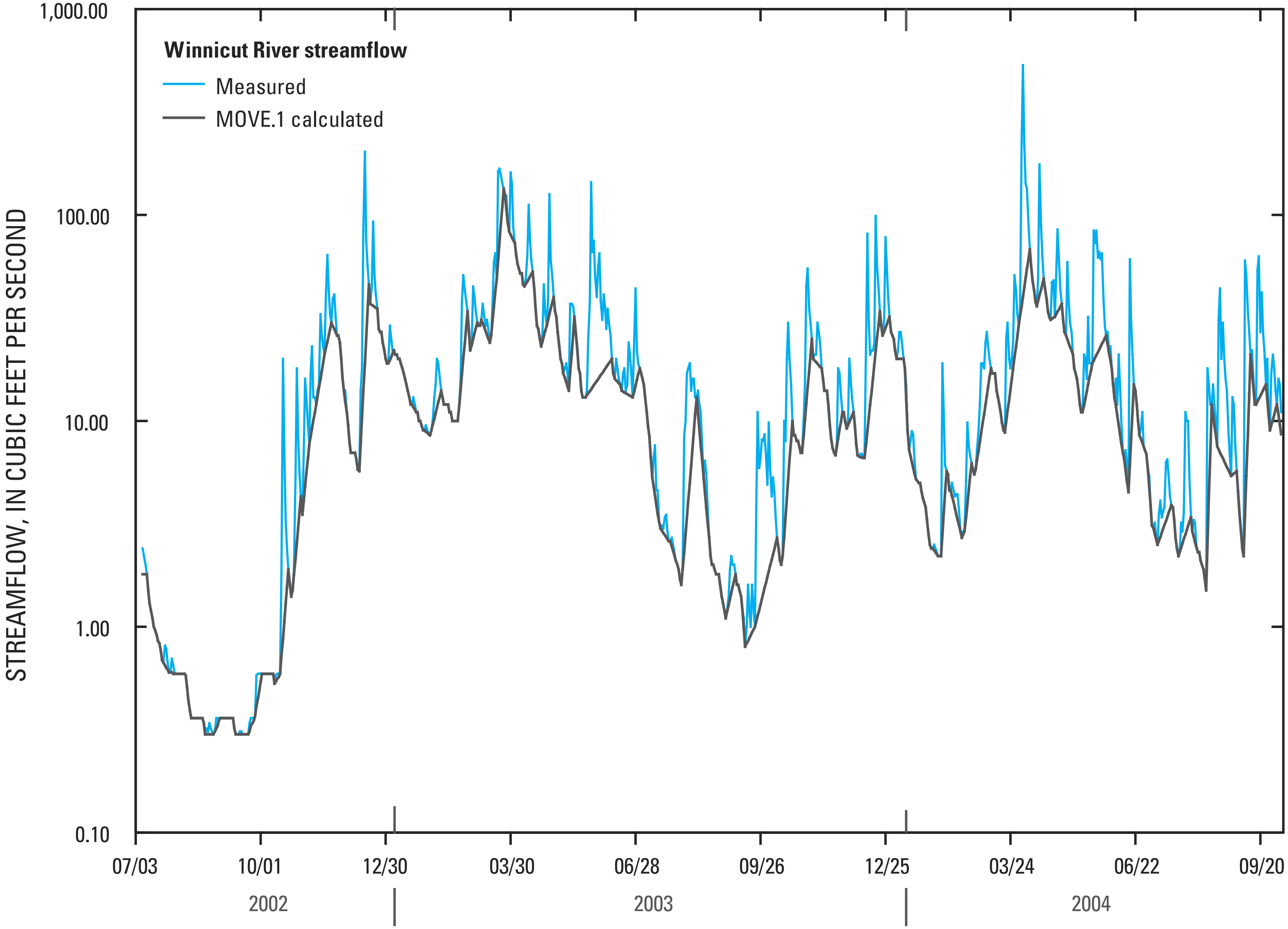
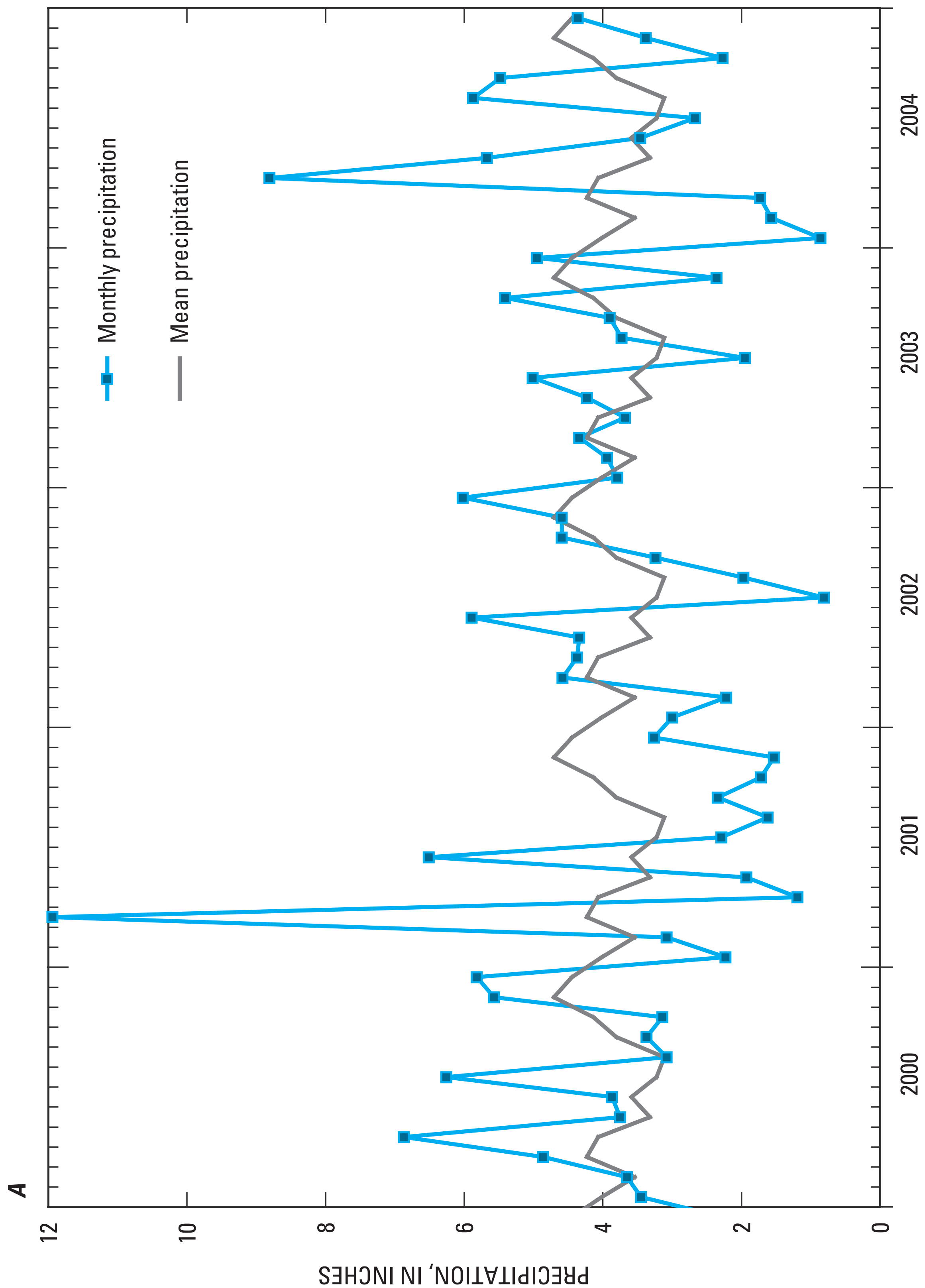
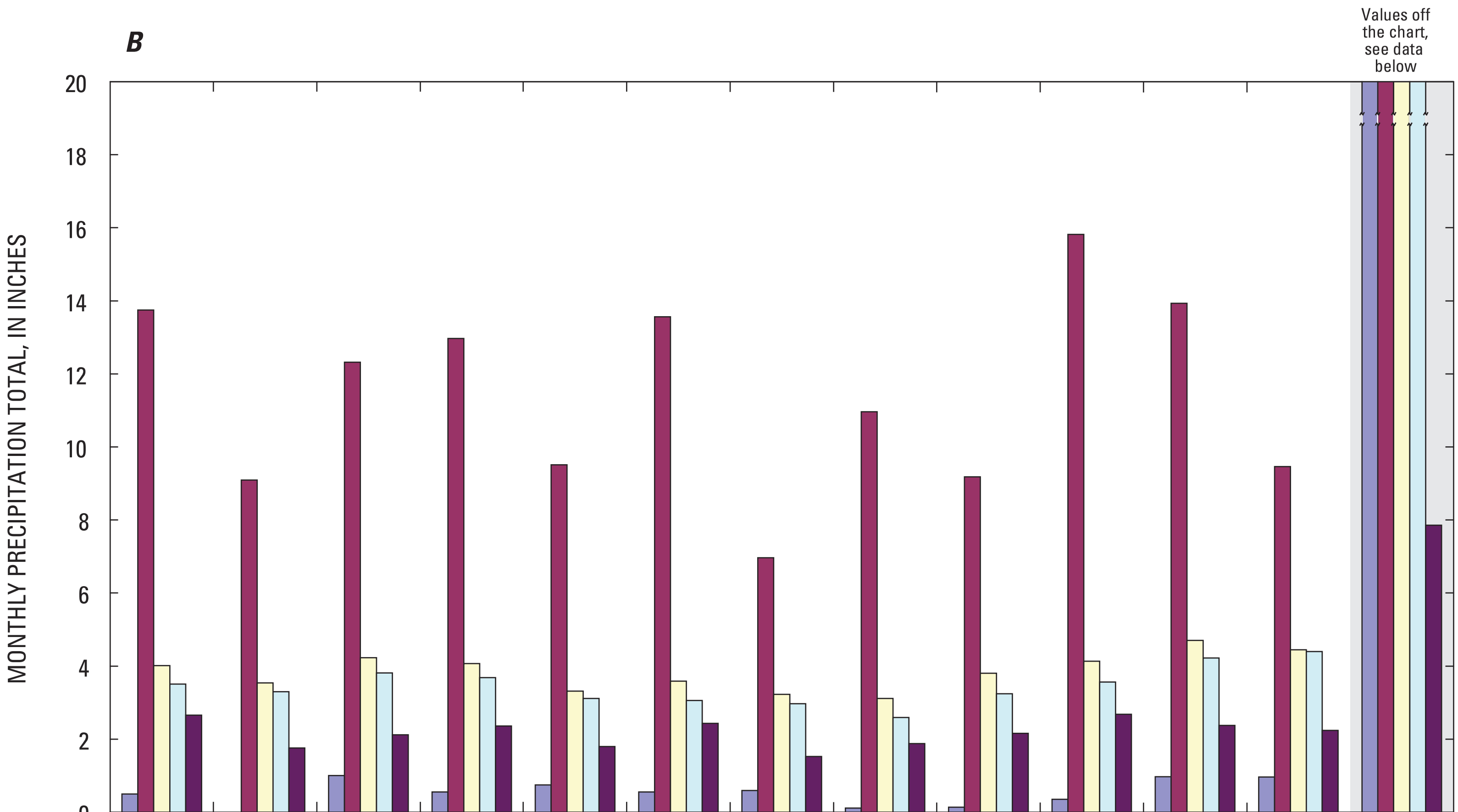


Figure 7–2. Measured and calculated MOVE.1 daily mean streamflows for 2002–04 for the Winnicut River in the Seacoast model area, southeastern New Hampshire.



Sources of data: Durham, State Climatologist; and Portsmouth and Greenland, National Oceanic and Atmospheric Administration.

Figure 7–3. *(A)* Monthly and mean precipitation at Portsmouth and Greenland, New Hampshire, from January 2000 through December 2004. (This figure is the same as figure 1–2 on page 56–57 in appendix 1.)



	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	Annual
MINIMUM	0.5	0	1	0.55	0.75	0.55	0.59	0.11	0.14	0.35	0.97	0.96	29.19
MAXIMUM	13.75	9.09	12.32	12.97	9.51	13.56	6.97	10.96	9.18	15.82	13.93	9.46	71.26
MEAN	4.02	3.54	4.23	4.07	3.32	3.59	3.22	3.11	3.81	4.14	4.71	4.44	45.37
MEDIAN	3.51	3.3	3.815	3.68	3.11	3.06	2.97	2.59	3.24	3.56	4.22	4.4	44.84
STD. DEVIATION	2.66	1.75	2.12	2.36	1.80	2.43	1.53	1.88	2.16	2.68	2.38	2.24	7.86

Sources of data: Durham, State Climatologist; and Portsmouth and Greenland, National Oceanic and Atmospheric Administration.

Figure 7–3. *(B)* Monthly precipitation statistics at Portsmouth and Greenland, New Hampshire, from 1955 through 2005.—Continued (This figure is the same as figure 1–2 on page 56–57 in appendix 1.)

Table 7–3. Mean monthly and annual average base flows calculated for selected watersheds in the Seacoast model area, southeastern New Hampshire.

[ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile]

Stream	January (ft^3/s)	February (ft^3/s)	March (ft^3/s)	April (ft^3/s)	May (ft^3/s)	June (ft^3/s)	July (ft^3/s)	August (ft^3/s)	September (ft^3/s)	October (ft^3/s)	November (ft^3/s)	December (ft^3/s)	Annual total (ft^3/s)	Annual total ($ft^3/s/mi^2$)
2000–04 average														
Winnicut River	10.32	11.92	33.98	37.64	20.45	12.75	3.20	3.40	3.13	4.88	12.17	17.32	171.2	12.1
Little River	3.32	3.93	12.02	11.92	6.32	3.65	.87	1.17	.80	1.51	3.31	4.98	53.8	8.8
Berrys Brook	4.00	5.01	16.48	15.53	8.56	4.95	1.17	1.66	1.01	2.31	4.11	6.90	71.7	13.3
Mill Brook	1.73	2.09	4.93	4.78	3.43	2.15	.67	.59	.50	.74	1.53	2.49	25.6	11.1
Hampton Falls River	2.74	3.43	8.57	8.24	5.09	3.12	.83	.82	.72	1.06	2.43	3.93	41.0	11.4
2003														
Winnicut River	14.53	15.82	34.61	33.12	23.40	20.49	5.79	5.05	1.91	7.27	14.00	20.20	196.2	13.8
Little River	6.10	4.82	11.71	8.44	4.88	5.05	1.11	2.28	0.93	1.86	3.89	6.42	57.5	9.4
Berrys Brook	5.60	6.04	19.61	16.55	9.89	7.67	1.63	2.33	1.40	6.81	6.56	10.64	94.7	17.6
Mill Brook	2.25	2.41	4.82	4.81	4.33	2.87	.62	.98	.49	.90	1.69	2.75	28.9	12.6
Hampton Falls River	3.79	4.19	7.74	6.65	5.54	4.08	.66	1.22	.58	1.50	2.94	4.95	43.8	12.1
2004														
Winnicut River	9.24	4.64	17.61	51.04	23.53	11.33	3.45	7.14	10.69	10.84	15.15	30.55	195.2	13.7
Little River	1.86	1.53	6.21	12.78	8.65	3.02	1.22	2.18	2.25	3.82	4.33	8.44	56.3	9.2
Berrys Brook	3.22	1.91	7.05	10.56	9.85	3.91	1.59	4.15	2.60	2.29	4.44	11.90	63.5	11.8
Mill Brook	1.40	1.28	2.43	5.67	3.97	1.90	.96	.80	1.18	1.24	1.71	4.19	26.7	11.6
Hampton Falls River	2.32	2.50	4.85	11.00	5.95	2.65	1.10	1.35	2.01	1.75	2.88	6.73	45.1	12.5

Ground-Water Levels

The model also was calibrated to monthly ground-water levels. There were very few monitoring wells with long-term continuous water-level data in the region. Continuous water levels were collected for varying periods between October 2003 and August 2005 at five monitoring wells in the study area by (HEW-44, HEW-45, SSW-7, GTW-141, GTW-157) (figs. 7–4 and 7–5). The longest water-level record in the study area consists of monthly measured water levels, from July of 1997, to the present (2005) at a bedrock (SSW-248) and overburden (SSW-249) well pair in Stratham (Raymond Talkington, Geopshere, Inc., written commun., 2006). Study-area water-level records and records from other nearby wells were extended to generate monthly synthetic water levels at the continuously monitored wells for additional periods. Water levels at wells SSW-248 and SSW-249 and long-term USGS wells generally were measured near the end of the month, and measurements within a week of each other were considered concurrent. Comparisons of the monthly measurements at SSW-248 with same-day readings at wells monitored for this study showed poor relations (R^2 less than 0.50). Only 7 to 14 concurrent monthly observations were made, however, at the monitoring wells during the study period.

The quality of relations between the records of the Stratham wells and the records of long-term monitoring wells outside the study area were assessed for use in extending water-level records. Good linear relations (R^2 greater than 0.70) were found in a comparison of the full record for SSW-248 (1997 to present) to observations at long-term monitoring wells (HTW-5, LIW-1, DDW-46, and PBW-148; Keirstead and others, 2005) with about 40 to 80 concurrent observations. Records for the well closest to the study area with a long-term water-level record, LIW-1 in Lee (1953 to present), and for the Stratham wells linearly correlated ($R^2 = 0.74$). The Lee well (LIW-1) is screened in well drained highly conductive outwash deposits; consequently, the water-level record fluctuates little from climatic events. A slightly better correlation ($R^2 = 0.77$) was found between the record for DDW-36, a well screened in stratified drift about 18 mi to the west, and the records for the Stratham wells. Coefficients of determination were 0.87 between the records for SSW-248 and PBW-148 and 0.82 between the records for HTW-5 and PBW-148. These analyses indicated that regional climatic patterns and well responses in southeastern New Hampshire permit record extension by using the records of PBW-148. Both HTW-5 and PBW-148 bedrock wells are about 100 ft deep. Well HTW-5, with more than 30 years of monthly record, is about 25 mi west of the Stratham wells, and PBW-148, with 5 years of continuous daily record, is about 30 mi west. On the basis of concurrent water-level measurements between 1997 and 2005, MOVE.1 relations were developed between the records of monitoring wells HTW-5 and SSW-248 to estimate water levels at the Stratham well for 10 months of missing record in 2002 and 2003.

Although the Stratham well record is valuable, it included too few observations to provide correlations with other wells. Because of the limited availability of concurrent monthly water levels for monitoring wells in the study area, relations with continuous records outside the study area were assessed to provide the necessary additional records. Available water-level records from monitoring-well networks were used for the 2003–04 period. Most wells in these networks were associated with specific large ground-water-withdrawal permits, however, and were clustered in a few areas of the model. Few transient water levels were available in records for wells outside of the network areas; as a result, initial calibrations indicated that the model was insensitive to some parameters. Surface-water levels were used to provide about 300 head observations for model layer 1. The observations generally were made in discharge areas with little seasonal surface water-level change where the water table is at or near land surface. Surface-water levels were not used as head observations for the months of June, July, and August because ground-water levels may drop below the topographic altitudes of stream surfaces (representing a dry stream) particularly at the higher altitudes.

Water levels in stratified-drift aquifers generally show very little seasonal variation (less than 5 ft), whereas water levels in till aquifers generally have an annual range of about 10 ft. Twenty-eight synthetic observation points were created on the basis of the depth-to-water ranges (about 10 ft) and patterns of till observation wells HEW-45 and SSW-7. Points were centrally placed in till bodies between streams without water-level observations and far from large registered withdrawals. Synthetic observation points also were created at the same locations using the seasonal (unstressed) bedrock-aquifer water-level patterns observed at HEW-44 and GTW-141.

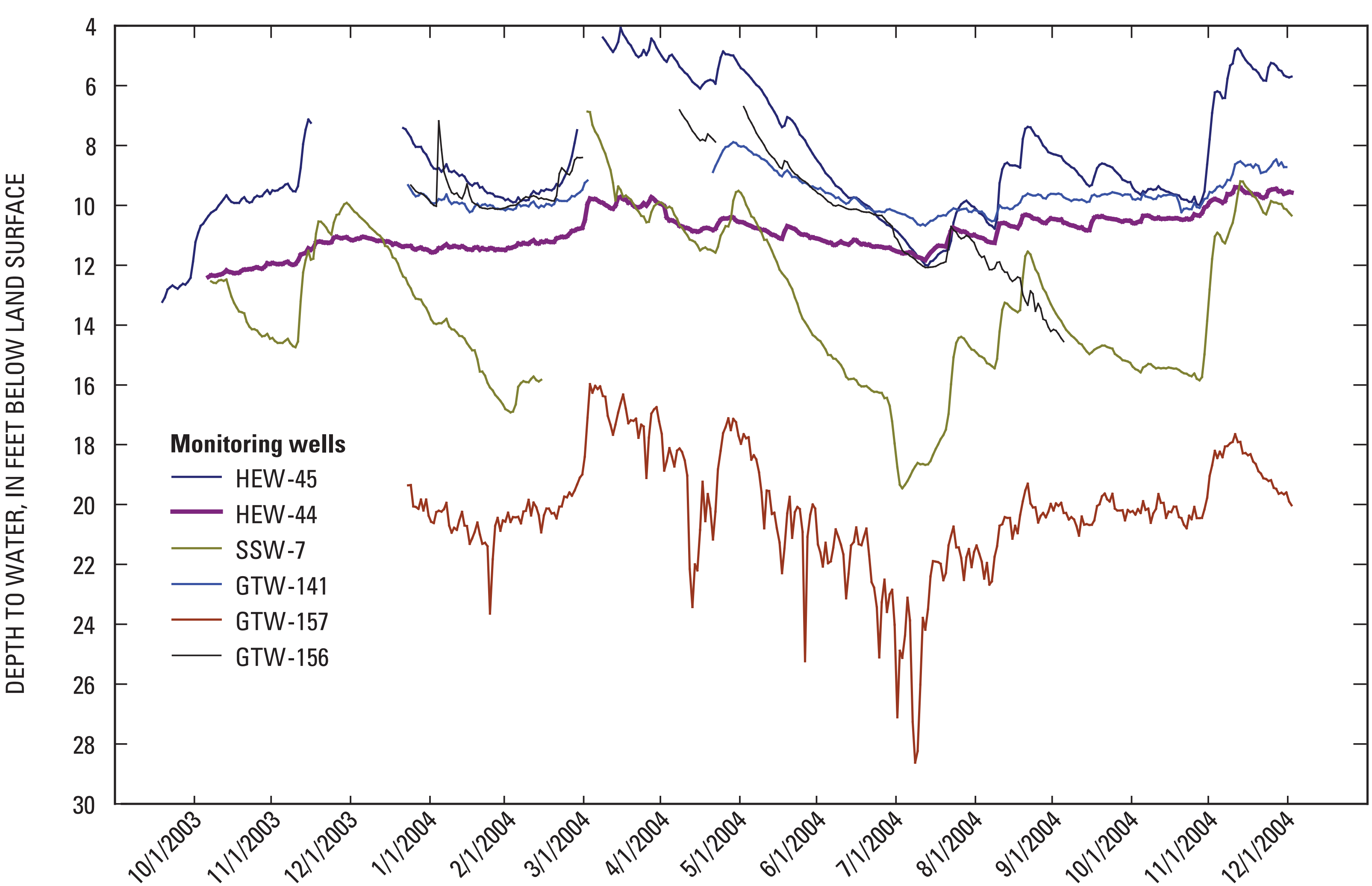


Figure 7–4. Daily mean depth to ground water in six monitoring wells in the Seacoast model area, southeastern New Hampshire, between October 2003 and January 2004. Areas of no data (data gaps) are missing record. (Well locations shown in figure 7. This figure is the same as figure 9 on page 20 in the report.)

Specific Storage

Initial values of specific storage were obtained from literature and other nearby investigations. Values of specific storage are relatively well known for surficial (glacial) aquifers, whereas the storage characteristics of crystalline bedrock aquifers throughout the Northeast, including the Seacoast, are not well known. It was necessary to estimate specific storage parameters with all model layers confined in order to simplify the parameter estimation calculations. Additionally, all surficial-aquifer properties were held constant during calibration simulations because they were better known than bedrock storage. Specific storage values determined from aquifer tests in glacial sediments (Randall, 2001) were typically about 1×10^{-4}. Imposing confined conditions on the surficial aquifers, however, can cause an unrealistic amount of water to be released from the surficial aquifers during transient seasonal (summer) simulations. For this reason DeSimone (2004) used specific storage value of 2.5×10^{-6} for till in seasonal simulations. Use of a low specific storage value for surficial sediment was tested in this investigation but was found not to be necessary; a value of 1×10^{-4} was used for all surficial sediments.

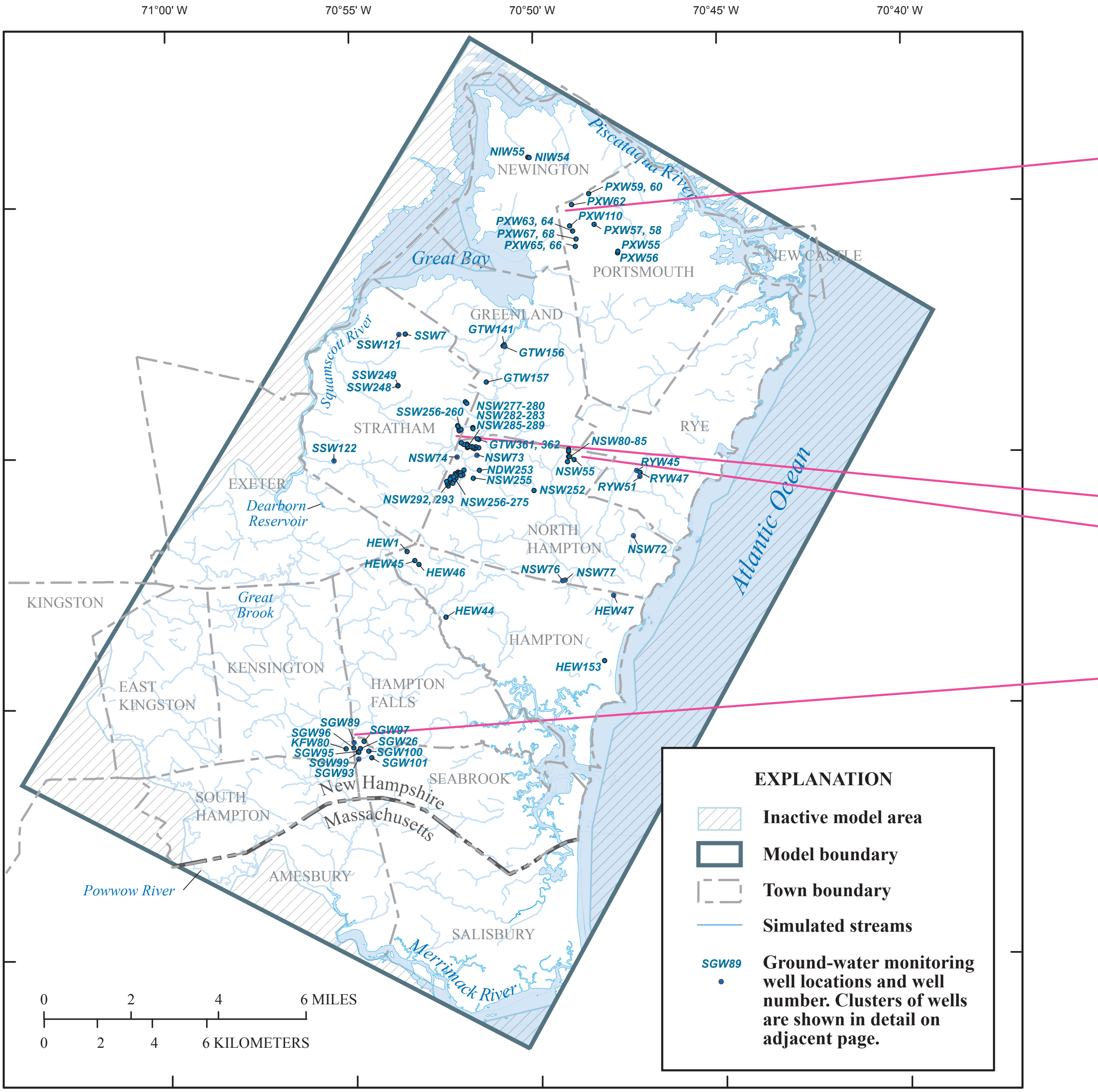
An investigation of the properties of a similar crystalline bedrock in North Carolina (Daniel and others, 1997) found that transmissivity, specific storage, and well yield varied in a consistent manner. In that investigation, it was found that well yield could be used as an index for specific storage. Specific storage in the Seacoast bedrock aquifers differs with the overall fracturing and connectivity as indicated by the well yields of each formation (appendix 2). The differences in bedrock well-yield probability observed in the Seacoast bedrock aquifer (Moore and others, 2002) are likely also to indicate differences in specific storage. This indication is supported by the fact that the Kittery Formation and Rye Complex have sustained several large groundwater withdrawals, whereas the formations to the west have been able to sustain fewer large withdrawals despite exploratory efforts by water suppliers. For this reason, the same four zones (fig. 7–6) used for other bedrock characteristics were used for parametization of specific storage in the bedrock aquifer. The bedrock aquifer was considered confined in all cases, and specific yield of the bedrock aquifer was not examined. Lyford and others (2003) estimated a specific storage of 1×10^{-5} for a high-yield bedrock formation (the Eliot Formation) on the basis of a long-term (30-day) aquifer test in West Newburyport, Mass. From observation of regional bedrock-well yields, the specific storage of the Eliot Formation in the vicinity of the West Newburyport well field is likely to be greater than the regional specific storage of the Eliot Formation in the Seacoast model area.

To limit inverse-model simulation time, specific-storage parameters for the bedrock aquifers were estimated with all other parameters held constant. The model was updated with the estimated value for specific storage, and then other model parameters, such as recharge and hydraulic conductivities, were re-estimated. Final specific storage values used in the model were approximately 8×10^{-7} (SSR1), 3×10^{-6} (SSR2), and 1×10^{-7} (SSR3). Because there were not enough observation data to estimate storage for bedrock-aquifer zone Rx4, and it was believed to be low, a value of 1×10^{-7} (SSR4) was used. It is important to note that the estimated specific storage values represented a bulk characteristic rather than the specific storage of individual fracture zones. Specific storage in the immediate vicinity of a bedrock well with a sustainable high yield is likely to be greater, possibly an order of magnitude greater, than the regional specific storage.

Estimated Model Parameters

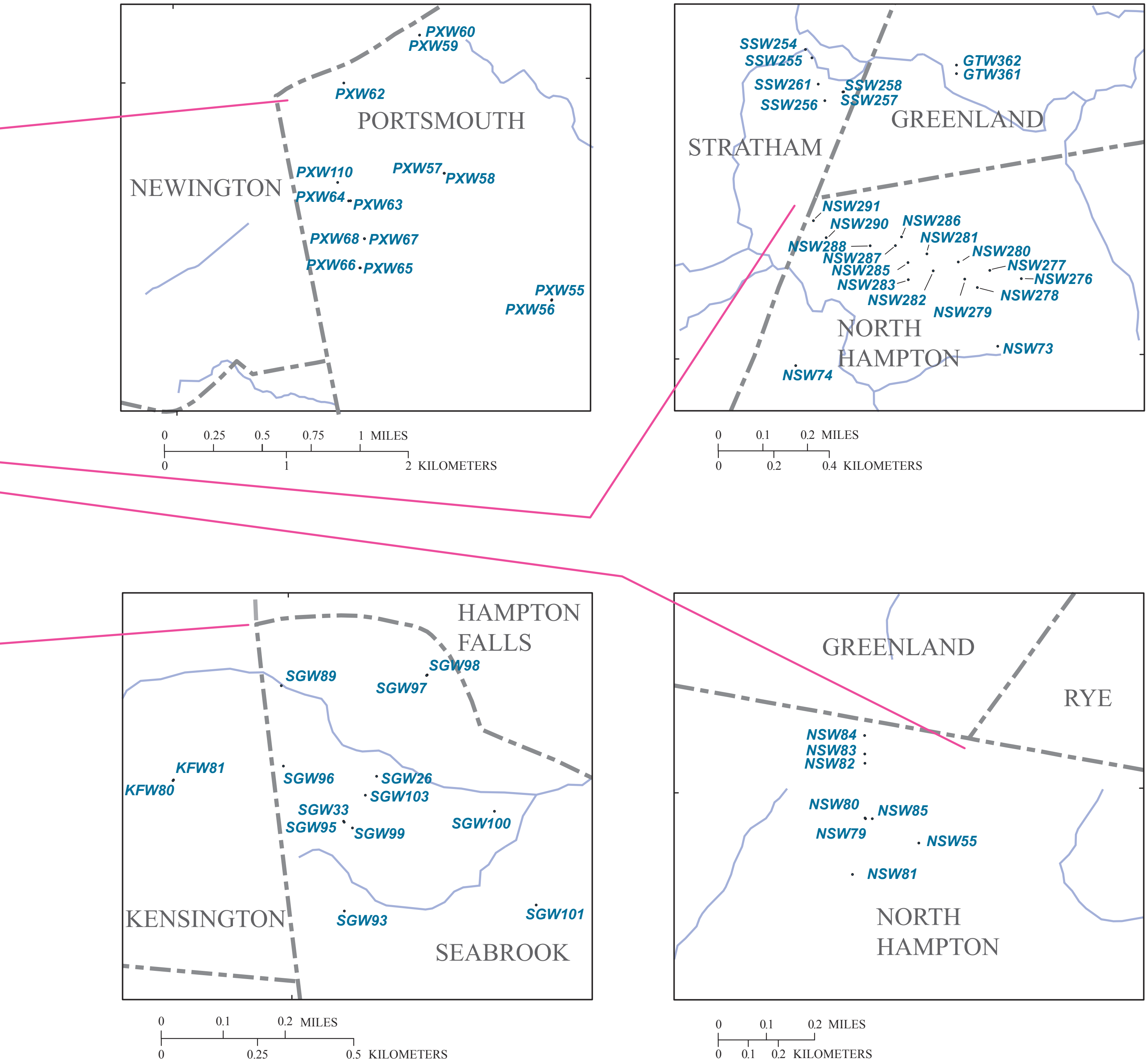
Estimated model parameters are listed in table 7–4 along with 95-percent confidence intervals and sensitivities are shown in figure 7–7. Model parameters, confidence intervals and sensitivities reflect not only the observation data and the weights placed on data, but also the conceptualization and parameterization of the ground-water-flow system. The parameter values were fairly unique in that similar values were calculated from different parameter starting values. Nonunique parameters were indicated by correlation coefficients between two parameters greater than 0.95 (appendix 8).

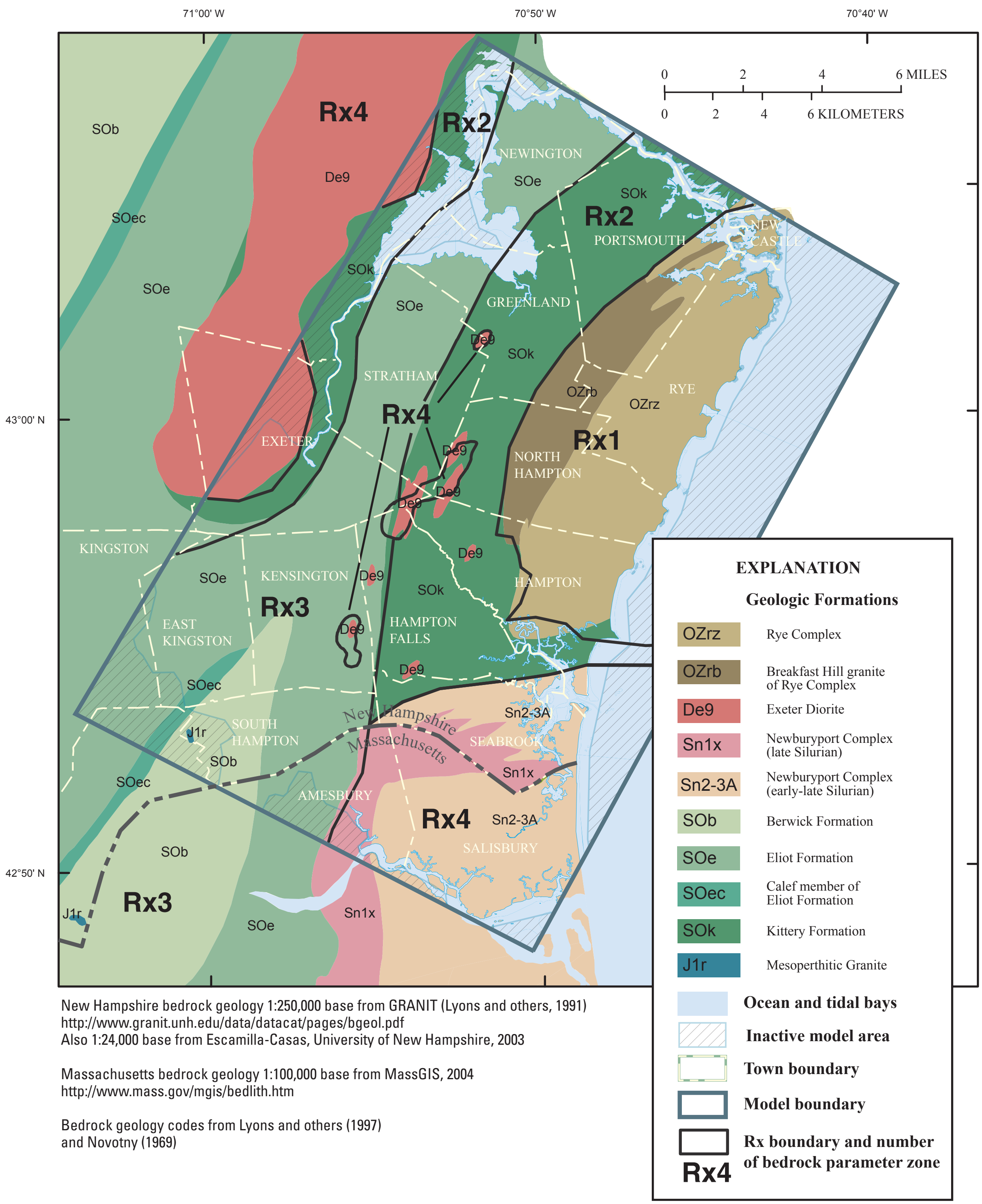
The problem of conceptual model uncertainty, and the fact that conceptual models are often changed because of additional data, is discussed by Bredehoft (2005). A principal of parsimony (Hill, 1998) was followed according to which model parameters were defined and zoned on the basis of physically defensible units such as major bedrock formations (fig. 7–6) or surficial-sediment groups (fig. 7–8). This approach lends confidence that the model was not overparameterized to fit observations rather than simply created to fit the available data. Use of fewer parameters is preferred in terms of model stability and parameter correlation. Some parameter zones may be too simple, however, and may not reflect important subzone hydraulic variations. For example, the bedrock zones used do not reflect variations within each bedrock unit, and the case could be made for increased parameterization based on regularized inversion techniques (Hunt and others, 2007).



Streams and water bodies, including tidal and estuaries from 1:24,000
National Hydrography Dataset, 1999

Figure 7–5. *(A)* Ground-water monitoring wells in the study area. (This figure is the same as figure 7 on page 16–17 in the report.)


PXW60
PXW59
PXW62
PORTSMOUTH
NEWINGTON
PXW110
PXW57
PXW58
PXW64
PXW63
PXW68
PXW67
PXW66
PXW65
PXW55
PXW56
0 0.25 0.5 0.75 1 MILES
0 1 2 KILOMETERS
SSW254
SSW255
SSW261
SSW256
SSW258
SSW257
GTW362
GTW361
GREENLAND
STRATHAM
NSW291
NSW290
NSW286
NSW281
NSW288
NSW287
NSW285
NSW283
NSW282
NSW280
NSW277
NSW276
NSW278
NSW279
NORTH
HAMPTON
NSW73
NSW74
0 0.1 0.2 MILES
0 0.2 0.4 KILOMETERS
HAMPTON
FALLS
SGW98
SGW89
SGW97
KFW81
KFW80
SGW96
SGW26
SGW103
SGW33
SGW95
SGW99
SGW100
KENSINGTON
SGW93
SGW101
SEABROOK
0 0.1 0.2 MILES
0 0.25 0.5 KILOMETERS
GREENLAND
RYE
NSW84
NSW83
NSW82
NSW80
NSW85
NSW79
NSW55
NSW81
NORTH
HAMPTON
0 0.1 0.2 MILES
0 0.1 0.2 KILOMETERS



New Hampshire bedrock geology 1:250,000 base from GRANIT (Lyons and others, 1991)
http://www.granit.unh.edu/data/datacat/pages/bgeol.pdf
Also 1:24,000 base from Escamilla-Casas, University of New Hampshire, 2003

Massachusetts bedrock geology 1:100,000 base from MassGIS, 2004
http://www.mass.gov/mgis/bedlith.htm

Bedrock geology codes from Lyons and others (1997)
and Novotny (1969)

Figure 7–6. Dominant bedrock formations in the Seacoast area and bedrock parameter zones used in the Seacoast model, southeastern New Hampshire. (This figure is the same as figure 4 on page 7 in the report.)

Table 7–4. Transient model parameters and confidence intervals for the Seacoast model, southeastern New Hampshire.

[Parameter descriptions listed in appendix H1; ft/d, feet per day; d.f., dimensionless or dimensionless factor; C.I., 95-percent confidence interval]

Parameters for surficial-sediment hydraulic properties														
	Hydraulic conductivity, or conductivity multiplier, and streambed conductance										**Specific storage**			
	Ktill (ft/d)	**Ktillv (ft/d)**	**Ksd (d.f.)**	**Ksdv (d.f.)**	**Km (ft/d)**	**Kmv (ft/d)**	**Kwet (ft/d)**	**Kwetv (ft/d)**	**Ksb1 (ft/d)**		**SSsd (d.f.)**	**SSwet (d.f.)**		
Upper C.I.	1.8E+0	3.6E-1	1.4E+1	4.5E+8	3.4E+0	4.4E-2	2.3E+1	2.9E-1	5.6E+0		1.4E-4	4.2E-4		
Final values	1.0E+0	1.0E-1	1.0E+1	1.0E+0	1.0E-1	1.0E-2	1.0E+1	1.0E-1	5.0E+0		1.0E-4	1.0E-4		
Lower C.I.	5.6E-1	2.8E-2	7.3E+0	2.2E-9	2.9E-3	2.3E-3	4.3E+0	3.5E-2	4.5E+0		7.0E-5	2.4E-5		
Parameters for bedrock hydraulic properties														
	Hydraulic conductivities								**Horizontal anisotropy**		**Specific storage**			
	Rxk1 (ft/d)	**Rxk2 (ft/d)**	**Rxk3 (ft/d)**	**Rxk4 (ft/d)**	**Rxk1v (ft/d)**	**Rxk2v (ft/d)**	**Rxk3v (ft/d)**	**Rxk4v (ft/d)**	**Hani1 (d.f.)**	**Hani2 (d.f.)**	**SSR1 (d.f.)**	**SSR2 (d.f.)**	**SSR3 (d.f.)**	**SSR4 (d.f.)**
Upper C.I.	5.8E-1	1.2E+0	1.2E-1	7.4E-1	1.3E+0	2.8E+0	1.4E-1	8.1E-1	6.2E+0	7.9E+0	5.0E-6	5.3E-6	1.2E-2	1.1E+3
Final values	5.0E-1	1.0E+0	1.0E-1	2.0E-1	5.0E-1	1.0E+0	1.0E-1	2.0E-1	5.0E+0	1.0E+0	7.8E-7	2.8E-6	1.2E-7	1.0E-7
Lower C.I.	4.3E-1	8.2E-1	8.4E-2	5.4E-2	1.9E-1	3.6E-1	7.0E-2	4.9E-2	4.0E+0	1.3E-1	1.2E-7	1.5E-6	1.3E-12	8.8E-18
Parameters for 2000–04 average recharge														
	R1 (ft/d)	**R2 (ft/d)**	**R3 (ft/d)**	**R4 (ft/d)**	**R5 (ft/d)**	**R6 (ft/d)**	**R7 (ft/d)**	**R8 (ft/d)**	**R9 (ft/d)**	**R10 (ft/d)**	**R11 (ft/d)**	**R12 (ft/d)**		
Upper C.I.	4.5E-3	4.3E-3	1.7E-2	1.4E-2	6.9E-3	3.7E-3	1.4E-4	1.3E-3	1.2E-3	2.4E-3	6.9E-3	7.1E-3		
Final values	4.0E-3	3.8E-3	1.5E-2	1.3E-2	6.0E-3	3.0E-3	-5.0E-4	9.6E-4	9.5E-4	2.1E-3	6.2E-3	6.4E-3		
Lower C.I.	3.6E-3	3.3E-3	1.4E-2	1.2E-2	5.1E-3	2.3E-3	-1.1E-3	6.7E-4	7.2E-4	1.8E-3	5.6E-3	5.8E-3		
Parameters for 2003 recharge														
	RCH25 (ft/d)	**RCH26 (ft/d)**	**RCH27 (ft/d)**	**RCH28 (ft/d)**	**RCH29 (ft/d)**	**RCH30 (ft/d)**	**RCH31 (ft/d)**	**RCH32 (ft/d)**	**RCH33 (ft/d)**	**RCH34 (ft/d)**	**RCH35 (ft/d)**	**RCH36 (ft/d)**		
Upper C.I.	6.8E-3	4.9E-3	1.6E-2	1.1E-2	5.3E-3	4.5E-3	-6.5E-5	2.8E-3	5.1E-4	4.2E-3	6.3E-3	8.0E-3		
Final values	6.2E-3	4.3E-3	1.5E-2	1.0E-2	4.5E-3	3.9E-3	-7.3E-4	2.6E-3	1.7E-4	3.8E-3	5.7E-3	7.3E-3		
Lower C.I.	5.7E-3	3.8E-3	1.4E-2	9.1E-3	3.7E-3	3.3E-3	-1.4E-3	2.4E-3	-1.7E-4	3.4E-3	5.2E-3	6.6E-3		
Parameters for 2004 recharge														
	RCH37	**RCH38**	**RCH39**	**RCH40**	**RCH41**	**RCH42**	**RCH43**	**RCH44**	**RCH45**	**RCH46**	**RCH47**	**RCH48**		
Upper C.I.	1.7E-3	1.4E-3	8.7E-3	2.0E-2	7.0E-3	2.5E-3	6.0E-4	3.5E-3	3.2E-3	4.2E-3	6.1E-3	10.0E-3		
Final values	6.7E-4	9.3E-4	7.8E-3	1.8E-2	6.0E-3	1.8E-3	-1.0E-5	3.2E-3	2.9E-3	3.8E-3	5.6E-3	9.0E-3		
Lower C.I.	2.7E-4	6.3E-4	7.0E-3	1.7E-2	5.0E-3	1.1E-3	-6.2E-4	2.9E-3	2.6E-3	3.4E-3	5.1E-3	8.1E-3		

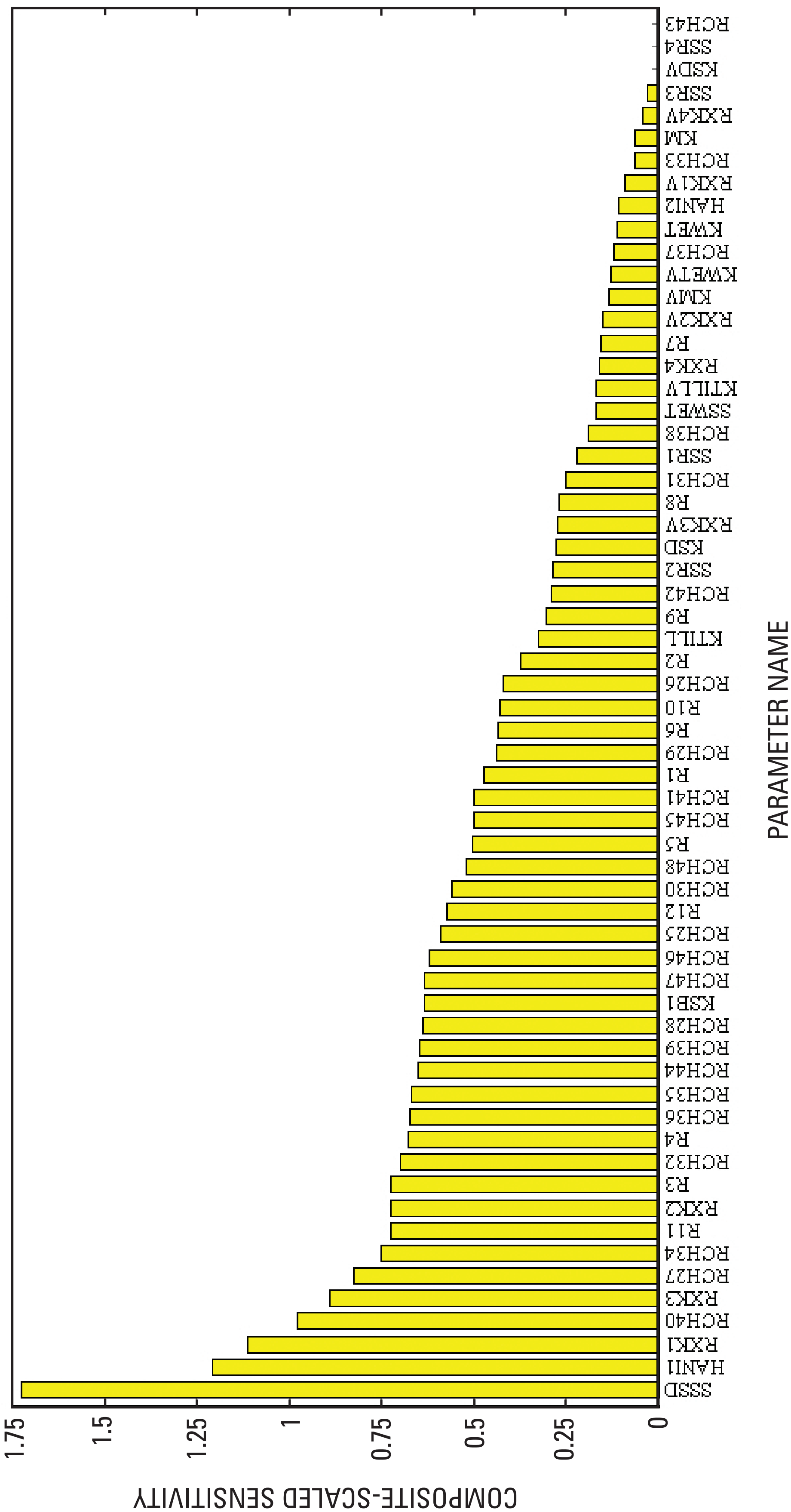
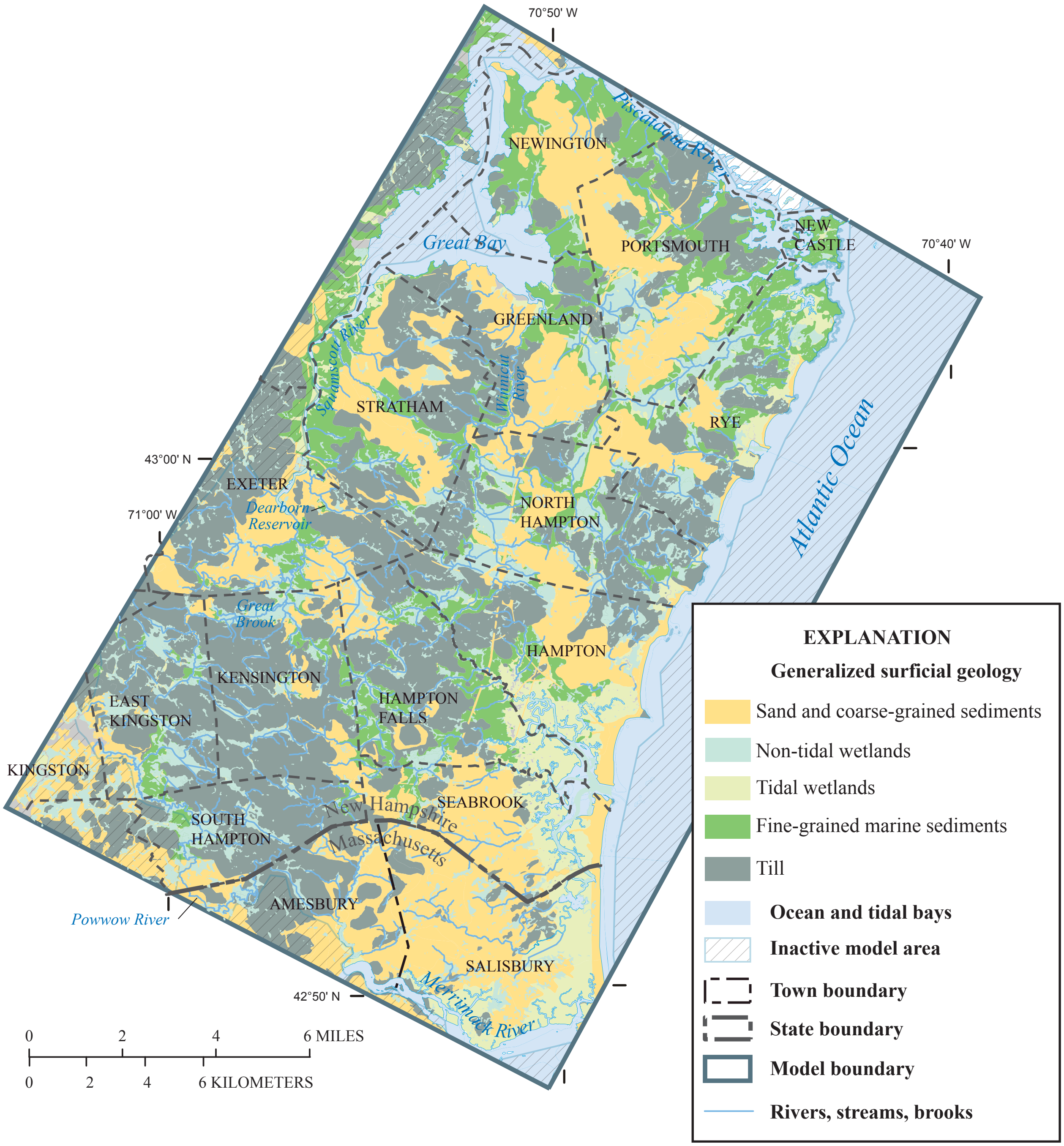


Figure 7–7. Composite-scaled sensitivity plot for transient model parameters for the Seacoast model, southeastern New Hampshire. List of parameters is in table 7–1.



New Hampshire surficial geology base from 1:24,000 N.H. State Geologist, 2005
Massachusetts base from 1:250,000 MassGIS, 1999

Figure 7–8. Distribution of surficial sediments, wetlands, and water bodies in the Seacoast model area, southeastern New Hampshire. (This figure is the same as figure 3 on page 6 in the report.)

Parameter-sensitivity analysis indicated that ground-water-flow simulation is most sensitive to the overburden sediment storage; bedrock horizontal hydraulic conductivity for units Rx1, Rx2, and Rx3 (fig. 7–6); recharge; and anisotropy (HANI1, fig. 7–7). The simulation was least sensitive to overburden or bedrock vertical hydraulic conductivities, bedrock storage, and wetland and fine-grained sediment properties. The simulation was insensitive to vertical hydraulic conductivity of coarse-grained sediments (Ksdv), specific storage in bedrock zone 4 (SSR4), and recharge in stress period 43 (RCH43) (fig. 7–7). Vertical hydraulic conductivity is well known to be about 1:10 in glacial sediments in New Hampshire. Because of the small area and thickness of stratified-drift sediments relative to the dimensions of the entire regional-flow system, the associated parameters (Ksd, Ksdv) had little effect on the regional-flow system. The sensitivity of the specific storage in bedrock zone 4 was estimated as low as a result of the few large stresses (large ground-water withdrawals) and observations in this zone. This zone consists of the Exeter Diorite and Newburyport Complex where ground-water explorations in general have resulted in the completion of few high-yielding bedrock wells. The recharge in stress period 43, July 2004, was very close to zero (-1E–5 ft/d), and the observation residuals were relatively small compared to other stress periods (fig. 7–7).

The bedrock hydraulic conductivities in table 7–4 are bulk values for the regional scale. Regional bedrock hydraulic conductivities in the Seacoast model area appear to be in the range of 0.1 to 1 ft/d. The calculated values reflect the general density and connectivity of bedrock fracturing at the regional scale for bedrock zones which are based on mapped geologic units. The values do not reflect the hydraulic conductivity of individual fracture zones or variations within zones. The bedrock hydraulic-conductivity parameters calculated with the transient model were about an order of magnitude greater than those calculated with the steady-state model. The reason for this is that the transient observation data, which includes higher base flows than the steady-state observation data, require simulation with greater hydraulic conductivities. This illustrates the effect of different observation data on the estimated parameters. The transient calibrated parameters generally were more robust because of the greater range of observation values. The poor distribution of head-observation points in the transient model compared to the steady-state model, however, limits the ability with which the transient inverse model can solve for parameters important to simulating head variations.

Local bedrock hydraulic conductivities at high-yield bedrock wells will be much higher than the regionally estimated values. As with the steady-state model, calculated heads within a few model cells of large withdrawals will not be realistic. The calculated heads in the bedrock aquifer that were more than a few model cells from the large ground-water withdrawals are regionally realistic because flow in the regional bedrock aquifer is controlled by regional bedrock aquifer properties and not individual fracture zones. For example, the drawdowns reported at large ground-water withdrawals in the model area generally were localized and did not propagate great distances away from the well because the hydraulic conductivity of the bulk rock matrix is lower than the conductivity near a high-yield bedrock well.

Few observation data were obtained for bedrock parameter zone Rx4, particularly base-flow data in either the steady-state or transient model for use with inverse modeling. The lack of stress data is reflected in the large confidence interval, several orders of magnitude, calculated for bedrock storage in this zone. In the transient model, hydraulic conductivity in this zone was simulated with greater values (Rxk4/Rxk4v, 0.02/.02) than the values used in the steady-state model (Rxk4/Rxk4v, 0.001/0.01). Because the model was not very sensitive to this parameter, however, the use of different estimated values was not very meaningful. Parameter values differed between the models, as should be expected, because of the different stresses and observation data used.

Investigation of bedrock well yields in the geologic units corresponding to parameter zone Rx4 (Exeter Diorite Formation and Newburyport Complex) indicated that well yields were higher inside the model area than they were outside the model area and were greater than may have been expected on the basis of examination of the statewide bedrock-yield-probability map. These differences reflect the value of the additional bedrock-well data that were collected for this investigation. It is important to note, however, that the geologic contacts as presently mapped, which form the boundaries of the bedrock parameter zones, are only approximately known and may not reflect the true rock at depth. Moore and others (2002) demonstrated the importance of detailed geologic mapping with respect to analysis of bedrock-well yields. Although bedrock hydraulic conductivity and specific storage cannot be estimated with a high degree of certainty for bedrock zone Rx4, lower well yields and the small number of large water-supply systems in this area indicate that the regional water availability in this zone is low relative to the other bedrock zones.

Model Calibration and Calculated Water Balance

Simulated flows and heads in the transient model were calibrated to monthly observations. The simulated recharge rate was an important variable in the monthly transient simulation. The annual totals of the 2003 and 2004 simulated monthly recharge rates (23 and 22 in.) were comparable to the simulated average recharge rate (22 in.) (fig. 7–9). Peak recharge was earlier in simulation year 2003, and late summer recharge was lower. Recharge rates were similar in the summer and fall for both years with greater differences in the spring recharge rates (fig. 7–9). Base flows in 2003 and 2004 were about 30 percent of the total annual precipitation and simulated recharge was about 48 percent of the total annual precipitation (table 7–5). Differences between the simulated rates of net recharge (fig. 7–9) and the calculated rates of base flow per unit of drainage area (tables 7–3 and 7–4), which were less than recharge rates, were caused by runoff during intense precipitation events, consumptive water use, and water transfers out of the system. Figures 7–10A–B illustrate the calibration in terms of simulated and observed base flows for all observations (fig. 7–10A) and base flows by drainage area by month (fig. 7–10B).

The steady-state simulated recharge rate (approximately 11 in/yr or about 1 in/mo), based on the October 2004 synoptic observations of head and flows, is about the same as the October 2004 transient simulated recharge rate (1.4 in/mo). The average October monthly recharge rate (0.8 in.) for 2000–04, which includes a drought period (fig. 7–3A), is lower than the 2004 rate (fig. 7–9). The October simulated recharge rate used in the steady-state model is about half of the mean annual rate of recharge and represents a seasonal low-flow condition. The transient model results indicated that the ground-water-flow system changes by season and over the course of a year and does not remain in a true steady-state condition. The fall is the most stable period of the year (has the least change) and may be considered to be the season which the ground-water-flow system is in a quasi-steady-state condition. The October synoptic conditions are representative of a fall flow rate but do not represent long-term or average conditions.

Simulated average recharge in January and February is low, about 1.5 and 1.3 in. (fig. 7–9), compared to actual precipitation (3.5 to 3.3 in.) (fig. 7–3B); this difference reflects an accumulation of precipitation in the snowpack. In March and April, simulated net recharge (5.6 and 4.7 in.) was greater than median precipitation (3.8 and 3.7 in.) (fig. 7–3B) because of the addition of recharge from the melting snowpack. Simulated net recharge in the month of May (2.2 in.) is slightly below the median precipitation (3.1) and likely reflects both runoff and a low ET rate. During the month of July, average net recharge is negative, (-0.2 in.) and in August and September it is about 0.3 in. for each month. Net recharge in October is less than 1 in. and increases to about 2.2 in. by December. On average, more than half of the total annual recharge occurs in the spring—about 25 percent in March, 20 percent in April, and 10 percent in May—whereas about 20 percent of the total recharge occurs in the fall (10 percent each in November and December).

Table 7–5. Annual base flows calculated for selected watersheds in the Seacoast model area from 2000 to 2004, southeastern New Hampshire.

[in., inches; in/yr, inches per year; —, not available]

Year	Precipitation (in.)	Winnicut River (in/yr)	Little River (in/yr)	Berrys Brook (in/yr)	Mill Brook (in/yr)	Hampton Falls River (in/yr)	Average (in/yr)	Base flow as percentage of precipitation	Recharge as percentage of precipitation
2000	53.7	17.0	13.4	19.5	15.9	16.5	16.5	31	41
2001	39.6	12.5	10.3	15.0	12.1	13.1	12.6	32	55
2002	45.6	11.0	7.8	10.9	10.3	10.1	10.0	22	48
2003	47.3	18.3	12.6	23.9	16.6	16.0	17.5	37	49
[1]2003	47.3	15.6	10.6	20.0	14.2	13.7	14.8	31	49
2004	46.1	15.6	10.4	13.4	13.2	14.1	13.3	29	48
					Averages				
2000–04	46.5	14.3	10.5	15.7	13.2	13.5	13.4	—	—
2003–04	46.7	15.6	10.5	16.7	13.7	13.9	14.1	—	—

[1] With streamflow peaks reduced.

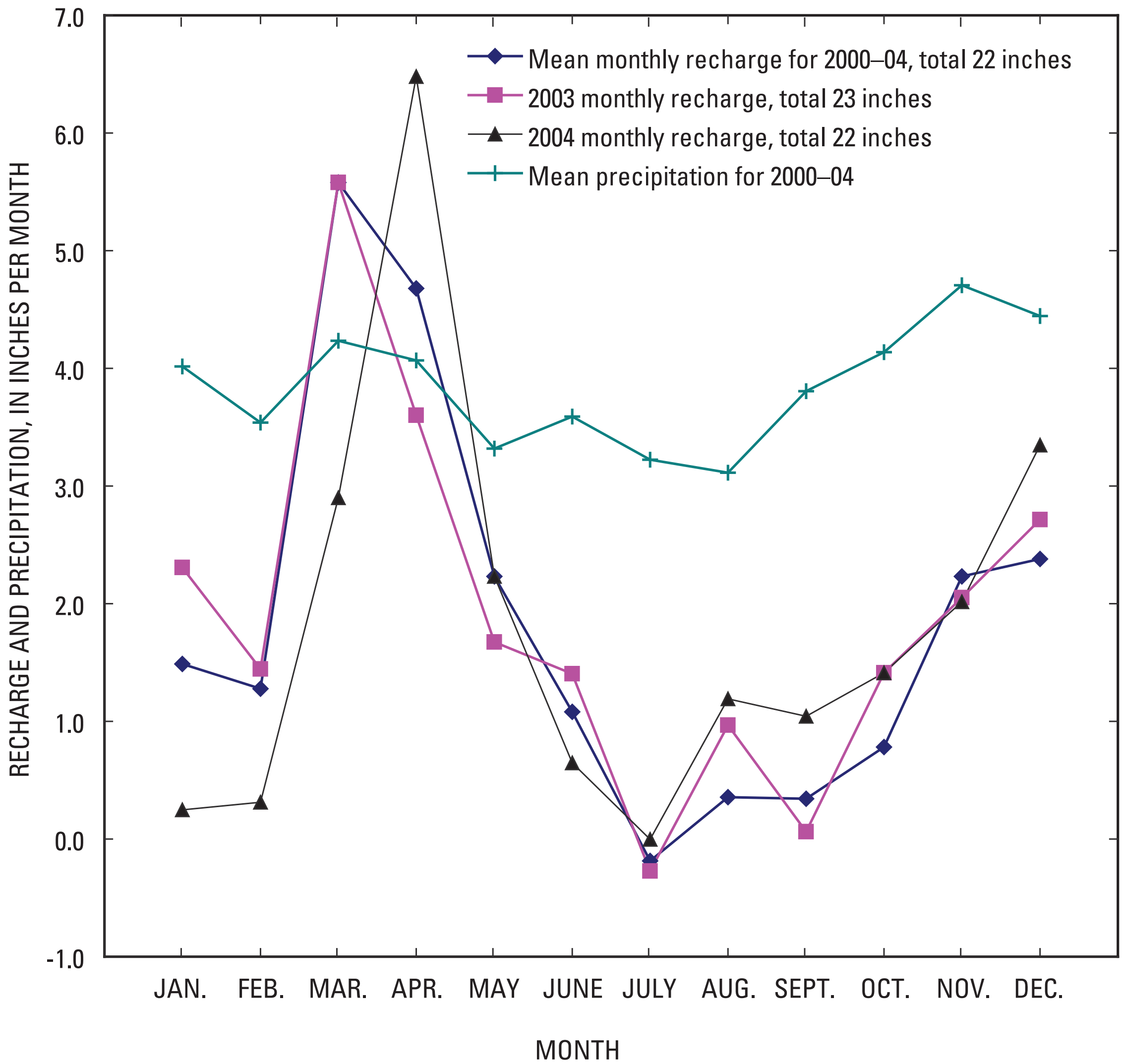


Figure 7–9. Average monthly recharge for 2000–04, monthly recharge for 2003 and 2004, and mean precipitation for 2003–04 for the Seacoast model area, southeastern New Hampshire. (This figure is the same as figure 15 on page 31 in the report.)

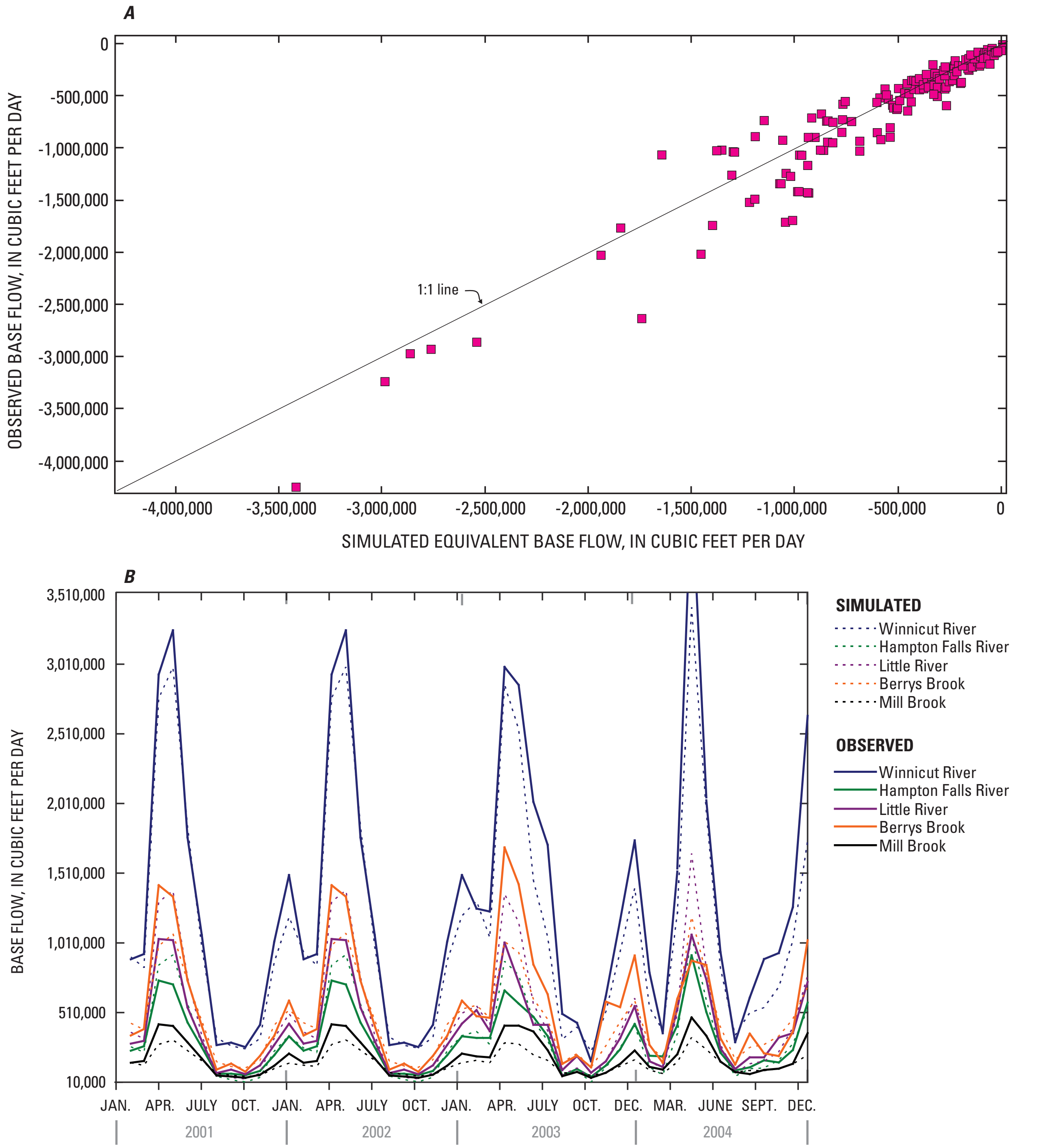


Figure 7–10. *(A)* Simulated and observed monthly base flows compared to a 1:1 line, and *(B)* simulated and observed base flows by month, in the Seacoast model area, southeastern New Hampshire.

A commonly used water-balance method of estimating actual ET for a land area can be obtained by subtracting streamflow and base flow from precipitation (Dingman, 1994). In this investigation, where monthly net recharge is defined as the direct recharge minus ET, a comparison of monthly total and average precipitation with the simulated monthly and average net recharge (fig. 7–9) provided insight into the magnitude and timing of runoff and ET in the Seacoast aquifer system. In the months November through February, the melting of the snowpack runoff was generally about 2 in. per month and recharge was about 50 percent (in the fall) and 40 percent (in the winter) of the monthly precipitation. ET in the study area increased through the growing season, May to September, but depended on climatic factors and vegetation. Precipitation fell as rainfall during this period and was consistent at about 3 to 4 in/mo. However, simulated net recharge ranged from about 2 in. in May to a slightly negative value in July (-0.2 in.), to about 0.3 in. in August and September. Monthly ET in the Seacoast ground-water system was inferred to be about 0.9 in. in May, 2 in. in June, 3.2 in. in July, 2.2 in. in August, and 2.9 in. in September. ET in October was probably about 0.75 to 1 in.; however, it was difficult to assess by this method. The inferred ET rates were slightly less than rates calculated for the Winnicut River watershed (table 8; GeoInsight, Inc., 1999) by the Thornthwaite method (Dingman, 1994), which gave a maximum rate of 4 in/mo for July and August.

Seasonal variations in net recharge provide a complicated picture of ground-water availability. The ground-water-flow system is continually discharging water (draining) throughout the year, and the net recharge is greater than the discharge in the spring and late fall. During a typical annual cycle, the aquifer system is storing water during the winter and spring when inflows are greater than outflows and losing water during the summer and early fall when outflows are greater than inflows. Figure 7–11 illustrates this process by showing the total amount of water moving into and out of storage in the bedrock aquifer for the model area over a simulated average annual period. Larger inflows are simulated in the spring and outflows in the summer than in the fall and winter when both fluxes are less. As noted above, the fall is the most stable period of the year, a quasi-steady state period, when fluxes are less and inflows and outflows are approximately balanced.

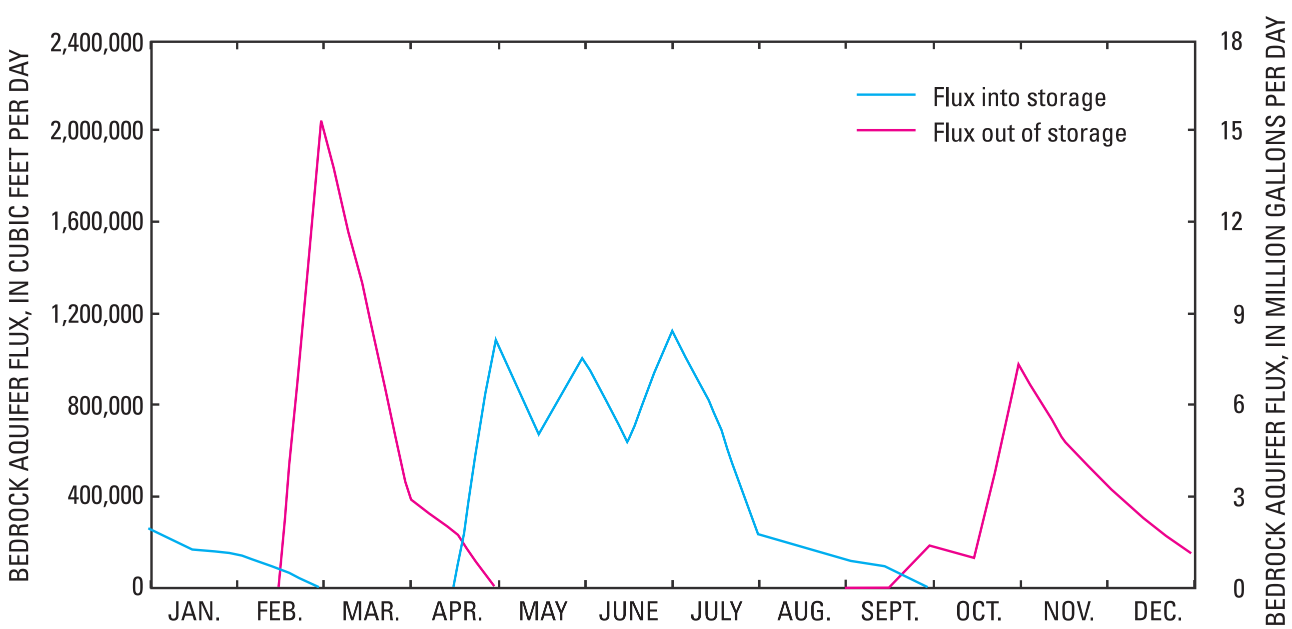


Figure 7–11. The total flux of water into and out of storage in the bedrock aquifer for a simulated average annual period in the Seacoast model area, southeastern New Hampshire.

Unweighted residuals for simulated heads are shown in figure 7–12. The weighted residuals are dimensionless but can be compared to the model-calculated error variance (s^2) or to the standard error of regression (s), which represents the expected residual based on data accuracy and weighting. In this case the model-calculated standard error of regression is ±2.77. Overall, the simulated heads fit the regional trend, and the average weighted residual for all observations was 0.15. Eighty-six percent of all weighted residuals were within one standard error of regression, and 95 percent were within two standard errors of regression. The average weighted residual for the network observations was -1.47, indicating that in general network heads were higher than observations. Regionally, discrepancies calculated by the transient model between the simulated and observed heads were similar to those that were calculated by the steady-state model. The distribution of monthly head observations available for the transient-head simulation, however, was poor and was almost entirely limited to a few areas with head networks. Synthetic heads were used to create observations outside the network areas, but model fit to the synthetic observations was poor. The average weighted residual for synthetic observations was 3.20, indicating that the simulated heads for some till covered areas were poorly fit and less than the expected heads. Some error can be attributed to the fact that the monthly head observations, unlike the base-flow observations, were made at a point in time that may not be representative of a monthly mean value. Other head errors were attributed to the use of approximate (DEM) reference elevations and topographic variations. Differences between actual and monthly approximated water uses also contributed to differences between observed and simulated heads. Water levels in the till aquifer generally rose to the land surface during the spring; these high water levels exceeded the pressure range on the continuous water-level recorders and thus were not recorded (breaks in the records shown in fig. 7–4). It is possible that the potentiometric surface in the till aquifer is above the land surface during the spring melt and that the water-level fluctuations were greater than the ranges indicated by the data.

Comparisons of simulated and observed monthly ground-water heads for four wells are shown in figure 7–13A–D. Simulated seasonal head variations generally were greater than the observed variations. The fit between simulated and observed heads was closer for wells in areas with greater ranges in head (fig. 7–13B–D) caused by local withdrawals and poorer in areas with few withdrawals (fig. 7–13A). This result indicated that the ground-water-flow model simulated the dynamics of ground-water flow better in areas with stresses, but that the simulated hydrologic parameters were not as well suited to other areas. It is likely that a model designed for use solely in an area without complex stresses may provide better results than a model designed for use in both areas; however, it is difficult to estimate hydraulic properties without stresses on the aquifer system. Efforts to reduce the simulated seasonal head variations by manually increasing hydraulic conductivities and decreasing recharge were not successful and reduced the overall model fit. The overall head configurations for the October 2004 transient and steady-state simulations (appendix 5) were comparable; differences resulted from the use of slightly different water-use tabulations for the two simulations.

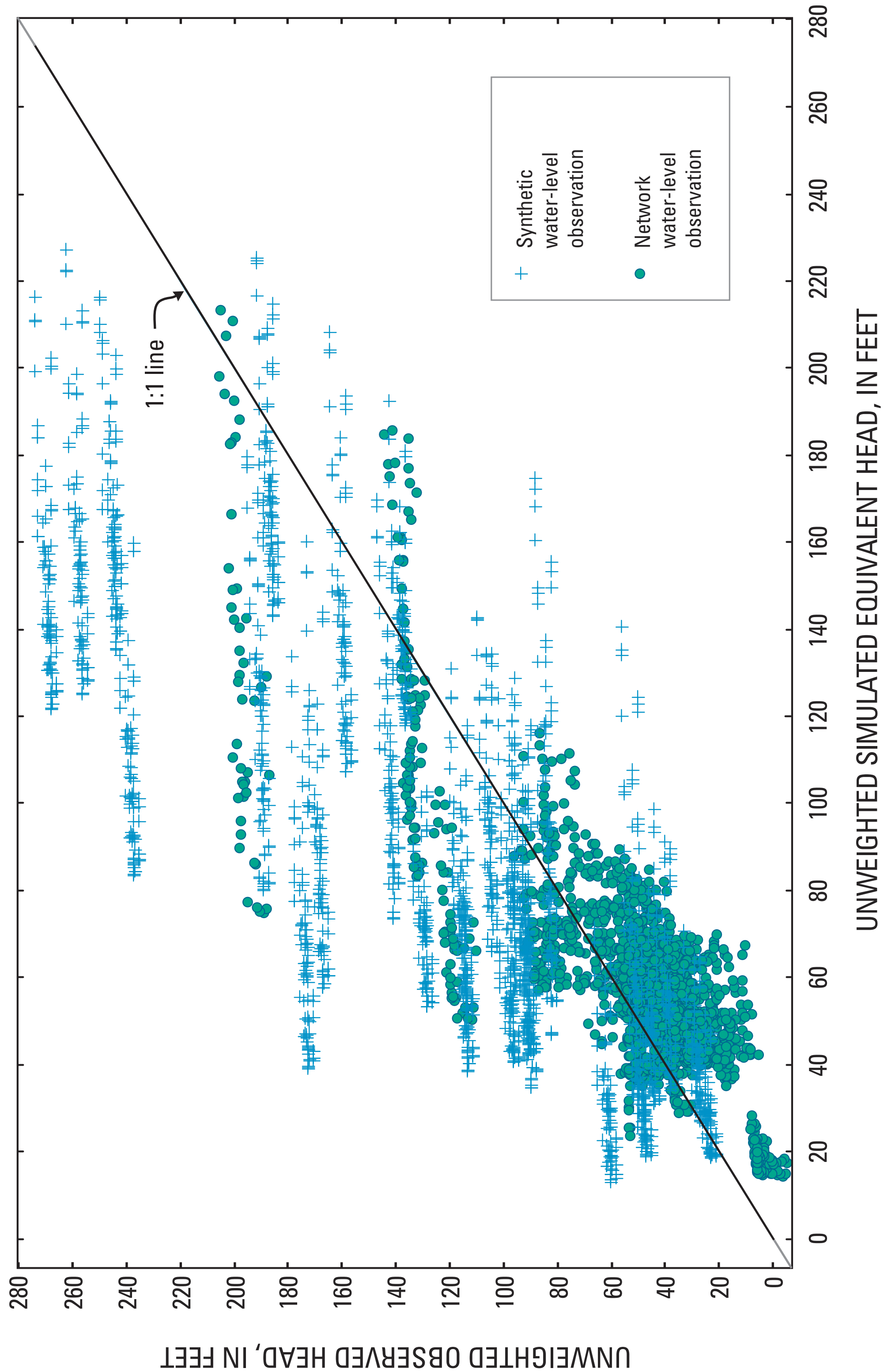


Figure 7–12. Selected simulated and observed monthly ground-water heads for the Seacoast model area, southeastern New Hampshire.

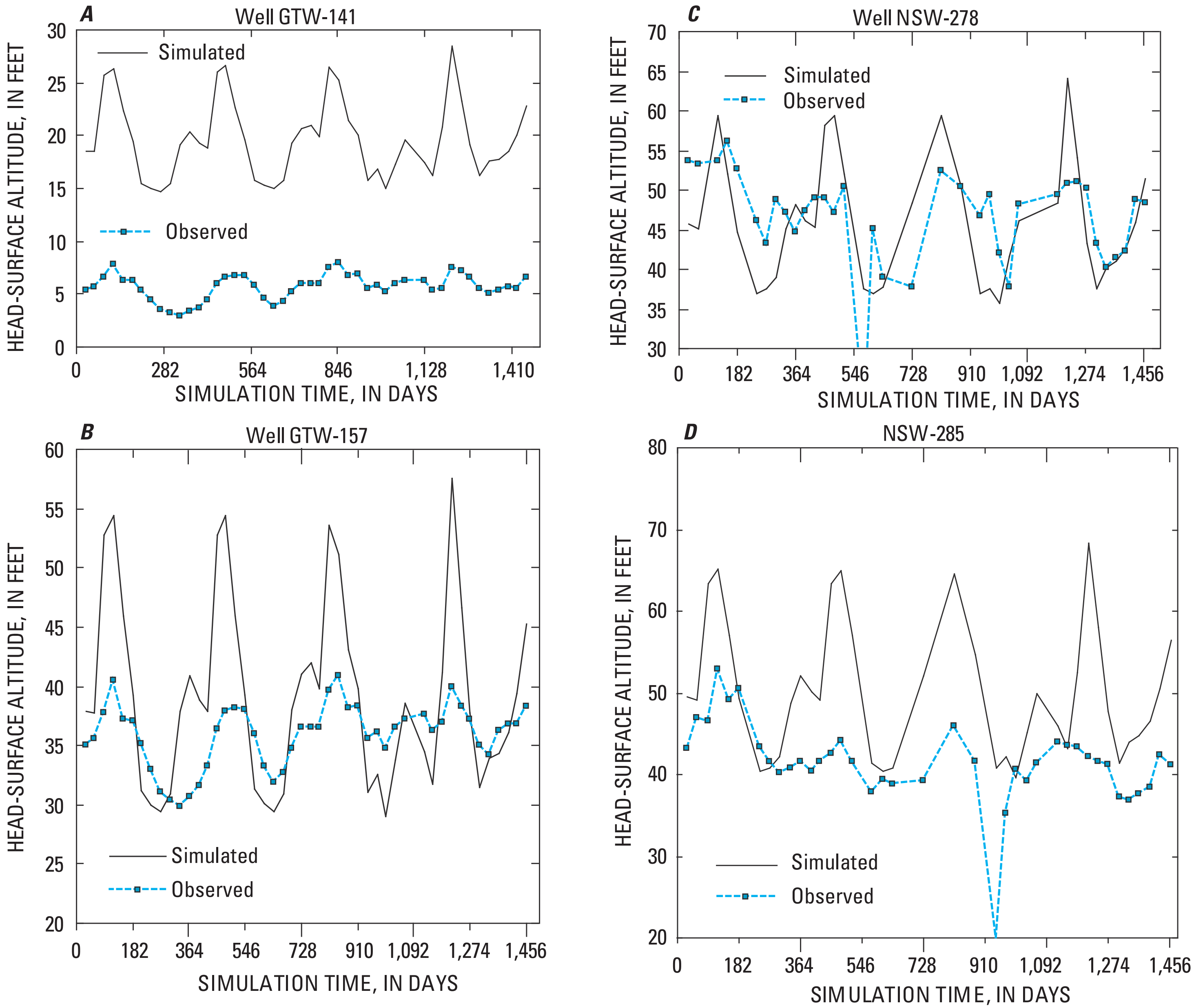


Figure 7–13. Simulated and observed ground-water heads at monitoring wells *(A)* GTW-141, *(B)* GTW-157, *(C)* NSW-278, and *(D)* NSW-285 for the Seacoast model, southeastern New Hampshire. (Location of wells shown on figure 7 on page 16–18 in the report.)

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Appendix 8. Transient Model Parameter Correlation Coefficient Matrix

Table

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.

[See footnote for values in **bold**]

Parameter name	Parameter name									
	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	**Ktillv Rxk4v SSR3 R7 RCH29 RCH39**	**Ksd Ksb1 SSR4 R8 RCH30 RCH40**	**Ksdv Km SSsd R9 RCH31 RCH41**	**Rxk1 Kmv SSwet R10 RCH32 RCH42**	**Rxk2 Kwet R1 R11 RCH33 RCH43**	**Rxk3 Kwetv R2 R12 RCH34 RCH44**	**Rxk4 Hani1 R3 RCH25 RCH35 RCH45**	**Rxk1v Hani2 R4 RCH26 RCH36 RCH46**	**Rxk2v SSR1 R5 RCH27 RCH37 RCH47**
Ktill	1 -0.582 -9.78E-2 .155 6.31E-2 .119 -6.27E-2	-0.208 -.260 -3.64E-2 .184 .144 -.127	0.149 -7.91E-2 -6.40E-2 7.85E-2 9.45E-2 -5.06E-2	-1.53E-2 9.51E-2 2.77E-2 5.00E-2 0.183 .143	-0.136 -.103 -.176 -8.66E-2 -7.42E-2 .177	-0.155 -.197 .102 -.132 .124 .157	-0.539 -7.49E-2 7.29E-2 -1.90E-2 -.169 -.137	-0.250 .216 -6.13E-2 1.36E-2 -8.69E-2 -1.13E-2	8.44E-2 0.137 5.04E-2 .106 -5.62E-2 -8.62E-2	0.146 -5.23E-2 .136 -7.70E-2 .171 -.103
Ktillv	-.208 2.15E-2 -.105 .118 .198 -4.89E-2 9.83E-2	1 9.86E-2 -5.44E-2 -2.60E-2 .172 7.42E-2	.143 6.36E-2 -2.54E-2 -9.46E-2 .101 8.47E-2	-.251 8.42E-2 .118 -.154 -1.94E-2 .184	.190 -.200 -7.26E-2 -7.08E-2 -8.40E-2 .104	5.99E-2 -1.81E-2 .142 7.56E-2 -.117 -5.26E-2	-3.47E-2 -.292 .119 .148 3.95E-2 -1.60E-2	.101 7.94E-2 7.55E-2 .162 .105 2.17E-2	-.299 -.147 .159 .17 .121 .104	-.701 -6.13E-2 .175 7.82E-2 6.80E-2 .121
Ksd	.149 5.26E-2 .229 -.117 8.11E-2 -.288 .198	.143 -.104 .179 -.305 -4.90E-2 .205	1 3.92E-2 4.93E-2 -.342 -7.77E-2 .28	-.152 -.159 1.62E-2 -.383 -.322 -3.82E-2	-.222 2.20E-2 -.205 -.144 -.215 -.168	-.136 -.319 2.03E-2 .193 -.373 -.321	-.414 9.04E-2 1.33E-2 .153 7.90E-2 2.28E-3	-5.71E-2 .188 .249 .105 .176 -6.40E-2	4.14E-2 -.100 .178 2.40E-3 .145 .160	-6.91E-2 .237 -1.91E-2 .244 -.214 .188
Ksdv	-1.53E-2 .104 7.75E-2 -7.65E-2 -5.39E-2 -1.61E-2 3.35E-2	-.251 5.70E-2 8.77E-2 -8.03E-2 -8.08E-2 6.82E-2	-.152 -.192 8.02E-2 -4.58E-2 -4.03E-2 4.28E-2	1 1.12E-2 -3.11E-2 8.70E-3 -6.74E-2 -9.71E-2	9.90E-2 9.21E-2 4.54E-2 9.31E-2 .132 -7.62E-2	.474 .135 -8.92E-2 9.09E-2 -7.46E-2 -6.76E-2	6.01E-2 6.08E-2 -3.21E-2 2.63E-2 .153 .101	-.235 -.183 4.17E-2 -2.43E-2 5.99E-2 4.55E-2	3.00E-2 .201 -1.71E-2 -5.21E-2 1.38E-2 8.75E-2	-.232 .113 -8.45E-2 4.90E-2 -7.43E-2 5.37E-2

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
Rxk1	-0.136	0.190	-0.222	9.90E-2	1	0.555	0.535	0.155	-0.112	-0.243
	.130	6.11E-2	-3.04E-2	6.25E-2	5.58E-3	-.252	.292	-.521	-5.84E-2	-5.36E-2
	-.319	-7.45E-2	-6.95E-2	5.66E-3	-0.106	.132	.119	-.144	-2.58E-2	.177
	.234	.324	.327	0.343	.125	-.126	-1.50E-2	2.59E-2	.178	-.151
	8.81E-2	.223	.189	.325	.180	.352	-4.21E-2	-7.23E-2	-3.45E-2	.287
	.31	-.125	-.162	.182	.267	.331	1.06E-2	.126	-8.69E-2	-7.79E-2
	-9.16E-2									
Rxk2	-.155	5.99E-2	-.136	.474	.555	1	.370	.106	-.127	-.345
	.221	5.56E-2	-2.45E-3	-2.37E-2	.142	6.31E-2	9.93E-2	-.581	-.135	-8.22E-3
	-8.97E-2	3.65E-2	4.36E-2	6.33E-3	8.96E-2	-1.73E-2	2.76E-2	1.27E-2	8.41E-3	1.34E-2
	2.60E-2	1.29E-2	2.38E-2	7.45E-2	.135	6.24E-2	4.68E-2	3.39E-2	4.20E-2	2.73E-2
	4.22E-2	3.03E-2	5.05E-2	2.56E-2	.178	1.09E-2	.147	5.52E-2	4.17E-2	2.99E-2
	6.55E-2	4.51E-2	1.36E-2	1.00E-2	3.06E-2	1.94E-2	.111	7.63E-2	8.45E-2	5.28E-2
	2.86E-2									
Rxk3	-.539	-3.47E-2	-.414	6.01E-2	.535	.370	1	.288	-3.56E-2	6.64E-3
	.111	.189	-5.38E-3	-.142	.316	-2.38E-2	.272	-.587	-.202	-8.51E-2
	-.126	-7.23E-2	5.97E-3	6.57E-2	.195	-8.99E-2	-5.56E-2	-8.65E-3	-8.55E-2	-.122
	-8.89E-2	-1.76E-2	.114	.182	.185	5.21E-2	-2.21E-2	-5.28E-2	-7.95E-2	2.67E-3
	-8.51E-2	-.107	-4.64E-2	-2.19E-2	.190	7.01E-2	.139	2.55E-2	-5.34E-4	-6.46E-2
	2.98E-2	4.54E-2	-1.37E-2	-.117	-9.54E-2	6.61E-3	.147	7.13E-2	3.34E-2	2.11E-2
	-1.01E-2									
Rxk4	-.250	.101	-5.71E-2	-.235	.155	.106	.288	1	1.32E-2	1.04E-2
	.168	-.153	-.111	-8.43E-2	.151	7.48E-2	4.66E-2	-.342	-.899	-5.38E-2
	-.113	-4.19E-2	-3.57E-2	5.17E-2	.124	-7.15E-2	-5.82E-2	8.73E-3	-2.51E-2	-6.33E-2
	-8.08E-2	-7.68E-2	-6.81E-2	-6.10E-2	2.66E-2	1.77E-2	-1.55E-2	-4.20E-2	-6.96E-2	1.59E-2
	-4.51E-2	-6.07E-2	-6.55E-2	-7.51E-2	-8.33E-3	-8.44E-2	3.42E-2	4.07E-3	-6.78E-3	-8.54E-2
	-7.43E-2	2.58E-2	1.44E-2	-5.84E-2	-8.64E-2	-8.43E-2	-3.48E-3	-2.69E-2	1.49E-2	8.74E-3
	1.04E-2									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Parameter name									
	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	**Ktillv Rxk4v SSR3 R7 RCH29 RCH39**	**Ksd Ksb1 SSR4 R8 RCH30 RCH40**	**Ksdv Km SSsd R9 RCH31 RCH41**	**Rxk1 Kmv SSwet R10 RCH32 RCH42**	**Rxk2 Kwet R1 R11 RCH33 RCH43**	**Rxk3 Kwetv R2 R12 RCH34 RCH44**	**Rxk4 Hani1 R3 RCH25 RCH35 RCH45**	**Rxk1v Hani2 R4 RCH26 RCH36 RCH46**	**Rxk2v SSR1 R5 RCH27 RCH37 RCH47**
Rxk1v	8.44E-2	-0.299	4.14E-2	3.00E-2	-0.112	-0.127	-3.56E-2	1.32E-2	1	0.399
	6.58E-2	-7.34E-3	-4.62E-2	-0.224	.239	-5.95E-2	-0.144	5.20E-2	-3.39E-2	.114
	4.18E-2	-3.62E-2	1.61E-2	5.29E-2	.192	-.131	-4.58E-2	9.50E-2	-3.75E-3	-6.62E-2
	-0.102	-.198	-0.136	-.143	2.42E-2	.115	5.04E-2	-2.34E-3	-5.13E-2	6.27E-2
	-5.33E-2	-5.66E-2	-7.89E-2	-.207	2.00E-2	-.192	9.04E-2	8.83E-2	3.07E-2	-.167
	-.129	.114	6.66E-2	-9.02E-2	-.119	-.177	6.35E-2	-8.68E-3	9.94E-2	8.19E-2
	4.57E-2									
Rxk2v	.146	-.701	-6.91E-2	-.232	-.243	-.345	6.64E-3	1.04E-2	0.399	1
	1.54E-3	-9.18E-2	-5.31E-2	-.222	.252	2.38E-2	-7.96E-2	0.136	8.74E-2	-2.19E-2
	3.27E-2	-4.47E-2	-2.72E-2	-4.98E-3	4.52E-2	-2.18E-2	-4.00E-2	1.99E-3	-4.80E-2	-9.22E-2
	-7.12E-2	5.48E-3	8.51E-2	.125	7.34E-2	-1.29E-2	-5.91E-2	-4.37E-2	-8.09E-2	1.09E-2
	-8.11E-2	-.101	-5.31E-2	-1.58E-2	7.70E-2	7.14E-2	-4.16E-3	-2.89E-2	-2.91E-2	-5.50E-2
	3.04E-2	-5.23E-3	1.67E-2	-9.62E-2	-7.96E-2	2.54E-2	3.65E-2	2.72E-2	-3.64E-2	-3.70E-2
	-1.58E-2									
Rxk3v	-.582	2.15E-2	5.26E-2	.104	.130	.221	.111	.168	6.58E-2	1.54E-3
	1	.130	-2.58E-3	-.244	.157	2.36E-2	.153	-.263	-.139	5.65E-2
	5.40E-2	6.15E-2	7.79E-2	-4.79E-2	7.66E-2	-6.87E-2	-5.16E-2	4.21E-2	-8.37E-3	-7.03E-2
	-8.75E-2	-.125	-8.68E-2	-9.50E-2	1.35E-3	5.99E-2	-1.12E-3	-1.26E-2	-6.55E-2	5.33E-2
	-1.52E-2	-8.00E-2	-5.20E-2	-.130	1.16E-2	-.127	7.01E-2	2.88E-2	2.60E-2	-.120
	-9.46E-2	6.69E-2	4.03E-2	-7.60E-2	-.106	-.113	4.76E-2	-3.44E-2	3.69E-2	4.42E-2
	3.68E-2									
Rxk4v	-.260	9.86E-2	-.104	5.70E-2	6.11E-2	5.56E-2	.189	-.153	-7.34E-3	-9.18E-2
	.130	1	1.81E-2	-3.88E-2	3.66E-2	2.94E-2	-1.23E-3	-3.17E-2	1.34E-2	.110
	.148	.102	.131	-9.44E-2	2.07E-2	-2.36E-2	9.31E-4	3.65E-2	1.27E-2	-2.31E-2
	-2.66E-2	-5.14E-2	-4.27E-3	-2.28E-4	2.94E-2	5.85E-2	2.61E-2	1.64E-2	-1.00E-2	4.28E-2
	6.04E-3	-2.82E-2	-4.19E-3	-5.36E-2	6.00E-2	-4.32E-2	7.26E-2	4.36E-2	3.23E-2	-4.76E-2
	-2.16E-2	5.38E-2	3.35E-2	-2.79E-2	-3.85E-2	-4.40E-2	6.73E-2	2.04E-2	4.00E-2	4.75E-2
	3.34E-2									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Parameter name									
	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
Ksb1	-7.91E-2	6.36E-2	3.92E-2	-0.192	-3.04E-2	-2.45E-3	-5.38E-3	-0.111	-4.62E-2	-5.31E-2
	-2.58E-3	1.81E-2	1	-.12	-1.39E-2	-0.204	-5.48E-2	.115	8.75E-2	-0.117
	-0.109	-4.04E-2	-3.91E-2	-5.61E-2	0.127	2.09E-2	-5.75E-3	-7.64E-2	5.56E-3	7.85E-2
	9.12E-2	2.10E-2	-1.49E-2	-8.33E-2	-.179	-8.43E-2	-5.94E-2	-3.36E-2	3.20E-2	-9.90E-2
	2.32E-2	0.113	5.03E-2	6.18E-2	-.134	4.24E-2	-0.151	-8.84E-2	-5.77E-2	9.06E-2
	-1.92E-2	-8.69E-2	-0.101	.102	.113	3.68E-2	-8.84E-2	-7.33E-2	-8.02E-2	-5.68E-2
	-6.12E-2									
Km	9.51E-2	8.42E-2	-.159	1.12E-2	6.25E-2	-2.37E-2	-.142	-8.43E-2	-0.224	-.222
	-.244	-3.88E-2	-.12	1	**-.911**	7.26E-2	-.176	-3.74E-2	.163	-3.00E-2
	-3.06E-2	5.71E-2	-4.03E-2	-8.38E-2	1.69E-2	-1.97E-2	1.00E-2	-.101	-4.35E-2	6.35E-2
	8.67E-2	.184	7.11E-2	7.52E-2	-3.79E-2	-.151	-6.44E-2	-4.60E-2	3.15E-2	-.116
	-1.44E-2	8.32E-2	4.54E-2	.205	-5.88E-2	.157	-.157	-.121	-8.77E-2	.163
	.138	-.145	-.110	6.80E-2	.124	.164	-.110	-1.92E-2	-.108	-.130
	-9.47E-2									
Kmv	-.103	-.200	2.20E-2	9.21E-2	5.58E-3	.142	.316	.151	.239	.252
	.157	3.66E-2	-1.39E-2	**-.911**	1	-2.67E-3	.174	-.159	-.226	1.11E-3
	-3.48E-3	-8.63E-2	3.91E-2	6.21E-2	4.61E-2	-3.48E-2	-4.39E-2	2.81E-2	-2.45E-2	-8.46E-2
	-8.94E-2	-.126	-3.48E-2	-1.92E-2	5.65E-2	8.52E-2	9.11E-4	-1.49E-2	-6.99E-2	4.54E-2
	-4.08E-2	-9.67E-2	-5.86E-2	-.146	8.02E-2	-.103	.117	5.28E-2	2.36E-2	-.134
	-8.41E-2	7.89E-2	3.55E-2	-8.80E-2	-.110	-.106	7.51E-2	3.69E-3	5.73E-2	5.74E-2
	3.30E-2									
Kwet	-.197	-1.81E-2	-.319	.135	-.252	6.31E-2	-2.38E-2	7.48E-2	-5.95E-2	2.38E-2
	2.36E-2	2.94E-2	-.204	7.26E-2	-2.67E-3	1	-.486	-3.17E-2	-2.41E-2	-2.74E-2
	1.01E-2	1.72E-2	2.69E-3	-5.89E-2	.238	-.110	-5.18E-2	-1.31E-2	-2.16E-2	-2.72E-2
	-4.85E-2	-5.73E-2	-.117	-.103	-2.61E-2	3.56E-3	-1.86E-2	-3.62E-2	-5.01E-2	-1.53E-4
	-9.18E-3	-3.12E-2	-2.94E-2	-5.01E-2	-2.08E-2	-.118	4.67E-2	-1.31E-2	-1.12E-2	-2.79E-2
	-3.70E-2	-4.98E-3	-2.43E-2	-1.88E-2	-3.23E-2	-4.54E-2	-1.59E-2	-3.06E-2	-2.83E-2	-7.28E-3
	-4.56E-3									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Parameter name									
	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	**Ktillv Rxk4v SSR3 R7 RCH29 RCH39**	**Ksd Ksb1 SSR4 R8 RCH30 RCH40**	**Ksdv Km SSsd R9 RCH31 RCH41**	**Rxk1 Kmv SSwet R10 RCH32 RCH42**	**Rxk2 Kwet R1 R11 RCH33 RCH43**	**Rxk3 Kwetv R2 R12 RCH34 RCH44**	**Rxk4 Hani1 R3 RCH25 RCH35 RCH45**	**Rxk1v Hani2 R4 RCH26 RCH36 RCH46**	**Rxk2v SSR1 R5 RCH27 RCH37 RCH47**
Kwetv	-7.49E-2	-0.292	9.04E-2	6.08E-2	0.292	9.93E-2	0.272	4.66E-2	-0.144	-7.96E-2
	0.153	-1.23E-3	-5.48E-2	-0.176	.174	-0.486	1	-0.328	-6.99E-2	3.64E-2
	2.64E-2	1.13E-2	3.01E-2	-2.17E-2	-.114	-6.92E-2	-7.11E-2	-7.72E-2	-.120	-0.101
	-5.01E-2	7.15E-2	0.131	.145	4.50E-2	-8.57E-2	-9.97E-2	-.121	-8.71E-2	-7.49E-2
	-.135	-8.78E-2	-5.22E-2	5.87E-2	3.55E-2	.159	-5.39E-2	-8.12E-2	-8.69E-2	-1.78E-2
	4.57E-2	-6.65E-2	-8.82E-2	-9.82E-2	-4.22E-2	7.98E-2	7.10E-3	-4.09E-2	-.103	-9.57E-2
	-7.70E-2									
Hani1	.216	7.94E-2	.188	-.183	-.521	-.581	-.587	-.342	5.20E-2	.136
	-.263	-3.17E-2	.115	-3.74E-2	-.159	-3.17E-2	-.328	1	.363	7.47E-2
	.147	-1.54E-2	-1.35E-2	4.26E-2	-.270	.202	.139	.116	.142	.106
	8.49E-2	1.84E-2	7.53E-2	5.68E-2	4.38E-2	9.27E-2	.132	.157	.134	.114
	.131	8.65E-2	8.44E-2	1.50E-2	4.61E-2	6.24E-2	6.43E-2	.122	.118	5.58E-2
	4.24E-2	9.25E-2	.114	9.97E-2	6.17E-2	2.20E-2	7.25E-2	.110	8.73E-2	.118
	.107									
Hani2	.137	-.147	-.100	.201	-5.84E-2	-.135	-.202	**-.899**	-3.39E-2	8.74E-2
	-.139	1.34E-2	8.75E-2	.163	-.226	-2.41E-2	-6.99E-2	.363	1	-8.23E-2
	-3.71E-2	-9.50E-2	-1.95E-2	4.48E-2	-.113	.120	8.47E-2	-5.14E-2	3.80E-3	8.78E-2
	.127	.175	.186	.196	4.65E-2	-5.28E-2	2.39E-4	5.04E-2	9.91E-2	-5.59E-2
	5.45E-2	9.10E-2	.103	.177	7.88E-2	.222	-3.86E-2	-2.46E-2	-1.46E-3	.164
	.168	-6.31E-2	-6.17E-2	9.09E-2	.143	.188	2.43E-2	7.60E-2	-3.47E-2	-3.21E-2
	-3.90E-2									
SSR1	-5.23E-2	-6.13E-2	.237	.113	-5.36E-2	-8.22E-3	-8.51E-2	-5.38E-2	.114	-2.19E-2
	5.65E-2	.110	-.117	-3.00E-2	1.11E-3	-2.74E-2	3.64E-2	7.47E-2	-8.23E-2	1
	.854	**.885**	.608	-.602	-.488	-.144	-5.03E-2	.245	3.31E-2	-.182
	-.213	-.282	-.142	-.112	6.17E-2	.25	.133	3.09E-2	-9.20E-2	.244
	-6.68E-2	-.207	-.125	-.293	5.85E-2	-.242	.235	.205	.132	-.305
	-.186	.255	.252	-.244	-.270	-.266	.187	4.27E-2	.162	.188
	.177									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
SSR2	-9.78E-2	-0.105	0.229	7.75E-2	-0.319	-8.97E-2	-0.126	-0.113	4.18E-2	3.27E-2
	5.40E-2	.148	-.109	-3.06E-2	-3.48E-3	1.01E-2	2.64E-2	.147	-3.71E-2	**0.854**
	1	.756	.504	-0.429	-.303	-0.212	-.111	.360	4.86E-2	-.328
	-0.383	-.489	-.287	-.208	.104	.389	.175	4.03E-2	-0.194	.378
	-.117	-.375	-.246	-.495	4.73E-2	-.430	.371	.309	.192	-.492
	-.367	.387	.393	-.390	-.469	-.481	.284	4.63E-2	.285	.290
	.270									
SSR3	-3.64E-2	-5.44E-2	.179	8.77E-2	-7.45E-2	3.65E-2	-7.23E-2	-4.19E-2	-3.62E-2	-4.47E-2
	6.15E-2	.102	-4.04E-2	5.71E-2	-8.63E-2	1.72E-2	1.13E-2	-1.54E-2	-9.50E-2	**.885**
	.756	1	.613	-.831	-.269	-.112	-4.05E-2	7.92E-2	-2.61E-2	-8.67E-2
	-7.95E-2	-9.33E-2	-3.36E-2	-6.66E-2	-2.61E-2	6.99E-2	1.18E-2	-2.49E-2	-6.16E-2	7.87E-2
	-7.24E-2	-8.45E-2	-5.01E-2	-.107	3.66E-2	-.115	6.27E-2	3.46E-2	1.15E-2	-.136
	-5.77E-2	8.31E-2	7.41E-2	-.139	-9.83E-2	-8.65E-2	7.32E-2	-3.57E-2	1.64E-2	3.25E-2
	4.20E-2									
SSR4	-6.40E-2	-2.54E-2	4.93E-2	8.02E-2	-6.95E-2	4.36E-2	5.97E-3	-3.57E-2	1.61E-2	-2.72E-2
	7.79E-2	.131	-3.91E-2	-4.03E-2	3.91E-2	2.69E-3	3.01E-2	-1.35E-2	-1.95E-2	.608
	.504	.613	1	-.483	-9.38E-2	-.142	-5.09E-2	.167	1.02E-2	-.153
	-.160	-.204	-7.64E-2	-7.20E-2	3.59E-2	.184	7.57E-2	8.04E-3	-8.55E-2	.169
	-6.72E-2	-.161	-9.28E-2	-.223	7.39E-2	-.193	.179	.136	7.79E-2	-.227
	-.133	.180	.172	-.197	-.199	-.189	.154	1.17E-2	.106	.126
	.114									
SSsd	2.77E-2	.118	1.62E-2	-3.11E-2	5.66E-3	6.33E-3	6.57E-2	5.17E-2	5.29E-2	-4.98E-3
	-4.79E-2	-9.44E-2	-5.61E-2	-8.38E-2	6.21E-2	-5.89E-2	-2.17E-2	4.26E-2	4.48E-2	-.602
	-.429	**-.831**	-.483	1	9.88E-2	-1.49E-3	-9.62E-3	.294	.156	-.160
	-.238	-.348	-.267	-.126	.159	.326	.223	.132	-4.18E-2	.308
	5.93E-2	-.207	-.147	-.342	8.50E-3	-.273	.310	.307	.224	-.264
	-.271	.295	.342	-.13	-.296	-.352	.176	.133	.304	.290
	.250									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
SSwet	-0.176	-7.26E-2	-0.205	4.54E-2	-0.106	8.96E-2	0.195	0.124	0.192	4.52E-2
	7.66E-2	2.07E-2	.127	1.69E-2	4.61E-2	0.238	-.114	-.270	-.113	-0.488
	-.303	-0.269	-9.38E-2	9.88E-2	1	-.163	-.103	-4.86E-2	-7.17E-2	-8.82E-2
	-.109	-.154	-.126	-0.159	-3.01E-2	2.71E-2	-8.18E-2	-8.72E-2	-.117	-5.15E-2
	-9.08E-2	-6.02E-2	-9.95E-2	-.137	-3.72E-3	-.211	3.62E-2	-2.80E-2	-7.15E-2	-.111
	-.141	1.40E-2	-5.10E-2	-8.55E-2	-9.51E-2	-.145	3.08E-2	-8.79E-2	1.81E-2	-1.06E-2
	-4.97E-2									
R1	.102	.142	2.03E-2	-8.92E-2	.132	-1.73E-2	-8.99E-2	-7.15E-2	-.131	-2.18E-2
	-6.87E-2	-2.36E-2	2.09E-2	-1.97E-2	-3.48E-2	-.110	-6.92E-2	.202	.120	-.144
	-.212	-.112	-.142	-1.49E-3	-.163	1	-.107	-.149	2.59E-2	.226
	.259	.304	.237	.190	-1.13E-2	-.171	-.190	.118	.180	-.139
	.125	.241	.193	.301	3.90E-2	.288	-.149	-.109	-3.97E-2	.296
	.251	-.159	-.151	.241	.289	.296	-8.88E-2	4.30E-2	-.110	-.102
	-8.95E-2									
R2	7.29E-2	.119	1.33E-2	-3.21E-2	.119	2.76E-2	-5.56E-2	-5.82E-2	-4.58E-2	-4.00E-2
	-5.16E-2	9.31E-4	-5.75E-3	1.00E-2	-4.39E-2	-5.18E-2	-7.11E-2	.139	8.47E-2	-5.03E-2
	-.111	-4.05E-2	-5.09E-2	-9.62E-3	-.103	-.107	1	-.153	3.09E-2	.145
	.161	.175	.145	.119	1.39E-2	-7.53E-2	-2.29E-5	6.01E-2	.126	-5.85E-2
	9.34E-2	.157	.126	.172	4.78E-2	.164	-5.65E-2	-3.67E-2	-2.11E-3	.176
	.154	-6.90E-2	-6.50E-2	.152	.176	.171	-2.65E-2	4.75E-2	-4.16E-2	-3.47E-2
	-3.17E-2									
R3	-6.13E-2	7.55E-2	.249	4.17E-2	-.144	1.27E-2	-8.65E-3	8.73E-3	9.50E-2	1.99E-3
	4.21E-2	3.65E-2	-7.64E-2	-.101	2.81E-2	-1.31E-2	-7.72E-2	.116	-5.14E-2	.245
	.360	7.92E-2	.167	.294	-4.86E-2	-.149	-.153	1	-3.34E-2	-.323
	-.423	-.610	-.403	-.273	.177	.537	.309	.150	-.134	.513
	-3.79E-3	-.371	-.256	-.613	6.39E-2	-.539	.511	.463	.318	-.534
	-.453	.515	.551	-.343	-.524	-.598	.352	.135	.437	.444
	.392									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Parameter name									
	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	**Ktillv Rxk4v SSR3 R7 RCH29 RCH39**	**Ksd Ksb1 SSR4 R8 RCH30 RCH40**	**Ksdv Km SSsd R9 RCH31 RCH41**	**Rxk1 Kmv SSwet R10 RCH32 RCH42**	**Rxk2 Kwet R1 R11 RCH33 RCH43**	**Rxk3 Kwetv R2 R12 RCH34 RCH44**	**Rxk4 Hani1 R3 RCH25 RCH35 RCH45**	**Rxk1v Hani2 R4 RCH26 RCH36 RCH46**	**Rxk2v SSR1 R5 RCH27 RCH37 RCH47**
R4	5.04E-2	0.159	0.178	-1.71E-2	-2.58E-2	8.41E-3	-8.55E-2	-2.51E-2	-3.75E-3	-4.80E-2
	-8.37E-3	1.27E-2	5.56E-3	-4.35E-2	-2.45E-2	-2.16E-2	-0.120	0.142	3.80E-3	3.31E-2
	4.86E-2	-2.61E-2	1.02E-2	0.156	-7.17E-2	2.59E-2	3.09E-2	-3.34E-2	1	-0.328
	-9.07E-2	-.173	-.133	-.102	3.97E-2	0.180	.143	.103	2.72E-2	.191
	7.55E-2	-4.41E-2	-2.90E-2	-.170	8.32E-3	-.168	.164	.172	0.137	-.119
	-0.126	.175	.207	-2.92E-2	-0.109	-.171	.107	6.54E-2	.161	.17
	.156									
R5	.136	.175	-1.91E-2	-8.45E-2	.177	1.34E-2	-.122	-6.33E-2	-6.62E-2	-9.22E-2
	-7.03E-2	-2.31E-2	7.85E-2	6.35E-2	-8.46E-2	-2.72E-2	-.101	.106	8.78E-2	-.182
	-.328	-8.67E-2	-.153	-.160	-8.82E-2	.226	.145	-.323	-.328	1
	.205	.482	.308	.196	-.135	-.368	-.142	-6.36E-3	.226	-.327
	.132	.402	.283	.494	-3.96E-2	.414	-.355	-.285	-.164	.479
	.378	-.347	-.351	.382	.485	.479	-.247	-4.49E-2	-.276	-.267
	-.231									
R6	.155	.118	-.117	-7.65E-2	.234	2.60E-2	-8.89E-2	-8.08E-2	-.102	-7.12E-2
	-8.75E-2	-2.66E-2	9.12E-2	8.67E-2	-8.94E-2	-4.85E-2	-5.01E-2	8.49E-2	.127	-.213
	-.383	-7.95E-2	-.160	-.238	-.109	.259	.161	-.423	-9.07E-2	.205
	1	.502	.416	.296	-.145	-.480	-.208	-3.76E-2	.254	-.434
	.125	.471	.339	.639	-2.07E-2	.561	-.450	-.380	-.230	.597
	.495	-.454	-.468	.444	.595	.625	-.302	-5.54E-2	-.367	-.360
	-.315									
R7	.184	-2.60E-2	-.305	-8.03E-2	.324	1.29E-2	-1.76E-2	-7.68E-2	-.198	5.48E-3
	-.125	-5.14E-2	2.10E-2	.184	-.126	-5.73E-2	7.15E-2	1.84E-2	.175	-.282
	-.489	-9.33E-2	-.204	-.348	-.154	.304	.175	-.610	-.173	.482
	.502	1	.604	.489	-.150	-.685	-.335	-.109	.284	-.623
	9.63E-2	.568	.421	**.896**	9.00E-3	**.829**	-.623	-.556	-.355	.795
	.704	-.651	-.673	.532	.770	**.883**	-.406	-7.69E-2	-.540	-.539
	-.468									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
R8	7.85E-2	-9.46E-2	-0.342	-4.58E-2	0.327	2.38E-2	0.114	-6.81E-2	-0.136	8.51E-2
	-8.68E-2	-4.27E-3	-1.49E-2	7.11E-2	-3.48E-2	-0.117	.131	7.53E-2	.186	-0.142
	-0.287	-3.36E-2	-7.64E-2	-0.267	-.126	.237	.145	-0.403	-.133	.308
	.416	0.604	1	.259	6.80E-3	-.425	-.207	-5.05E-2	.207	-.400
	6.35E-2	.368	.303	.640	.142	.654	-.342	-.335	-.213	.543
	.539	-.402	-.440	.334	.514	.644	-.172	2.94E-2	-.333	-.332
	-.301									
R9	5.00E-2	-.154	-.383	8.70E-3	.343	7.45E-2	.182	-6.10E-2	-.143	.125
	-9.50E-2	-2.28E-4	-8.33E-2	7.52E-2	-1.92E-2	-.103	.145	5.68E-2	.196	-.112
	-.208	-6.66E-2	-7.20E-2	-.126	-.159	.190	.119	-.273	-.102	.196
	.296	.489	.259	1	-2.34E-2	-.274	-.127	-1.85E-2	.155	-.261
	4.00E-2	.231	.220	.486	.203	.548	-.177	-.204	-.127	.395
	.440	-.261	-.292	.209	.352	.497	-5.49E-2	9.55E-2	-.210	-.213
	-.197									
R10	-8.66E-2	-7.08E-2	-.144	9.31E-2	.125	.135	.185	2.66E-2	2.42E-2	7.34E-2
	1.35E-3	2.94E-2	-.179	-3.79E-2	5.65E-2	-2.61E-2	4.50E-2	4.38E-2	4.65E-2	6.17E-2
	.104	-2.61E-2	3.59E-2	.159	-3.01E-2	-1.13E-2	1.39E-2	.177	3.97E-2	-.135
	-.145	-.150	6.80E-3	-2.34E-2	1	.111	.131	8.43E-2	-2.48E-2	.202
	-7.27E-4	-.152	-6.53E-2	-.156	.216	-5.78E-2	.292	.215	.146	-.165
	-5.79E-2	.220	.206	-.148	-.185	-.138	.249	.163	.202	.192
	.154									
R11	-.132	7.56E-2	.193	9.09E-2	-.126	6.24E-2	5.21E-2	1.77E-2	.115	-1.29E-2
	5.99E-2	5.85E-2	-8.43E-2	-.151	8.52E-2	3.56E-3	-8.57E-2	9.27E-2	-5.28E-2	.25
	.389	6.99E-2	.184	.326	2.71E-2	-.171	-7.53E-2	.537	.180	-.368
	-.480	-.685	-.425	-.274	.111	1	.216	.155	-.162	.561
	-1.97E-2	-.431	-.292	-.689	.114	-.597	.599	.525	.353	-.608
	-.501	.584	.601	-.404	-.597	-.671	.421	.164	.500	.502
	.430									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Parameter name									
	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
R12	-1.90E-2	0.148	0.153	2.63E-2	-1.50E-2	4.68E-2	-2.21E-2	-1.55E-2	5.04E-2	-5.91E-2
	-1.12E-3	2.61E-2	-5.94E-2	-6.44E-2	9.11E-4	-1.86E-2	-9.97E-2	0.132	2.39E-4	0.133
	0.175	1.18E-2	7.57E-2	0.223	-8.18E-2	-0.190	-2.29E-5	.309	0.143	-.142
	-.208	-.335	-.207	-.127	0.131	.216	1	-.129	-3.94E-2	.320
	4.64E-2	-.176	-.114	-.341	6.84E-2	-.296	0.331	.308	.222	-.282
	-.238	.325	.347	-.158	-.273	-.332	.231	.120	.287	.295
	.257									
RCH25	1.36E-2	.162	.105	-2.43E-2	2.59E-2	3.39E-2	-5.28E-2	-4.20E-2	-2.34E-3	-4.37E-2
	-1.26E-2	1.64E-2	-3.36E-2	-4.60E-2	-1.49E-2	-3.62E-2	-.121	.157	5.04E-2	3.09E-2
	4.03E-2	-2.49E-2	8.04E-3	.132	-8.72E-2	.118	6.01E-2	.150	.103	-6.36E-3
	-3.76E-2	-.109	-5.05E-2	-1.85E-2	8.43E-2	.155	-.129	1	-.226	.150
	7.83E-2	-2.21E-2	-9.44E-4	-.114	6.33E-2	-9.42E-2	.164	.162	.131	-7.49E-2
	-6.40E-2	.155	.170	-1.26E-2	-6.96E-2	-.111	.120	9.21E-2	.151	.156
	.134									
RCH26	.106	.17	2.40E-3	-5.21E-2	.178	4.20E-2	-7.95E-2	-6.96E-2	-5.13E-2	-8.09E-2
	-6.55E-2	-1.00E-2	3.20E-2	3.15E-2	-6.99E-2	-5.01E-2	-8.71E-2	.134	9.91E-2	-9.20E-2
	-.194	-6.16E-2	-8.55E-2	-4.18E-2	-.117	.180	.126	-.134	2.72E-2	.226
	.254	.284	.207	.155	-2.48E-2	-.162	-3.94E-2	-.226	1	-.229
	.116	.250	.186	.281	2.74E-2	.251	-.143	-.104	-4.28E-2	.284
	.234	-.151	-.148	.238	.286	.276	-9.03E-2	3.09E-2	-.108	-9.80E-2
	-8.67E-2									
RCH27	-7.70E-2	7.82E-2	.244	4.90E-2	-.151	2.73E-2	2.67E-3	1.59E-2	6.27E-2	1.09E-2
	5.33E-2	4.28E-2	-9.90E-2	-.116	4.54E-2	-1.53E-4	-7.49E-2	.114	-5.59E-2	.244
	.378	7.87E-2	.169	.308	-5.15E-2	-.139	-5.85E-2	.513	.191	-.327
	-.434	-.623	-.400	-.261	.202	.561	.320	.150	-.229	1
	-.217	-.397	-.269	-.633	7.75E-2	-.552	.537	.482	.332	-.553
	-.464	.536	.574	-.357	-.544	-.616	.372	.145	.456	.461
	.409									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
RCH28	6.31E-2	0.198	8.11E-2	-5.39E-2	8.81E-2	4.22E-2	-8.51E-2	-4.51E-2	-5.33E-2	-8.11E-2
	-1.52E-2	6.04E-3	2.32E-2	-1.44E-2	-4.08E-2	-9.18E-3	-0.135	0.131	5.45E-2	-6.68E-2
	-0.117	-7.24E-2	-6.72E-2	5.93E-2	-9.08E-2	0.125	9.34E-2	-3.79E-3	7.55E-2	0.132
	.125	9.63E-2	6.35E-2	4.00E-2	-7.27E-4	-1.97E-2	4.64E-2	7.83E-2	0.116	-.217
	1	-.123	8.18E-2	8.91E-2	6.81E-3	6.90E-2	-1.99E-2	8.91E-3	3.49E-2	.121
	8.08E-2	-1.80E-2	-2.37E-3	0.138	0.128	8.87E-2	-1.51E-2	4.19E-2	3.88E-3	1.41E-2
	1.41E-2									
RCH29	.144	.172	-4.90E-2	-8.08E-2	.223	3.03E-2	-.107	-6.07E-2	-5.66E-2	-.101
	-8.00E-2	-2.82E-2	0.113	8.32E-2	-9.67E-2	-3.12E-2	-8.78E-2	8.65E-2	9.10E-2	-.207
	-.375	-8.45E-2	-.161	-.207	-6.02E-2	.241	.157	-.371	-4.41E-2	.402
	.471	.568	.368	.231	-.152	-.431	-.176	-2.21E-2	.250	-.397
	-.123	1	.137	.561	-4.58E-2	.479	-.413	-.338	-.202	.549
	.437	-.406	-.417	.430	.556	.555	-.284	-5.79E-2	-.326	-.317
	-.277									
RCH30	9.45E-2	.101	-7.77E-2	-4.03E-2	.189	5.05E-2	-4.64E-2	-6.55E-2	-7.89E-2	-5.31E-2
	-5.20E-2	-4.19E-3	5.03E-2	4.54E-2	-5.86E-2	-2.94E-2	-5.22E-2	8.44E-2	.103	-.125
	-.246	-5.01E-2	-9.28E-2	-.147	-9.95E-2	.193	.126	-.256	-2.90E-2	.283
	.339	.421	.303	.220	-6.53E-2	-.292	-.114	-9.44E-4	.186	-.269
	8.18E-2	.137	1	.225	-2.35E-2	.372	-.266	-.224	-.127	.396
	.335	-.276	-.284	.300	.395	.413	-.169	-9.41E-3	-.219	-.212
	-.186									
RCH31	.183	-1.94E-2	-.322	-6.74E-2	.325	2.56E-2	-2.19E-2	-7.51E-2	-.207	-1.58E-2
	-.130	-5.36E-2	6.18E-2	.205	-.146	-5.01E-2	5.87E-2	1.50E-2	.177	-.293
	-.495	-.107	-.223	-.342	-.137	.301	.172	-.613	-.170	.494
	.639	**.896**	.640	.486	-.156	-.689	-.341	-.114	.281	-.633
	8.91E-2	.561	.225	1	-2.79E-2	**.829**	-.626	-.559	-.358	.798
	.700	-.654	-.678	.535	.772	**.882**	-.407	-7.87E-2	-.540	-.541
	-.471									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Parameter name									
	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	**Ktillv Rxk4v SSR3 R7 RCH29 RCH39**	**Ksd Ksb1 SSR4 R8 RCH30 RCH40**	**Ksdv Km SSsd R9 RCH31 RCH41**	**Rxk1 Kmv SSwet R10 RCH32 RCH42**	**Rxk2 Kwet R1 R11 RCH33 RCH43**	**Rxk3 Kwetv R2 R12 RCH34 RCH44**	**Rxk4 Hani1 R3 RCH25 RCH35 RCH45**	**Rxk1v Hani2 R4 RCH26 RCH36 RCH46**	**Rxk2v SSR1 R5 RCH27 RCH37 RCH47**
RCH32	-7.42E-2 1.16E-2 4.73E-2 -2.07E-2 6.81E-3 7.40E-2 6.63E-2	-8.40E-2 6.00E-2 3.66E-2 9.00E-3 -4.58E-2 0.107	-0.215 -.134 7.39E-2 .142 -2.35E-2 7.71E-2	0.132 -5.88E-2 8.50E-3 .203 -2.79E-2 -5.17E-2	0.180 8.02E-2 -3.72E-3 .216 1 -3.80E-2	0.178 -2.08E-2 3.90E-2 .114 -.123 2.31E-2	0.190 3.55E-2 4.78E-2 6.84E-2 .176 .190	-8.33E-3 4.61E-2 6.39E-2 6.33E-2 0.113 .147	2.00E-2 7.88E-2 8.32E-3 2.74E-2 7.82E-2 0.106	7.70E-2 5.85E-2 -3.96E-2 7.75E-2 -2.21E-2 9.78E-2
RCH33	0.124 -.127 -.430 .561 6.90E-2 .671 -.412	-.117 -4.32E-2 -.115 **.829** .479 -.566	-.373 4.24E-2 -.193 .654 .372 -.596	-7.46E-2 .157 -.273 .548 **.829** .45	.352 -.103 -.211 -5.78E-2 -.123 .675	1.09E-2 -.118 .288 -.597 1 **.824**	7.01E-2 .159 .164 -.296 -.559 -.308	-8.44E-2 6.24E-2 -.539 -9.42E-2 -.478 -1.65E-2	-.192 .222 -.168 .251 -.304 -.472	7.14E-2 -0.242 .414 -.552 .714 -.469
RCH34	-.169 7.01E-2 .371 -.450 -1.99E-2 -.432 .413	3.95E-2 7.26E-2 6.27E-2 -.623 -.413 .567	7.90E-2 -.151 .179 -.342 -.266 .571	.153 -.157 .310 -.177 -.626 -.391	-4.21E-2 .117 3.62E-2 .292 .176 -.561	.147 4.67E-2 -.149 .599 -.559 -.605	.139 -5.39E-2 -5.65E-2 .331 1 .450	3.42E-2 6.43E-2 .511 .164 .415 .199	9.04E-2 -3.86E-2 .164 -.143 .342 .490	-4.16E-3 .235 -.355 .537 -.564 .489
RCH35	-8.69E-2 2.88E-2 .309 -.380 8.91E-3 -.402 .375	.105 4.36E-2 3.46E-2 -.556 -.338 .497	.176 -8.84E-2 .136 -.335 -.224 .516	5.99E-2 -.121 .307 -.204 -.559 -.315	-7.23E-2 5.28E-2 -2.80E-2 .215 .113 -.480	5.52E-2 -1.31E-2 -.109 .525 -.478 -.546	2.55E-2 -8.12E-2 -3.67E-2 .308 .415 .363	4.07E-3 .122 .463 .162 1 .161	8.83E-2 -2.46E-2 .172 -.104 .187 .431	-2.89E-2 .205 -.285 .482 -.493 .436

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
RCH36	-5.62E-2	0.121	0.145	1.38E-2	-3.45E-2	4.17E-2	-5.34E-4	-6.78E-3	3.07E-2	-2.91E-2
	2.60E-2	3.23E-2	-5.77E-2	-8.77E-2	2.36E-2	-1.12E-2	-8.69E-2	0.118	-1.46E-3	0.132
	0.192	1.15E-2	7.79E-2	0.224	-7.15E-2	-3.97E-2	-2.11E-3	.318	0.137	-.164
	-.230	-.355	-.213	-.127	0.146	0.353	0.222	.131	-4.28E-2	.332
	3.49E-2	-.202	-.127	-.358	7.82E-2	-.304	.342	.187	1	-.556
	-.277	.329	.353	-.183	-.300	-.351	.241	.118	.293	.300
	.261									
RCH37	.171	6.80E-2	-.214	-7.43E-2	.287	2.99E-2	-6.46E-2	-8.54E-2	-.167	-5.50E-2
	-.120	-4.76E-2	9.06E-2	.163	-.134	-2.79E-2	-1.78E-2	5.58E-2	.164	-.305
	-.492	-.136	-.227	-.264	-.111	.296	.176	-.534	-.119	.479
	.597	.795	.543	.395	-.165	-.608	-.282	-7.49E-2	.284	-.553
	.121	.549	.396	.798	-2.21E-2	.714	-.564	-.493	-.556	1
	.499	-.58	-.594	.519	.716	.780	-.378	-7.17E-2	-.471	-.466
	-.405									
RCH38	.119	-4.89E-2	-.288	-1.61E-2	.31	6.55E-2	2.98E-2	-7.43E-2	-.129	3.04E-2
	-9.46E-2	-2.16E-2	-1.92E-2	.138	-8.41E-2	-3.70E-2	4.57E-2	4.24E-2	.168	-.186
	-.367	-5.77E-2	-.133	-.271	-.141	.251	.154	-.453	-.126	.378
	.495	.704	.539	.440	-5.79E-2	-.501	-.238	-6.40E-2	.234	-.464
	8.08E-2	.437	.335	.700	7.40E-2	.671	-.432	-.402	-.277	.499
	1	-.529	-.503	.405	.594	.698	-.265	-1.41E-2	-.391	-.389
	-.343									
RCH39	-.127	7.42E-2	.205	6.82E-2	-.125	4.51E-2	4.54E-2	2.58E-2	.114	-5.23E-3
	6.69E-2	5.38E-2	-8.69E-2	-.145	7.89E-2	-4.98E-3	-6.65E-2	9.25E-2	-6.31E-2	.255
	.387	8.31E-2	.180	.295	1.40E-2	-.159	-6.90E-2	.515	.175	-.347
	-.454	-.651	-.402	-.261	.220	.584	.325	.155	-.151	.536
	-1.80E-2	-.406	-.276	-.654	.107	-.566	.567	.497	.329	-.58
	-.529	1	.489	-.388	-.568	-.639	.396	.151	.471	.476
	.410									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
RCH40	-5.06E-2	8.47E-2	0.28	4.28E-2	-0.162	1.36E-2	-1.37E-2	1.44E-2	6.66E-2	1.67E-2
	4.03E-2	3.35E-2	-.101	-0.110	3.55E-2	-2.43E-2	-8.82E-2	0.114	-6.17E-2	0.252
	0.393	7.41E-2	.172	.342	-5.10E-2	-0.151	-6.50E-2	.551	0.207	-.351
	-.468	-0.673	-.440	-.292	.206	.601	0.347	.170	-.148	.574
	-2.37E-3	-.417	-.284	-.678	7.71E-2	-.596	.571	.516	.353	-.594
	-.503	.489	1	-.566	-.594	-.670	.384	.150	.487	.493
	.438									
RCH41	.143	.184	-3.82E-2	-9.71E-2	.182	1.00E-2	-.117	-5.84E-2	-9.02E-2	-9.62E-2
	-7.60E-2	-2.79E-2	.102	6.80E-2	-8.80E-2	-1.88E-2	-9.82E-2	9.97E-2	9.09E-2	-.244
	-.390	-.139	-.197	-.13	-8.55E-2	.241	.152	-.343	-2.92E-2	.382
	.444	.532	.334	.209	-.148	-.404	-.158	-1.26E-2	.238	-.357
	.138	.430	.300	.535	-5.17E-2	.45	-.391	-.315	-.183	.519
	.405	-.388	-.566	1	.319	.504	-.284	-5.40E-2	-.302	-.293
	-.253									
RCH42	.177	.104	-.168	-7.62E-2	.267	3.06E-2	-9.54E-2	-8.64E-2	-.119	-7.96E-2
	-.106	-3.85E-2	.113	.124	-.110	-3.23E-2	-4.22E-2	6.17E-2	.143	-.270
	-.469	-9.83E-2	-.199	-.296	-9.51E-2	.289	.176	-.524	-.109	.485
	.595	.770	.514	.352	-.185	-.597	-.273	-6.96E-2	.286	-.544
	.128	.556	.395	.772	-3.80E-2	.675	-.561	-.480	-.300	.716
	.594	-.568	-.594	.319	1	.675	-.363	-7.45E-2	-.435	-.441
	-.390									
RCH43	.157	-5.26E-2	-.321	-6.76E-2	.331	1.94E-2	6.61E-3	-8.43E-2	-.177	2.54E-2
	-.113	-4.40E-2	3.68E-2	.164	-.106	-4.54E-2	7.98E-2	2.20E-2	.188	-.266
	-.481	-8.65E-2	-.189	-.352	-.145	.296	.171	-.598	-.171	.479
	.625	**.883**	.644	.497	-.138	-.671	-.332	-.111	.276	-.616
	8.87E-2	.555	.413	**.882**	2.31E-2	**.824**	-.605	-.546	-.351	.780
	.698	-.639	-.670	.504	.675	1	-.488	-8.91E-2	-.573	-.551
	-.474									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Parameter name									
	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
RCH44	-0.137	-1.60E-2	2.28E-3	0.101	1.06E-2	0.111	0.147	-3.48E-3	6.35E-2	3.65E-2
	4.76E-2	6.73E-2	-8.84E-2	-.110	7.51E-2	-1.59E-2	7.10E-3	7.25E-2	2.43E-2	0.187
	.284	7.32E-2	0.154	.176	3.08E-2	-8.88E-2	-2.65E-2	0.352	0.107	-.247
	-.302	-0.406	-.172	-5.49E-2	0.249	.421	.231	.120	-9.03E-2	.372
	-1.51E-2	-.284	-.169	-.407	.190	-.308	.450	.363	.241	-.378
	-.265	.396	.384	-.284	-.363	-.488	1	-3.73E-2	.368	.358
	.294									
RCH45	-1.13E-2	2.17E-2	-6.40E-2	4.55E-2	.126	7.63E-2	7.13E-2	-2.69E-2	-8.68E-3	2.72E-2
	-3.44E-2	2.04E-2	-7.33E-2	-1.92E-2	3.69E-3	-3.06E-2	-4.09E-2	.110	7.60E-2	4.27E-2
	4.63E-2	-3.57E-2	1.17E-2	.133	-8.79E-2	4.30E-2	4.75E-2	.135	6.54E-2	-4.49E-2
	-5.54E-2	-7.69E-2	2.94E-2	9.55E-2	.163	.164	.120	9.21E-2	3.09E-2	.145
	4.19E-2	-5.79E-2	-9.41E-3	-7.87E-2	.147	-1.65E-2	.199	.161	.118	-7.17E-2
	-1.41E-2	.151	.150	-5.40E-2	-7.45E-2	-8.91E-2	-3.73E-2	1	-7.06E-2	.141
	.121									
RCH46	-8.62E-2	.104	.160	8.75E-2	-8.69E-2	8.45E-2	3.34E-2	1.49E-2	9.94E-2	-3.64E-2
	3.69E-2	4.00E-2	-8.02E-2	-.108	5.73E-2	-2.83E-2	-.103	8.73E-2	-3.47E-2	.162
	.285	1.64E-2	.106	.304	1.81E-2	-.110	-4.16E-2	.437	.161	-.276
	-.367	-.540	-.333	-.210	.202	.500	.287	.151	-.108	.456
	3.88E-3	-.326	-.219	-.540	.106	-.472	.490	.431	.293	-.471
	-.391	.471	.487	-.302	-.435	-.573	.368	-7.06E-2	1	.290
	.352									
RCH47	-.103	.121	.188	5.37E-2	-7.79E-2	5.28E-2	2.11E-2	8.74E-3	8.19E-2	-3.70E-2
	4.42E-2	4.75E-2	-5.68E-2	-.130	5.74E-2	-7.28E-3	-9.57E-2	.118	-3.21E-2	.188
	.290	3.25E-2	.126	.290	-1.06E-2	-.102	-3.47E-2	.444	.17	-.267
	-.360	-.539	-.332	-.213	.192	.502	.295	.156	-9.80E-2	.461
	1.41E-2	-.317	-.212	-.541	9.78E-2	-.469	.489	.436	.300	-.466
	-.389	.476	.493	-.293	-.441	-.551	.358	.141	.290	1
	.259									

Table 8–1. Correlation matrix for transient-model parameters, Seacoast model, southeastern New Hampshire.—Continued

[See footnote for values in **bold**]

Parameter name	Ktill Rxk3v SSR2 R6 RCH28 RCH38 RCH48	Ktillv Rxk4v SSR3 R7 RCH29 RCH39	Ksd Ksb1 SSR4 R8 RCH30 RCH40	Ksdv Km SSsd R9 RCH31 RCH41	Rxk1 Kmv SSwet R10 RCH32 RCH42	Rxk2 Kwet R1 R11 RCH33 RCH43	Rxk3 Kwetv R2 R12 RCH34 RCH44	Rxk4 Hani1 R3 RCH25 RCH35 RCH45	Rxk1v Hani2 R4 RCH26 RCH36 RCH46	Rxk2v SSR1 R5 RCH27 RCH37 RCH47
RCH48	-6.27E-2	9.83E-2	0.198	3.35E-2	-9.16E-2	2.86E-2	-1.01E-2	1.04E-2	4.57E-2	-1.58E-2
	3.68E-2	3.34E-2	-6.12E-2	-9.47E-2	3.30E-2	-4.56E-3	-7.70E-2	0.107	-3.90E-2	0.177
	0.270	4.20E-2	.114	0.250	-4.97E-2	-8.95E-2	-3.17E-2	.392	0.156	-.231
	-.315	-0.468	-.301	-.197	0.154	0.430	0.257	.134	-8.67E-2	.409
	1.41E-2	-.277	-.186	-.471	6.63E-2	-.412	.413	.375	.261	-.405
	-.343	.410	.438	-.253	-.390	-.474	.294	.121	.352	.259
	1									

* The correlation between Km and Kmv is 0.91.

* The absolute correlations between the following parameters are between 0.85 and 0.90.

Parameter	Parameter	Correlation
Rxk4	Hani2	-0.90
SSR1	SSR2	.85
SSR1	SSR3	.88
R7	RCH31	.90
R7	RCH43	.88
RCH31	RCH43	.88

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In reference to report:
Mack, T.J., 2009, Assessment of ground-water resources in the Seacoast region of New Hampshire: U.S. Geological Survey Scientific Investigations Report 2008–5222, 188 p., available online at http://pubs.usgs.gov/sir/2008/5222.

Appendix 9. Historical Ground-Water-Flow Conditions

Figures

Table

Appendix 9. Historical Ground-Water-Flow Conditions

The nature of a regional ground-water-flow system at a specific time is determined by the hydraulic characteristics, previous conditions, and stresses of the system. The source and residence time of ground water at a location depend on hydrologic and anthropogenic factors such as location in the ground-water-flow field, hydraulic conductivity and anisotropy, and ground-water withdrawals and returns. For example, a regional investigation in Pennsylvania (Burton and others, 2002) found bedrock-fracture anisotropy to influence ground-water residence times significantly. Ground-water residence times represent a mixture of travel times and are affected by changes in regional withdrawals over time (Zinn and Konikow, 2007). The regional ground-water-flow system in the Seacoast model area was evaluated with respect to climate conditions and historical water uses over recent decades.

Historical hydrologic observations in the study area are at most 10 years old; some monitoring-well data were collected over a 10-year period, whereas the only continuous streamflow data were those data collected for this study. A multidecade simulation was developed to examine the Seacoast ground-water-flow system in relation to environmental tracers used in determining residence time of ground-water samples collected in this study (chlorofluorocarbons). Chlorofluorocarbons (CFCs) have previously been used to determine the residence time, commonly referred to as "age dating," of ground water in New Hampshire (Ayotte and others, 2003; Busenberg and Plummer, 1993; Flanagan and others, 1999). The residence time of ground water in selected bedrock aquifers in New England ranged from approximately 50 years to very short for recently recharged water, with a median of about 25 years (Ayotte and others, 2003). Ground-water residence times, including those listed in table 9–1, are commonly analyzed by assuming a piston-flow model for ground-water flow (Busenberg and Plummer, 1993). The piston-flow model is based on the assumption that the water sampled is of one age, not a mixture of waters with different ages. A piston-flow analysis may be more applicable for wells with little or no water use, such as a monitoring well or domestic well with little use, and may not be suitable for wells in which the water is highly mixed (Hunt and others, 2005). An uncertainty in the residence-time calculation, particularly for water that is actually younger than 1990, is that atmospheric CFC concentrations peaked between 1990 and 2000; the result is that two ages, one before and the other after the peak, correspond to the CFC concentration in water.

Fifteen bedrock wells (fig. 9–1) were sampled and analyzed for CFC-11, CFC-12, and CFC-113 at the USGS Reston Chlorofluorocarbon Laboratory (L.N. Plummer and E. Busenberg, U.S. Geological Survey, written commun., 2005). Table 9–1 provides a summary of well conditions, water use, and analysis of ground-water age. Detailed results are provided in appendix 10 (table 10–1). The wells sampled were subject to withdrawal conditions (table 9–1) that ranged from unused monitoring wells (not used for supply), seasonally or intermittently used supply wells, domestic-supply wells with a low rate of household use (estimated to be about 200 gal/d), and supply wells that were pumped nearly continuously at high rates of withdrawal (400,000 gal/d or greater). The variety of wells provided ground water with a range of use types and locations in the ground-water-flow system. Uncertainties in the CFC analysis are indicated by the different ages calculated with different CFCs for specific wells (table 9–1). Additional isotopic or dissolved gas analyses can be used to further refine residence-time analyses, but such data were not available for this analysis.

To illustrate the effect of changing recharge and water use on the Seacoast hydrologic system, long-term ground-water flow was simulated with time-varying recharge and water-use rates. Figure 9–2 illustrates the effect of changing recharge and water use on simulated average base flows over time. The 55-year simulation was discretized into six steady-state stress periods approximating recharge and water-use conditions over the five 10-year periods between 1950 and 2000 and the 5-year period between 2000 and 2004. Hydraulic conductivities were based on the transient model analysis (appendix 7). On the basis of the recharge analysis and the results of monthly transient simulations (appendix 7), recharge rates for these periods were assumed to be 54 percent of the Portsmouth-Greenland average annual precipitation for each period (fig. 9–3). The recharge rates used for the six stress periods differed slightly and, from 1950 on, were 24, 22, 26, 25, 27, and 25 in/yr. Rates of water use, however, have increased considerably in recent decades (Marilee A. Horn, U.S. Geological Survey, written commun., 2007). Changing water use was approximated over the 55-year period by reducing the total current (2003–04) water use by the approximate percentage of past total water use based on population changes. Withdrawals and returns for the five decades were reduced to 30 percent (1950), 35 percent (1960), 46 percent (1970), 57 percent (1980), and 79 percent (1990) of current uses. Water-use rates during the 5-year period (2000) were set equal to the present (2003–04) estimated water-use rates. Figure 9–2 illustrates the effects of low periods of recharge, in the 1950s and 1960s, and increasing water use in later decades (post 1990).

The simulation used approximate decadal-average recharges and stresses sufficient for the simulation of historical flow conditions; the use of current water-use rates or seasonal low-recharge rates in a long-term (multidecade) simulation would have resulted in greater stresses on the ground-water-flow system than historically were present. Ground-water residence times are

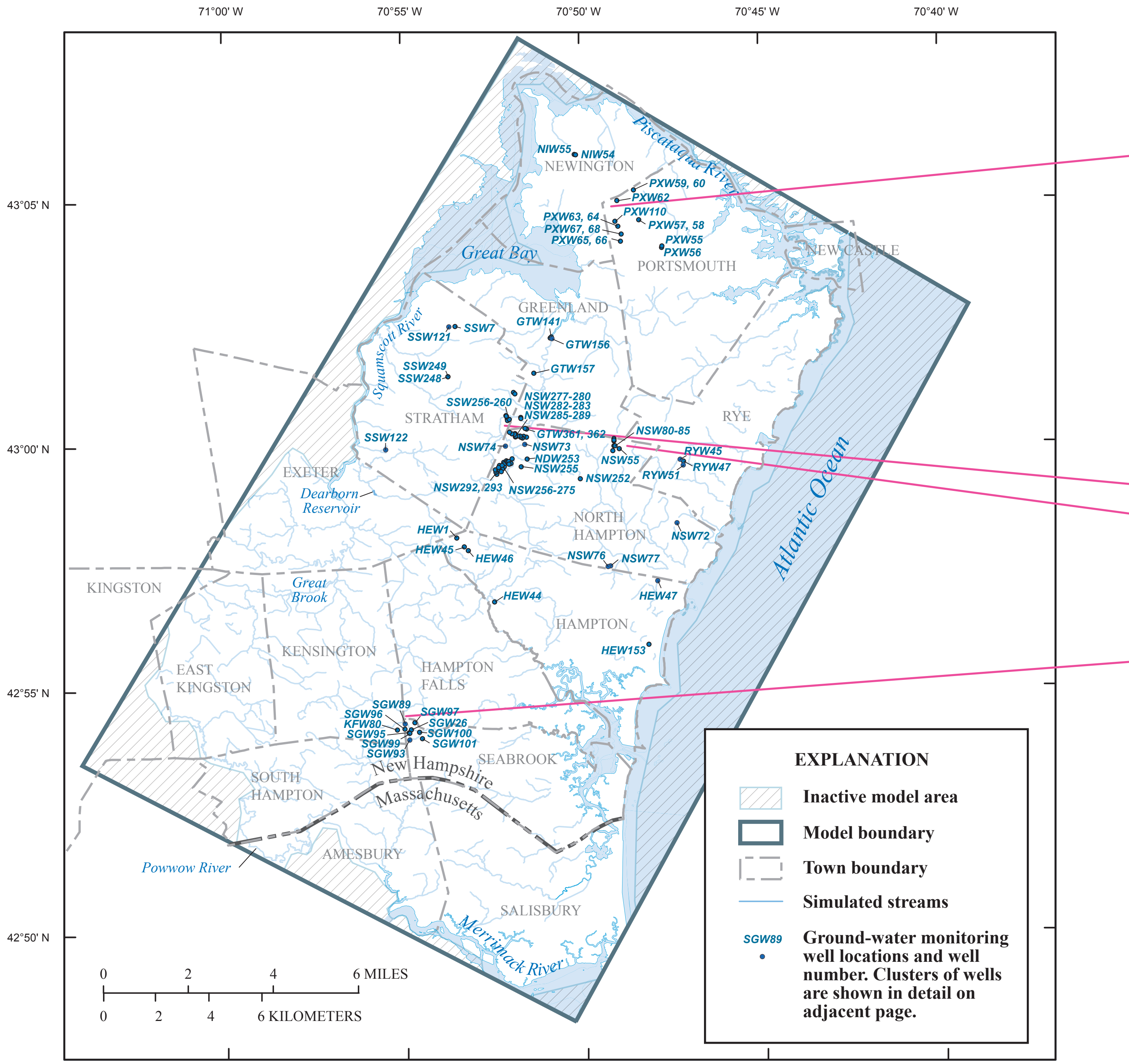
Table 9–1. Summary information and residence time of ground-water samples, determined by chlorofluorocarbon analysis, for selected wells in the Seacoast model area, southeastern New Hampshire.

[Multiple samples were analyzed from each well; ft, feet; gal/min, gallons per minute; yrs, years; —, not available or not calculated]

Sample number	Site name	Well depth (ft)	Use code[1]	Withdrawal or sampling rate (gal/min)	Sampling date	CFC-11 (yrs)	CFC-12 (yrs)	CFC-113 (yrs)	Age calculated from CFC113/CFC12 ratio[2] (yrs)	Percentage of young water in mixture from CFC113	Recommended age basis	Comments regarding sample analysis or age estimation
1	GTW-141	405	U	3	2/1/2005	31	56	48	18	2	CFC-12, 113	Early 1950s or older.
2						31	53	49	25	4		
3	HEW-46	170	D	3	10/13/2004	45	24	29	N	—	CFC-12	Early 1980s.
4						43	24	28	N	—		
5						46	23	33	N	—		CFC-11 possibly degraded.
6	HEW-47	480	D	3	10/13/2004	C	18	19	N	—	CFC-12, 113	Middle 1980s with late peaks.
7						C	18	19	N	—		High CFC-11 contamination.
8	NHW-44	500	U	3	2/2/2005	17	29	40	N	—	CFC-12	Middle 1970s.
9						18	30	42	N	—		
10	NSW-72	320	D	3	10/7/2004	39	30	29	27	87	CFC-12, 113	Middle 1970s.
11						40	30	30	N	—		
12						41	31	32	N	—		
13	NSW-73	500	P	93	10/8/2004	C	C	28	N	—	CFC-113	Middle 1970s.
14						C	C	29	N	—		High CFC-11 and CFC-12 contamination.
15	NSW-74	500	P	300	10/8/2004	48	M	36	N	—	CFC-113	Late 1960s to early 1970s.
16						48	M	35	N	—		
17	NSW-76	600	P	250	10/8/2004	50	19	34	N	—	CFC-113	Early 1970s.
18						50	20	33	N	—		CFC-11 degraded.
19	NSW-77	600	P	250	10/8/2004	51	C	42	N	—	CFC-113	Early to middle 1960s.
20						52	C	42	N	—		CFC-11 degraded.
21	RYW-45	551	P	100	10/7/2004	52	C	41	N	—	CFC-113	Middle 1960s.
22						52	C	40	N	—		High CFC-12 contamination. CFC-11 degraded.
23	RYW-51	437	P	100	10/7/2004	51	C	43	N	—	CFC-113	Early 1960s.
24						53	C	41	N	—		High CFC-12 contamination. CFC-11 degraded.
25	SGW-89	500	P	200	10/13/2004	40	C	24	N	—	CFC-113	Early 1980s.
26						40	C	24	N	—		CFC-11 degraded.
27	SGW-93	492	P	300	10/8/2004	55	22	48	N	—	CFC-12 or 113	Early 1980s if CFC-12 is not contaminated, otherwise use CFC-113 apparent age.
28						54	23	48	N	—		
29	SSW-121	300	S	3	10/8/2004	49	23	41	N	—	CFC-12 or 113	Early 1980s if CFC-12 is not contaminated, otherwise use CFC-113 apparent age.
30						49	23	41	N	—		
31	SSW-122	500	I	10	10/29/2004	32	C	21	N	—	CFC-113	Early to middle 1980s.
32						33	C	21	N	—		

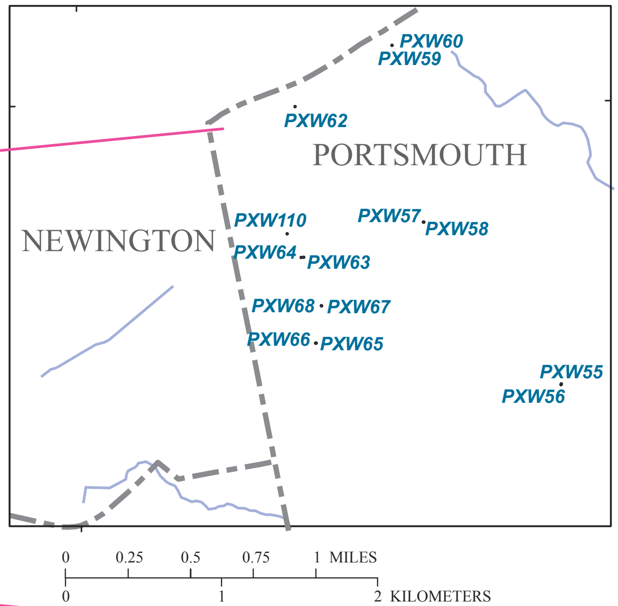
[1] Well use code: U, unused; D, domestic use; P, water supply (high use); S, summer use; I, intermittent.

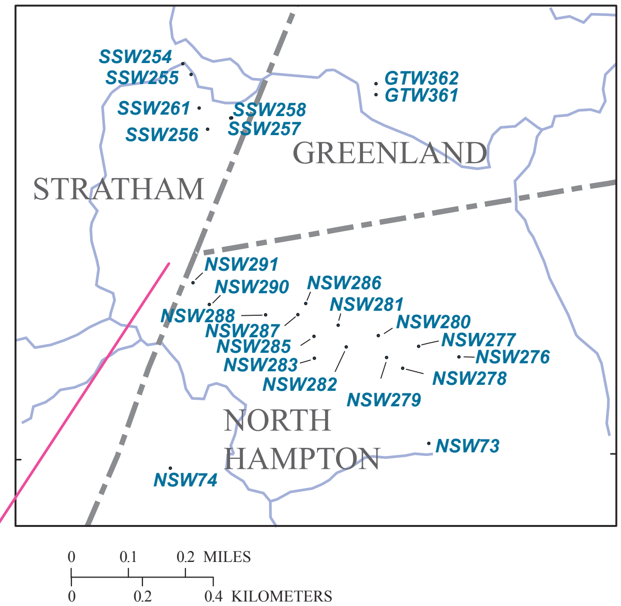
[2] Analysis codes: N, analysis was not possible; C, contaminated (concentration greater than in atmosphere); M, modern (concentration within the range for modern atmosphere).

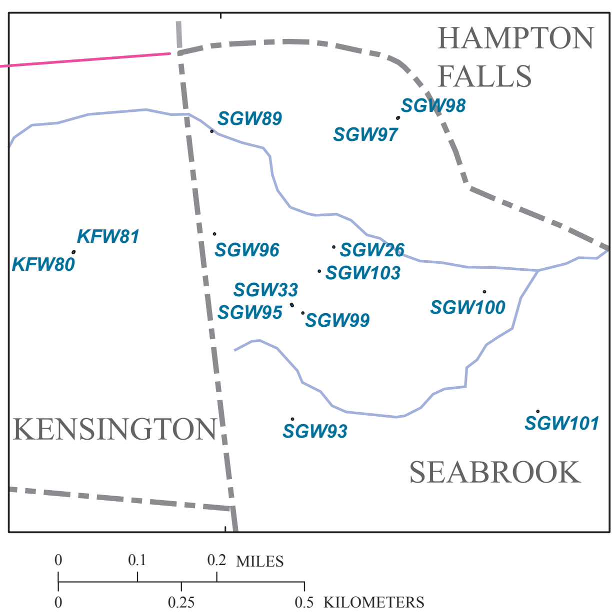


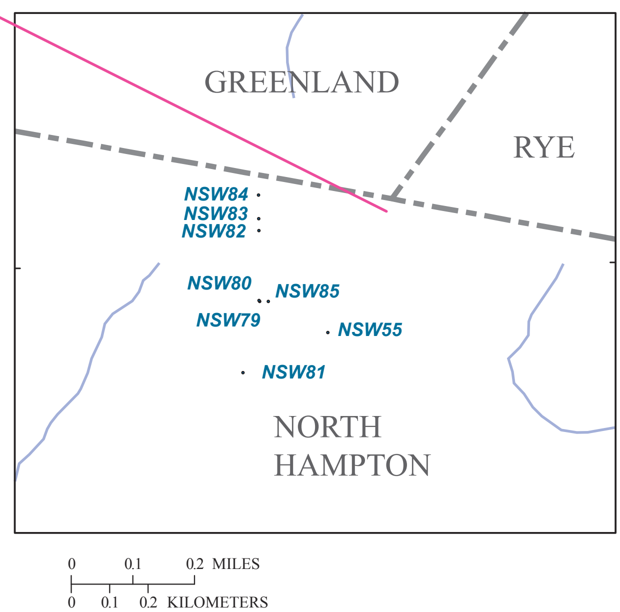
Streams and water bodies, including tidal and estuaries from 1:24,000 National Hydrography Dataset, 1999

Figure 9–1. *(A)* Ground-water monitoring wells in the study area. (This figure is the same as figure 7 on page 16–17 in the report.)


PXW60
PXW59
PXW62
PORTSMOUTH
NEWINGTON
PXW110
PXW57
PXW58
PXW64
PXW63
PXW68
PXW67
PXW66
PXW65
PXW55
PXW56
0 0.25 0.5 0.75 1 MILES
0 1 2 KILOMETERS


SSW254
SSW255
GTW362
GTW361
SSW261
SSW258
SSW257
SSW256
GREENLAND
STRATHAM
NSW291
NSW290
NSW286
NSW281
NSW288
NSW280
NSW287
NSW277
NSW285
NSW276
NSW283
NSW278
NSW282
NSW279
NORTH HAMPTON
NSW73
NSW74
0 0.1 0.2 MILES
0 0.2 0.4 KILOMETERS


HAMPTON FALLS
SGW98
SGW89
SGW97
KFW81
KFW80
SGW96
SGW26
SGW103
SGW33
SGW95
SGW99
SGW100
KENSINGTON
SGW93
SGW101
SEABROOK
0 0.1 0.2 MILES
0 0.25 0.5 KILOMETERS


GREENLAND
RYE
NSW84
NSW83
NSW82
NSW80
NSW85
NSW79
NSW55
NSW81
NORTH HAMPTON
0 0.1 0.2 MILES
0 0.1 0.2 KILOMETERS

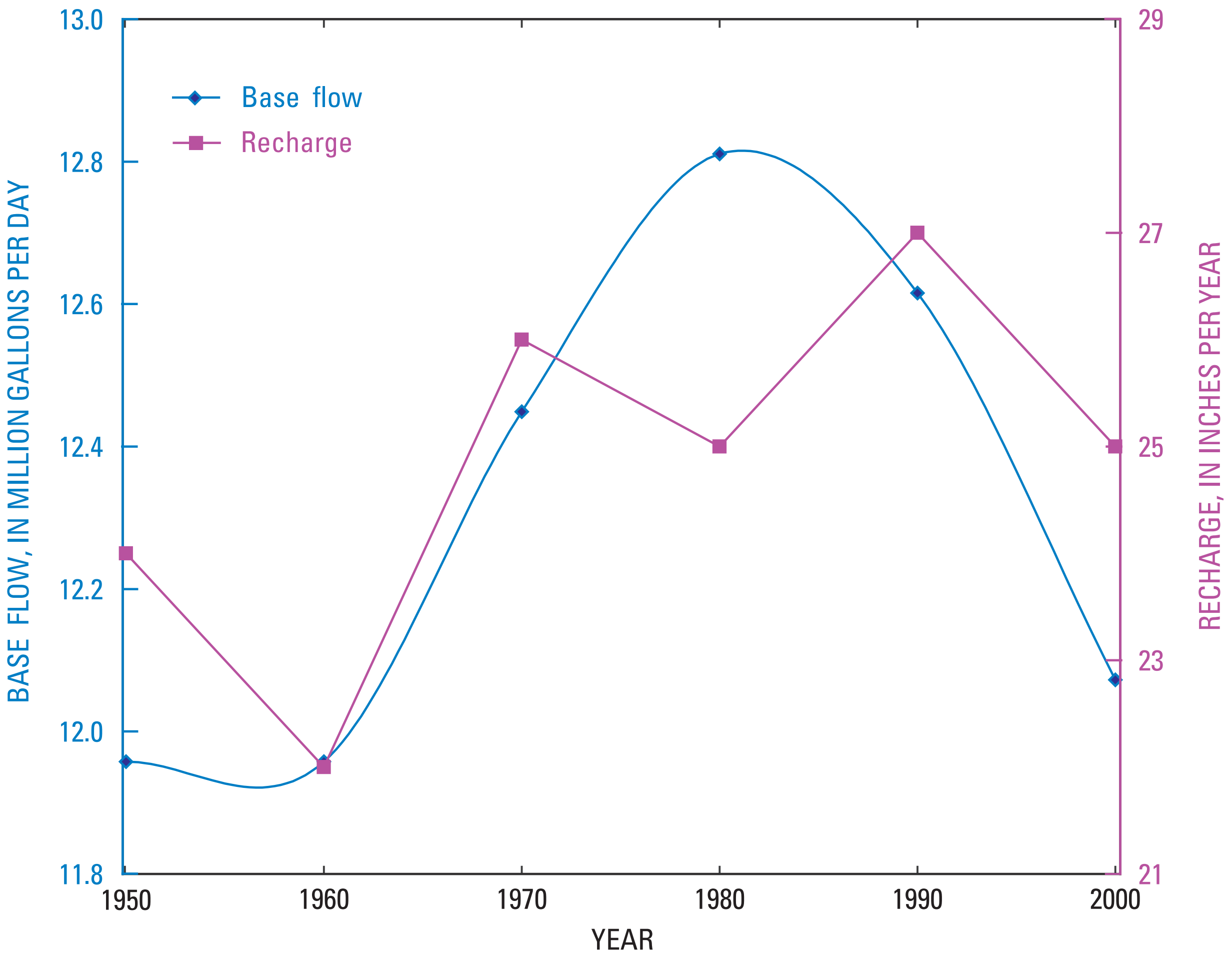


Figure 9–2. Simulated base flow in the Winnicut River and estimated recharge for 50 years from 1950 to 2000, Seacoast model area, southeastern New Hampshire.

influenced by climatic conditions and stresses during the period of ground-water flow through the system. The effects of seasonality and annual variations in recharge on the ground-water flow path, however, are likely to diminish with the age of the path (Reilly and Pollock, 1996). Water use has increased considerably over the apparent residence time of the ground water sampled. For example, withdrawals from wells near the source areas for some of the wells where CFC samples were collected were less in the decades before the sampled wells were installed. The CFC residence times were not compared to model-simulated residence times because of the uncertainties of the CFC-calculated ages and the inherent limitations of simulating ground-water flow in a fractured crystalline-bedrock aquifer with a bulk-property and EPM approach.

The length of the ground-water-flow path in the bedrock aquifer from recharge to discharge depends on several factors. Ground water flowing to large ground-water withdrawals likely follows both very short and long paths. Recharge near the withdrawal well follows short flow paths and, therefore, has relatively short residence times of months to a few years. Water recharged farther from the well, however, may travel farther or deeper in the aquifer and, therefore, has residence times on the order of many years or decades. Flow to a well near another withdrawal well will follow a path that is influenced by the interaction of both withdrawals. The residence-time analyses from large ground-water withdrawals (supply wells) indicate a mixture of young and old water (table 9–1). Wells with a low rate of use generally show less indication of mixing. For most samples it is not possible to determine the mixture of young and old water without additional data. The presence of young water in some of the supply wells, however, can be inferred by the presence of MTBE contamination (Ayotte and others, 2004). Because MTBE use greatly increased in 1990, MTBE contamination is most likely associated with water recharged after this date (Joseph D. Ayotte, U.S. Geological Survey, oral commun., 2006).

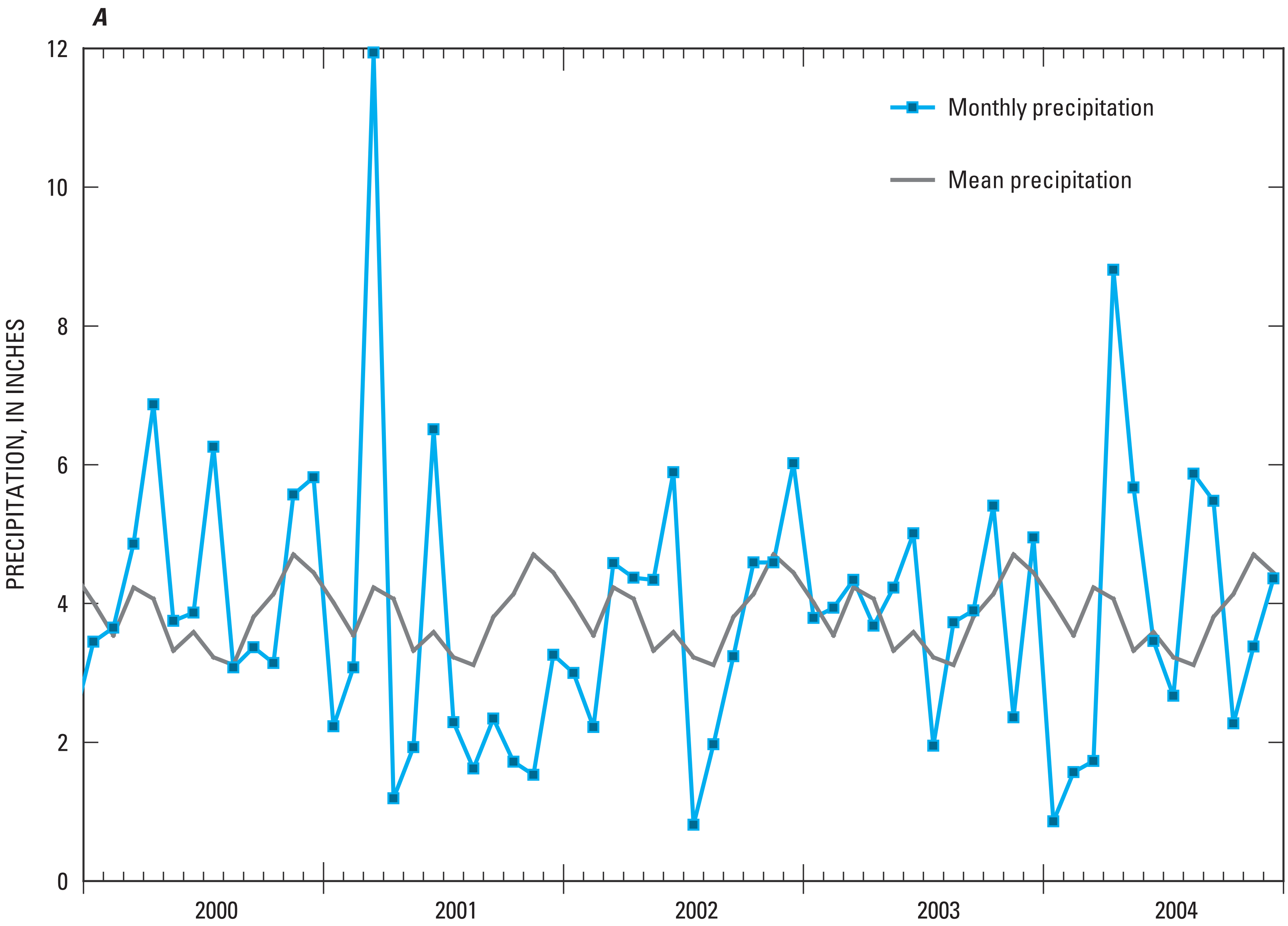
Residence times calculated by CFC-12 analysis for the water in monitoring wells with little or no use ranged from over 50 years (GTW-141) to about 30 years (HEW-44, fig. 9–1). In general, the less used bedrock wells intercepted water that was about 20 to 30 years old that recharged the aquifer in the 1980s. The longest estimated ground-water residence time was for water sampled in well GTW-141. This well is in a ground-water-discharge area near sea level at the base of the Winnicut River watershed in an area with a low ground-water-head gradient. The area immediately surrounding the well is lightly populated and supplied by individual wells where withdrawals are low. Well GTW-141 is 405 ft deep and was used for a few years in the 1980s to supply a small office prior to being discontinued. (A dug well was used at this location prior to the bedrock well). The percentage of young water in this well was estimated to be low (table 9–1).

Two nearby wells were sampled in Stratham in areas with steeper head gradients and closer to local topographic high areas. SSW-122 was installed for commercial supply and was sampled prior to the operation of the business. The ground water was estimated to be 21 to 33 years old. A very high concentration of MTBE (Ayotte and others, 2004) found in a bedrock well within a few hundred feet of SSW-122 (fig. 9–1) indicated that young water is in the bedrock aquifer in this area. Well SSW-121, however, is in an undeveloped area with few other ground-water withdrawals and is used only intermittently in the summer. Ground water at well SSW-121 was older (23 to 49 years) and likely contains little young water because withdrawal stresses are few.

Well HEW-44, with ground water estimated to be about 30 years old (table 9–1, fig. 9–1), is an unused water-supply exploration well 500 ft deep in an area with little water use. Presently the area near HEW-44 is being developed, and water-level fluctuations were measured in the well during nearby bedrock-well installations. This well is in an area of relatively low head gradients and historically few stresses. Well HEW-46 is in a similar environment but is higher in the watershed in an area of regional recharge. The residence time of the water was estimated to be about 20 years or more.

Ground-water residence-time analyses for wells in the Winnicut and Lovering Roads area (NSW-73 and -74, fig. 9–1) indicated a mix of water 28 to 36 years old along with young or modern water. The surficial aquifer is thin in the area, and bedrock ground water most likely contains young water induced from the surficial aquifer. Aquifer tests, discussed previously, have indicated that the surficial and bedrock aquifers are hydraulically connected in this area.

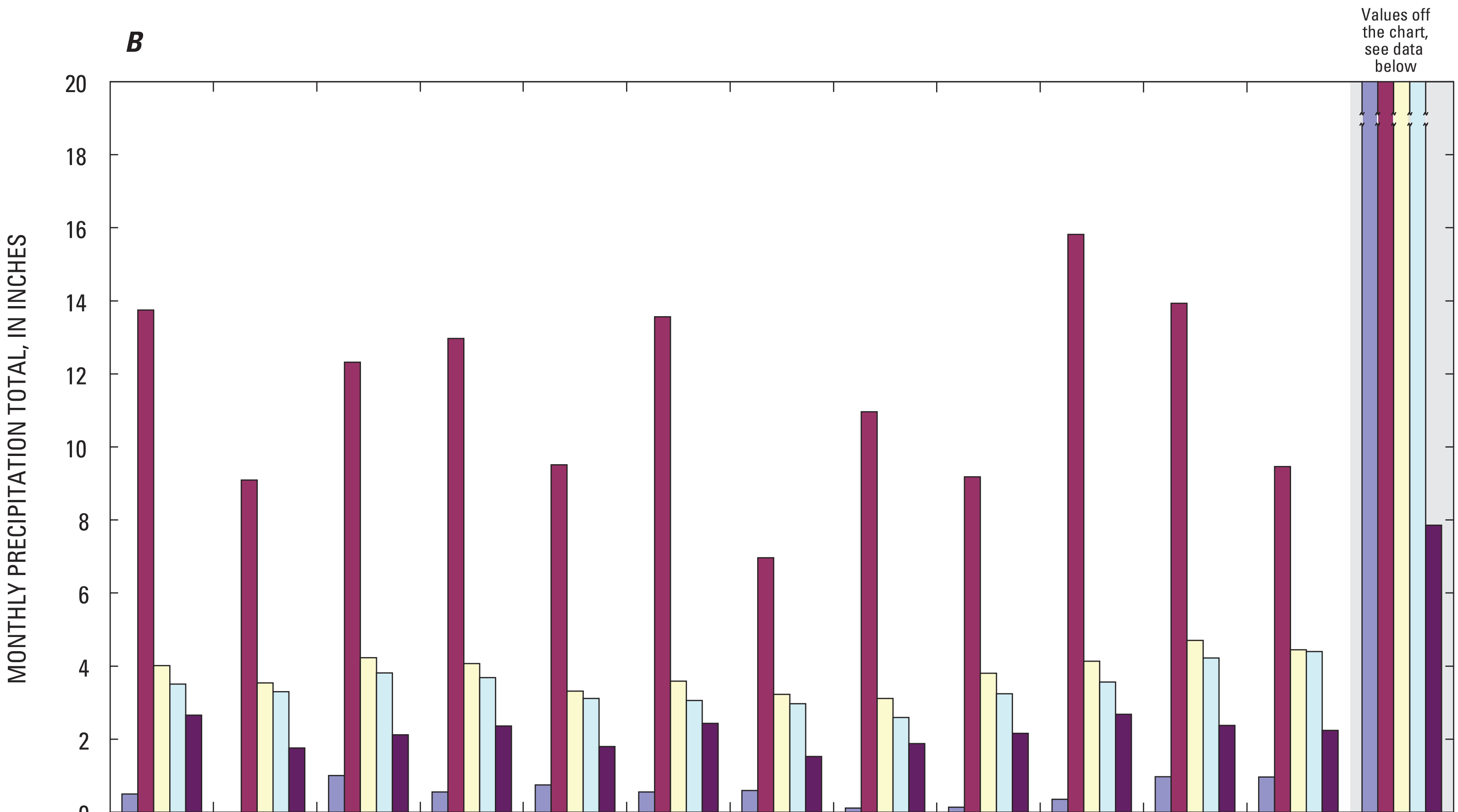
Similarly, ground water in the North Hampton-Hampton bedrock supply wells (NSW-76 and -77, fig. 9–1) was estimated to be 30 to 40 years old. Bedrock ground water in the Rye well field (RYW-45 and -51) was about 40 years old. The North Hampton-Hampton and Rye wells fields are in similar hydrogeologic settings, and both have well fields consisting of two bedrock wells (table 9–1). Wells NSW-76 and 77 are within a few hundred feet of each other and are likely influenced by nearby large withdrawals immediately to the west and topographically upgradient in the surficial aquifer. Water withdrawn from the surficial aquifer in this area has been reported to have chemical characteristics indicative of bedrock water. Given that the surficial-aquifer withdrawals capture water from the bedrock aquifer, it is very likely that withdrawals from the bedrock supply wells were influenced by the surficial-aquifer withdrawals.



Sources of data: Durham, State Climatologist; and Portsmouth and Greenland, National Oceanic and Atmospheric Administration.

Figure 9–3. *(A)* Monthly and mean precipitation at Portsmouth and Greenland, New Hampshire, from January 2000 through December 2004. (This figure is the same as figure 1–2 on page 56–57 in appendix 1.)

B



	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	Annual
MINIMUM	0.5	0	1	0.55	0.75	0.55	0.59	0.11	0.14	0.35	0.97	0.96	29.19
MAXIMUM	13.75	9.09	12.32	12.97	9.51	13.56	6.97	10.96	9.18	15.82	13.93	9.46	71.26
MEAN	4.02	3.54	4.23	4.07	3.32	3.59	3.22	3.11	3.81	4.14	4.71	4.44	45.37
MEDIAN	3.51	3.3	3.815	3.68	3.11	3.06	2.97	2.59	3.24	3.56	4.22	4.4	44.84
STD. DEVIATION	2.66	1.75	2.12	2.36	1.80	2.43	1.53	1.88	2.16	2.68	2.38	2.24	7.86

Sources of data: Durham, State Climatologist; and Portsmouth and Greenland, National Oceanic and Atmospheric Administration.

Figure 9–3. *(B)* Monthly precipitation statistics at Portsmouth and Greenland, New Hampshire, from 1955 through 2005.—Continued (This figure is the same as figure 1–2 on page 56–57 in appendix 1.)

Two domestic wells, HEW-47 and NSW-72 (table 9–1, fig. 9–1), with low estimated water-use rates of about 200 gal/d, were sampled that were in the same hydrogeologic setting as the North Hampton-Hampton and Rye well fields but were farther downgradient in the ground-water-flow system. The water sampled from well HEW-47 was young, about 20 years old, relative to the ages of water sampled from other low-use wells downgradient in the flow system. A young ground-water residence time in this area of the aquifer may be a result of the high-yield aquifer system and high rate of water usage. This aquifer serves a regional water-distribution network, and base flows in one of the primary drainages in the aquifer, the Little River, generally were lower, relative to the size of the drainage area, than base flows in other streams in the study area. Water sampled from the other domestic well in this area (NSW-72) was older (about 30 years old) than the water sampled from HEW-47 but was estimated to contain a high percentage (87) of young water. This part of the study area, where the bedrock aquifer is the high-yielding Rye Complex, has the potential for greater recharge and ground-water flow than other areas of the Seacoast.

Bedrock ground water sampled from well SGW-89 (well 2) and well SGW-93 (well 5) at a Seabrook supply well field near the Kingston town line (fig. 9–1) was fairly young, about 25 years old based on CFC-12 analysis. The CFC signatures for this well and well SGW-89, however, differ between the two wells; this difference indicates the possibility of different sources of water to the wells.

In an undisturbed ground-water-flow system, one with few withdrawals and low porosity, the ground-water residence time is primarily determined by the location of the water in the hydrologic system, the hydraulic conductivity, and the head gradient. Water moving to a well installed in a discharge area generally follows a longer flow path than water moving to a well near a topographic high. Ground-water withdrawals increase ground-water flow through the aquifer and may result in young water displacing older ground water. Without withdrawal stresses, very little water may move through or recharge a bedrock aquifer than would occur with stresses. The rate of water that recharges the bedrock aquifer depends on the rate of water recharging the overlying surficial aquifer, the hydraulic conductivity of the bedrock, and the stresses in the aquifer. A low-yielding bedrock aquifer has a low rate of recharge because water cannot readily move through it because of the low hydraulic conductivity. Stresses imposed on such an aquifer are less likely to be effective for the same reasons. A high-yielding bedrock aquifer may have a low rate of recharge unless withdrawals are present. With withdrawal stresses, a high-yield bedrock aquifer may have a recharge rate that is locally as high as the overlying aquifer. With continued or increasing withdrawals, the residence time of the water withdrawn may decrease because an increasing percentage of young water will be mixed into the regional ground-water system.

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Appendix 10. Chlorofluorocarbon Analysis of Ground-Water Samples

Table

Table 10–1. Chlorofluorocarbon analysis of ground-water samples for selected wells in the Seacoast model area, southeastern New Hampshire.

[Samples were analyzed at U.S. Geological Survey Reston Chlorofluorocarbon Laboratory. Time given is Eastern Standard Time, expressed as 24-hour time. ID, identifier; mo/d/yr, month/day/year; pmol, picomole; kg, kilogram]

Sample number	Sample ID	Sampling date (mo/d/yr)	Time	Uncorrected concentrations in solution			Corrected concentrations in solution		
				CFC-12 (pmol)	CFC-11 (pmol)	CFC-113 (pmol)	CFC-12 (pmol/kg)	CFC-11 (pmol/kg)	CFC-113 (pmol/kg)
1	GTW-141	2/1/2005	1247	0.04	2.31	0.01	0.04	2.39	0.01
2	GTW-141	2/1/2005	1249	.06	2.26	.01	.06	2.33	.01
3	HEW-46	10/13/2004	1442	1.80	.23	.09	1.80	.23	.09
4	HEW-46	10/13/2004	1444	1.68	.30	.10	1.82	.31	.10
5	HEW-46	10/13/2004	1440	1.80	.18	.04	1.98	.18	.05
6	HEW-47	10/13/2004	1224	2.51	55.43	.31	2.54	55.59	.32
7	HEW-47	10/13/2004	1228	2.55	59.70	.31	2.55	59.70	.31
8	NHW-44	2/2/2005	1150	1.35	5.41	.02	1.45	5.53	.02
9	NHW-44	2/2/2005	1153	1.27	5.21	.01	1.36	5.31	.02
10	NSW-72	10/7/2004	920	1.32	.72	.10	1.32	.72	.10
11	NSW-72	10/7/2004	930	1.23	.55	.07	1.24	.55	.07
12	NSW-72	10/7/2004	930	1.10	.48	.06	1.10	.48	.06
13	NSW-73	10/8/2004	1112	6.67	10.89	.10	6.67	10.89	.10
14	NSW-73	10/8/2004	1116	6.66	9.60	.09	6.66	9.60	.09
15	NSW-74	10/8/2004	1015	3.07	.15	.04	3.13	.15	.04
16	NSW-74	10/8/2004	1017	3.13	.14	.04	3.17	.14	.04
17	NSW-76	10/8/2004	919	2.35	.07	.05	2.38	.07	.05
18	NSW-76	10/8/2004	923	2.29	.07	.05	2.29	.07	.05
19	NSW-77	10/8/2004	822	3.55	.05	.01	3.80	.05	.02
20	NSW-77	10/8/2004	826	3.58	.05	.01	3.83	.05	.01
21	RYW-45	10/7/2004	1117	24.62	.04	.02	24.97	.04	.02
22	RYW-45	10/7/2004	1121	24.05	.05	.02	24.44	.05	.02
23	RYW-51	10/7/2004	1218	11.62	.06	.01	12.33	.06	.01
24	RYW-51	10/7/2004	1219	11.49	.03	.02	12.30	.03	.02
25	SGW-89	10/13/2004	1039	3.24	.53	.15	4.10	.57	.19
26	SGW-89	10/13/2004	1041	3.29	.51	.14	4.15	.55	.18
27	SGW-93	10/8/2004	1236	2.07	.01	.01	2.07	.01	.01
28	SGW-93	10/8/2004	1238	1.95	.02	.01	1.95	.02	.01
29	SSW-121	10/8/2004	1415	1.95	.10	.02	1.95	.10	.02
30	SSW-121	10/8/2004	1423	1.90	.11	.02	1.93	.11	.02
31	SSW-122	10/29/2004	1349	3.29	1.83	.25	3.32	1.83	.25
32	SSW-122	10/29/2004	1351	3.00	1.77	.23	3.24	1.81	.25